Rootstocks affect leaf and fruit mineral concentrations of Washington navel orange

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Abstract — Introduction. Because many soils in Greece exhibit poor drainage leading to inadequate soil aeration, the country needs rootstocks for flooding soils that do not have the same deficiencies as the most common sour orange rootstocks. A study was conducted to investigate the effects of the sour orange (SO), Swingle citrumelo (SC) and Volkamer lemon (VL) rootstocks, which are considered to be tolerant to flooding, on fruit quality, pulp and juice mineral concentrations of Washington navel orange. **Materials and methods**. The study was carried out in two locations and during two seasons. At harvest, fruits were weighed; the juice content and the rind thickness were measured. Analyses of internal quality were conducted using standard procedures. Leaf samples were analyzed for macro- and microelements. **Results**. The trees grafted on SC and VL had larger and heavier fruits than those on SO, but this last rootstock had the highest juice content for the two seasons. Trees on VL produced fruit with the lowest total soluble solids and total acids. Potassium, of which the concentration was dependent on the location, year and rootstock, was the most abundant nutrient in Washington navel orange pulp and juice; calcium was second. **Discussion**. Finally, SO and SC would be the most promising rootstocks for the Washington navel variety in Greece from a commercial point of view. (© Elsevier, Paris)

Citrus **/ leaves / fruits / