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EFFECTS OF ROOTSTOCKS ON YIELD AND FRUIT QUALITY OF 'PARENT WASHINGTON NAVEL' TREES

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Abstract. **The horticultural adaptability and performance of 'Parent Washington Navel' (*Citrus sinensis* (L.) Osbeck) orange trees were evaluated for seven years on nine commercial rootstocks in the Najran area of Saudi Arabia. Fruit yield, fruit size, peel thickness, percentage juice, soluble solids and acid were measured. Trees on Volkamer lemon (VL), *Citrus macrophylla* (CM) and rough lemon (RL) were the most productive, whereas trees on Swingle citrumelo (SC) and Cleopatra mandarin (Cleo) were the least productive. Trees on sour orange (SO), Carrizo citrange (CC), *Citrus Taiwanica* (CT), and Amblycarpa (Amb) were intermediate in fruit production. The largest fruit were from trees on VL, CM and RL, while the smallest fruit were on trees budded on Cleo and SO. Peel thickness was the highest in fruit collected from trees on RL and the lowest in fruit collected from those on Cleo and SO. Fruit from trees on Cleo had the highest juice content while those from trees on RL had the lowest juice content. Fruit from trees on CC and SO accumulated the highest soluble solids and fruit from trees on CM, CT, RL, and VL accumulated the lowest soluble solids. Overall, trees on vigorous rootstocks (VL, CM, RL) performed better and were more productive and more profitable than trees on other rootstocks. Trees on SC and Cleo performed the poorest.**

Citrus acreage in the Kingdom of Saudi Arabia is over 15 thousand ha (37.5 thousand acres). The Najran area, located in southwest Saudi Arabia, comprises 25% of the total citrus acreage. There are over one million trees and over 1,000 citrus orchards in the Najran area. Orchard size ranges from 1 to 50 ha (125 acres). In the Kingdom of Saudi Arabia, fruit is not sold based on soluble solids. All fruit is marketed fresh by weight and consumed locally (Zekri and Al-Jaleel, 2000).

'Clementine' mandarin and 'Parent Washington Navel' orange were among the most popular citrus cultivars grown in the Najran area. Fifteen years ago, the most popular rootstocks were sour orange, Troyer and Carrizo. Because of increasing problems with high pH and salinity, rootstocks have become a more critical issue than in previous years. Volkamer lemon, Macrophylla, and Cleopatra mandarin have been gaining ground and are becoming very popular (Al-Jaleel and Zekri, 2002).

Rootstocks have had a substantial role in the development of the citrus industry in the world. The effect of rootstocks on citrus fruit production and fruit quality has been intensively studied in many citrus producing areas (Continella et al., 1988; Economides and Gregoriou, 1993; Fallahi and Rodney, 1992; Fallahi et al., 1989; Gardner and Horanic, 1961, 1966; Grisoni et al., 1989; Monteverde et al., 1988; Roose et al., 1989; Rouse and Maxwell, 1979; Wheaton et al., 1991; Zekri, 1996, 1997, 1999, 2000a, b). Findings from these studies have revealed different results and inconsistent conclusions, which

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were attributed to several factors including climatic conditions and soil characteristics. Therefore, it is unwise to adopt rootstock recommendations from one part of the world to another without a thorough evaluation locally. Since environmental conditions and cultural practices are unique and vary considerably from one area to another, a long term study was carried out to determine the horticultural adaptability and performance of 'Parent Washington Navel' orange (*Citrus sinensis* (L.) Osbeck) trees on nine commercial rootstocks grown on a typical soil where the Saudi Arabian citrus industry is flourishing. On-site field evaluation of rootstocks benefits local growers in selecting the most suitable rootstocks for their citrus cultivars under their specific climatic and edaphic conditions.

Materials and Methods

Rootstocks used were sour orange (*Citrus aurantium* L.) (SO), Carrizo citrange [(*Citrus sinensis* (L.) Osbeck × *Poncirus trifoliata* (L.) Raf.] (CC), Cleopatra mandarin (*Citrus reshni* Hort. ex Tan.) (Cleo), rough lemon (*Citrus limon*) (RL), Swingle citrumelo [(*Citrus paradisi* (L.) × *Poncirus trifoliata* (L.) Raf.] (SC), Taiwanica (*Citrus Taiwanica*) (CT), Amblycarpa (*Citrus limonellus* var. Amblycarpa Hassk) (Amb), Volkamer lemon (*Citrus volkameriana* Ten and Pasq.) (VL), and Macrophylla (Alemow) (*Citrus macrophylla* Wester) (CM). Fruit parameters measured were fruit yield, fruit size, individual fruit weight, peel thickness, and percentage juice, soluble solids, and acid of 'Parent Washington Navel' orange trees. The budwood source and budded trees were free of all known virus and viroids. The trees were planted in 1987 with a 6.0 m (20 ft) by 6.0 m (20 ft) spacing and a tree density of 278 trees/hectare (111 trees per acre).

The soil texture was loamy sand (85% sand, 11% silt, and 4% clay) throughout the root zone having a 2.9% $CaCO_3$ content and a pH of 8.2. The trees were managed according to standard local commercial practices, pruned annually, and watered as needed using a drip irrigation system delivering 120 (30 gal) to 180 L (45 gal)/d. The irrigation water had a pH of 8.0 and an electrical conductivity of 1.02 $dS \cdot m^{-1}$. In early November, each tree was fertilized with 1.0 kg of 18-7.9-4.2-1.5 (N-P-K-Mg) and 25 kg (55 lbs) of composted manure. One kg (2.2 lbs) of N from urea was also applied 3 times (1/2 in January, 1/4 in March, and 1/4 in May). In the spring, foliar sprays of manganese and zinc were also applied. The soil was kept free of weeds using post-emergence herbicides. Pest populations were managed using a local pest management program.

Fruit yield of each tree was taken at harvest. Fruit samples from each experimental plot were collected for fruit quality measurements and evaluations. Individual fruit weight, fruit diameter, peel thickness, juice weight, total soluble solids or Brix, and titratable acid concentrations were determined in the laboratory using standard procedures. Juice was extracted from the fruit samples, weighed, and tested for Brix and acid. The Brix content (mostly soluble sugars) was determined using a hydrometer that measured the specific gravity, which was converted to degrees Brix. The percentage acid was determined by titration using sodium hydroxide and a phenolphthalein indicator.

The experiment was a complete randomized block design and consisted of nine treatments (rootstocks) with four replications of 4-tree plots. Statistical analysis was conducted using analysis of variance and means separation by Duncan's multiple range test at 5% level.

Results and Discussion

Fruit yield. Over the seven-year production period, trees on Volkamer lemon (VL), *Citrus macrophylla* (CM) and rough lemon (RL) were the most productive. Trees on Swingle citrumelo (SC) and Cleopatra mandarin (Cleo) were the least productive. Trees on sour orange (SO), Carrizo citrange (CC), *Citrus Taiwanica* (CT), and Amblycarpa (Amb) were intermediate in fruit production (Table 1). The poor crop for trees on Cleo was partly attributed to Phytophthora infestation, which also reduced growth and tree size. Trees on Cleo grew slowly and fruited poorly during the first few years. Trees on SC had dieback, were relatively small, and consistently produced fewer fruit. Similar results were obtained with 'Olinda Valencia' trees grown in the same area (Al-Jaleel and Zekri, 2002). This was also consistent with Gardner and Horanic (1961) who concluded that scions on Cleo were not precocious. Similar results of yield problems for trees on Cleo have been found from many citrus areas in the world. Cleo is considered a "lazy" rootstock because trees grafted to it fruit relatively poorly until they are 10 to 15 years of age (Castle et al., 1993).

The yield results of this study were consistent with results of several studies conducted in different citrus growing regions where cumulative yields were higher on trees budded on VL and RL than on those budded on SC and Cleo (Castle et al., 1988; Fallahi et al., 1989; Monteverde et al., 1988; Wutscher and Shull, 1973; Zekri, 2000b). However in other studies, no significant differences in cumulative yields were found

Table 1. Fruit yield (kg per tree) of 'Parent Washington Navel' trees on nine rootstocks.

	Rootstock								
Year	SO	CC	Cleo	RL	SC	CT	Amb	VL	CM
1993	38.00[z]	45.75	28.00	54.50	27.75	41.25	45.25	73.50	55.50
1994	60.75	74.00	54.75	93.50	61.50	70.25	64.00	101.00	101.00
1995	84.38	90.00	63.75	97.50	75.00	75.63	67.50	103.13	106.88
1996	82.13	73.75	75.81	76.06	48.71	74.88	89.52	89.13	90.69
1997	46.38	49.50	43.43	53.05	42.00	42.75	45.38	44.63	53.30
1998	62.78	39.38	50.20	62.70	31.20	42.00	60.38	62.88	51.73
1999	76.38	70.90	67.63	83.08	48.94	74.95	76.98	75.58	76.13
Average[y]	64.40 bc[x]	63.33 bc	54.79 cd	74.34 ab	47.87 d	60.24 c	64.14 bc	78.55 a	76.46 a

[z]Mean of four replications.
[y]Mean of twenty-eight measurements (four replications by seven years).
[x]Superscripts indicate mean separation within the last row (among rootstocks) by Duncan's multiple range test, 0.05 level.

among rootstocks including Cleo, SO, CC, VL, RL, CT, and CM (Fallahi et al., 1991; Hearn, 1989). Trees on SC produced the most fruit yield (Rouse and Maxwell, 1979; Wheaton et al., 1991; Wutscher et al., 1975; Wutscher and Shull, 1976a, 1976b). All these results indicated the inconsistency in yield differences as affected by rootstocks, which could be attributed to differences in scion cultivars, tree age, climatic conditions, and soil characteristics.

Fruit size. The largest fruit were found from trees on VL, CM and RL, while the smallest fruit were found on trees budded on Cleo and SO (Table 2). Similar results were found by several other workers where fruit were smaller or lighter from trees on SO and Cleo and larger or heavier from trees on VL, RL, and CM (Al-Jaleel and Zekri, 2002; Continella et al., 1988; Economides and Gregoriou, 1993; Monteverde et al., 1988; Rouse and Maxwell, 1979; Wutscher and Shull, 1976a; Zekri, 2000b). On the other hand, no significant differences were found in 'Valencia' orange fruit size and weight among trees growing on RL, Cleo, SO, and CT (Wutscher and Shull, 1973) and 'Fairchild' fruit weight was higher from trees on CT than fruit from trees on RL, CC, and CM (Fallahi and Rodney, 1992). Furthermore, 'Ambersweet' orange fruit from trees on Cleo were found larger and heavier than those from trees on SC, which could be attributed to the low number of fruit per tree on Cleo (Zekri, 1996). In general, fruit size is correlated with fruit number per tree. The fewer the fruit on the tree, the larger and heavier are the fruit. Moreover, in a particular year beside fruit load, the ultimate size a citrus fruit achieves is the result of many complex factors including nutrition and irrigation programs, rainfall distribution, pruning, and the rootstock/scion combination. Large fruit size is most often preferred in the fresh fruit market and brings higher prices early in the season.

Peel thickness. Another determinant of citrus fresh quality is peel thickness, firmness or texture. Both extremes in peel thickness are not desirable. Fruit with thick peel are usually low in juice, while those with thin peel are prone to splitting and are sensitive to postharvest problems that can occur during shipping and storage. Peel thickness was also affected by the rootstock. Peel thickness was the highest in fruit collected from trees on RL and the lowest in fruit collected from those on Cleo and SO (Table 3). Differences in fruit peel thickness as affected by rootstocks were also reported in some previous studies. Peel thickness was the highest in fruit collected from 'Olinda Valencia' trees on CT and CM and the lowest in fruit collected from those on Cleo, SC, and Amb (Al-Jaleel and Zekri, 2002). Peel thickness of 'Orlando' tangelo was higher for trees on RL (Fallahi et al., 1991) and that of grapefruit was higher on CT (Fallahi et al., 1989) as compared with CC. Fruit rind thickness was found to be the highest for 'Marsh' grapefruit trees on CT and Amb and the lowest for trees on SC, CC, and Estes RL (Economides and Gregoriou, 1993). Trees on SO and VL produced fruit with the thickest rind (Monteverde et al., 1988; Wutscher and Bistline, 1988). However, for 'Marrs' oranges, rind thickness was the highest from trees on SC (Wutscher and Shull, 1976b) and grapefruit rind thickness was higher for fruit from trees on Cleo than CT and RL (Wutscher et al., 1975). From all those studies, there is no consistent trend that the more vigorous rootstocks promoted thicker peel. Furthermore, not all rootstock studies showed differences in peel or rind thickness among rootstocks. Wutscher and Shull (1976a) did not find a significant difference in rind thickness of 'Orlando' tangelo fruit from trees grown on all the four rootstocks studied, SC, SO, Cleo, and CT.

Juice content. Overall, by being less than 45%, juice content was relatively low. The juicier the fruit, the better is its acceptance not only for the juice market but also as a fresh fruit. Like other fruit quality variables, juice content was affected by the rootstock and varied through the years. Fruit from trees on Cleo had the highest juice content while those from trees on RL had the lowest juice content (Table 4). Similar results were reported from some earlier studies. Fruit from trees on SC had the highest juice content while those from trees on SO, RL, and CT had the lowest juice content (Al-Jaleel and Zekri, 2002). Fruit from trees on SC and Cleo had the best juice percentage compared with trees on VL, CC, and SO (Monteverde et al., 1988). Fruit from trees on CT had the lowest percent juice compared with RL, VL, CM, and CC (Fallahi et al., 1989). Fruit from trees on CC and RL contained more juice than those from trees on CM (Fallahi et al., 1991). However, juice content of 'Marrs' orange was the highest for trees on SO and the lowest for trees on CT (Wutscher and Shull, 1976b). In general, the larger the fruit and the thicker the peel or rind, the lower is the juice content. Juice content was the highest for SO and the lowest for Estes RL, VL, Amb and Cleo (Economides and Gregoriou, 1993), and 'Hamlin' fruit from trees on RL and VL had the lowest percentage juice (Wutscher and Bistline, 1988). Not all rootstock studies demonstrated that rootstocks had an influence on juice content. No significant difference in juice content of 'Orlando' tangelo, 'Comune' Clementine, 'Fairchild' mandarin and grapefruit was found from trees grown on all the studied rootstocks (Continella et al., 1988; Fallahi and Rodney, 1992; Wutscher et al., 1975; Wutscher and Shull, 1976a).

Table 2. Fruit diameter (cm) of 'Parent Washington Navel' trees on nine rootstocks.

	Rootstock								
Year	SO	CC	Cleo	RL	SC	CT	Amb	VL	CM
1993	7.80[z]	7.83	7.95	8.20	7.75	7.95	7.75	8.03	8.30
1994	7.90	7.98	7.65	8.10	8.08	7.98	7.98	7.93	7.98
1995	7.73	7.75	7.75	7.98	7.93	8.00	7.95	8.33	8.18
1997	7.53	7.73	7.53	7.63	7.50	7.48	7.58	7.98	7.88
1998	8.20	8.05	8.10	8.30	8.33	8.35	8.08	8.45	8.35
1999	7.23	7.68	7.03	7.88	7.60	7.50	7.58	7.83	7.65
Average[y]	7.73 d[x]	7.83 cd	7.67 d	8.01 abc	7.86 bcd	7.88 bcd	7.82 cd	8.09 a	8.05 ab

[z]Mean of four replications.
[y]Mean of twenty-four measurements (four replications by six years).
[x]Superscripts indicate mean separation within the last row (among rootstocks) by Duncan's multiple range test, 0.05 level.

Table 3. Peel thickness (mm) of fruit from 'Parent Washington Navel' trees on nine rootstocks.

	Rootstock								
Year	SO	CC	Cleo	RL	SC	CT	Amb	VL	CM
1993	6.38[z]	6.83	5.98	7.50	7.08	6.15	6.78	6.98	6.70
1994	5.80	6.00	5.83	6.38	6.35	6.18	5.85	6.03	6.45
1995	5.03	5.35	5.20	5.88	5.70	5.48	5.45	5.65	5.43
1997	5.60	5.35	5.30	4.93	5.40	5.45	4.98	5.38	5.45
1998	6.60	6.53	6.75	7.00	7.35	6.98	6.30	6.58	6.83
1999	5.20	5.45	5.23	6.03	5.25	5.60	5.50	5.88	5.48
Average[y]	5.77 b[x]	5.92 ab	5.71 b	6.28 a	6.19 ab	5.97 ab	5.81 ab	6.08 ab	6.05 ab

[z]Mean of four replications.
[y]Mean of twenty-four measurements (four replications by six years).
[x]Superscripts indicate mean separation within the last row (among rootstocks) by Duncan's multiple range test, 0.05 level.

Soluble solids. The flavor and palatability of citrus fruits is a function of relative levels of soluble solids, acids, and presence or absence of various aromatic or bitter juice constituents. Although fruit quality standards, which determine minimum levels of acceptability, have not been established in Saudi Arabia, soluble solids concentration in the juice has not been completely ignored as an important parameter for fresh fruit. Rootstocks were found to affect soluble solids concentration in fruit juice. Soluble solids concentration in fruit from trees on CC and SO was the highest while it was the lowest for fruit from those on CM, CT, RL, and VL (Table 5). Similar results were obtained with 'Olinda Valencia' trees grown in the same area (Al-Jaleel and Zekri, 2002). Other workers also found similar results. Total soluble solids were the lowest for RL and the highest for Cleo and SO (Hearn, 1989; Wutscher et al., 1975). Total soluble solids were among the highest from fruit on SO (Monteverde et al., 1988; Wutscher and Shull, 1973; Wutscher and Shull, 1976b). Fruit from trees on SO, CC and/or Cleo had the highest soluble solids concentration, while those on VL and RL had the lowest soluble solids concentration (Castle et al., 1988; Continella et al., 1988; Fallahi et al., 1989; Fallahi and Rodney, 1992; Wutscher and Bistline, 1988). Total soluble solids were among the highest for fruit from trees on SC and the lowest for fruit from trees on RL, VL and Milam (Economides and Gregoriou, 1993; Zekri, 2000b). The results on soluble solids of all these studies are consistent showing poorer internal fruit quality for trees grown on relatively vigorous rootstocks such as RL and VL compared with trees grown on less vigorous rootstocks such SC and SO.

Acid content. Total acidity of citrus juices is an important factor in overall juice quality and in determining time of harvest in several citrus producing countries. In this study, acid content in the juice was not affected by the rootstocks (Table 6). However, in other studies, acid content in the juice differed among rootstocks. Acid content in the juice of fruit from 'Olinda Valencia' trees on SC and Amb was higher than that from trees on SO, Cleo, RL, CT, and VL (Al-Jaleel and Zekri, 2002). The lowest total acids in the fruit juice were from trees on CT and the highest were from trees on SC (Wutscher and Shull, 1976a, 1976b). Acid content was the highest for trees grown on SO and the lowest for trees on VL and RL (Continella, 1988). Total acid was among the highest in the juice from trees on CC, SC and Cleo and the lowest from trees on RL and VL (Fallahi et al., 1989, 1991; Fallahi and Rodney, 1992; Wutscher and Bistline, 1988; Wutscher et al., 1975). Although internal fruit quality including acid content can be affected by the scion cultivar, tree age and other factors, the results on acid content from most of these studies are consistent showing relatively lower acid content for trees grown on lemon rootstocks.

Conclusions

Rootstocks can affect the success and profitability of virtually any commercial citrus culture. Rootstock use is considered essential in citriculture because of its influence on how and where citrus can be grown successfully, and its influence on scion fruit quality and quantity. In this study, it was quite obvious that rootstocks had a significant effect on fruit yield

Table 4. Juice content (% by wt) of fruit from 'Parent Washington Navel' trees on nine rootstocks.

	Rootstock								
Year	SO	CC	Cleo	RL	SC	CT	Amb	VL	CM
1993	38.75[z]	38.15	41.48	37.58	38.00	40.48	37.75	39.50	41.03
1994	45.20	44.30	44.50	41.65	43.23	41.68	43.80	41.40	42.15
1995	51.33	49.65	51.25	47.63	51.33	49.25	51.53	49.45	48.63
1997	41.63	43.43	45.28	39.55	41.43	42.78	42.60	44.15	46.18
1998	41.58	41.30	42.78	39.80	41.05	39.93	41.70	40.20	41.43
1999	44.33	45.80	43.78	43.98	43.95	45.70	44.30	43.90	46.35
Average[y]	43.80 ab[x]	43.77 ab	44.84 a	41.70 b	43.16 ab	43.30 ab	43.61 ab	43.10 ab	44.29 ab

Mean of four replications.
[y]Mean of twenty-four measurements (four replications by six years).
[x]Superscripts indicate mean separation within the last row (among rootstocks) by Duncan's multiple range test, 0.05 level.

[z]Table 5. Total soluble solids concentration (%) of juice from 'Parent Washington Navel' trees on nine rootstocks.

	Rootstock								
Year	SO	CC	Cleo	RL	SC	CT	Amb	VL	CM
1993	12.15[z]	13.20	11.28	10.90	11.60	10.73	12.15	11.45	11.20
1994	12.65	13.15	12.40	11.48	12.28	11.60	12.80	11.63	11.43
1995	13.18	13.65	12.73	12.68	12.30	11.70	12.70	11.90	11.93
1997	12.38	11.98	11.60	10.65	11.85	11.58	11.70	10.60	10.58
1998	13.08	12.38	11.90	11.20	12.49	10.90	12.13	11.25	10.93
1999	11.85	11.88	11.30	10.50	11.23	10.43	11.28	10.95	10.50
Average[y]	12.55 a[x]	12.70 a	11.87 b	11.23 c	11.96 b	11.15 c	12.13 b	11.30 c	11.09 c

[z]Mean of four replications.
[y]Mean of twenty-four measurements (four replications by six years).
[x]Superscripts indicate mean separation within the last row (among rootstocks) by Duncan's multiple range test, 0.05 level.

Table 6. Acid content (%) of juice from 'Parent Washington Navel' trees on nine rootstocks.

	Rootstock								
Year	SO	CC	Cleo	RL	SC	CT	Amb	VL	CM
1993	0.72[z]	0.70	0.59	0.65	0.67	0.67	0.64	0.67	0.74
1994	0.67	0.64	0.62	0.68	0.71	0.66	0.72	0.87	0.69
1995	0.87	0.81	0.77	0.79	0.81	0.83	0.87	0.89	0.83
1997	0.85	0.89	0.85	0.89	0.89	0.86	0.86	0.83	0.81
1998	0.90	0.83	0.86	0.84	0.91	0.84	0.82	0.84	0.87
1999	0.73	0.84	0.78	0.71	0.79	0.76	0.83	0.71	0.78
Average[y]	0.79 a[x]	0.79 a	0.75 a	0.76 a	0.80 a	0.77 a	0.79 a	0.80 a	0.79 a

[z]Mean of four replications.
[y]Mean of twenty-four measurements (four replications by six years).
[x]Superscripts indicate mean separation within the last row (among rootstocks) by Duncan's multiple range test, 0.05 level.

and quality. Failure to assess accurately the impact of climate, soils, and rootstocks on economic profitability of citrus can be a major reason for crop losses or reduced income because of reduced yield and quality potential. Trees on CM, VL, and RL rootstocks were more vigorous, precocious and more productive than those on the other rootstocks. Cleo and SC rootstocks are not recommended for the Najran area of Saudi Arabia because of Cleo's high susceptibility to Phytophthora particularly in poorly drained situations and because of SC poor adaptability to high pH soil, calcareous soils, and/or relatively saline environment. Based on this study, CM, VL, and RL are good choices as rootstocks for 'Parent Washington Navel' orange in the Najran area of Saudi Arabia.

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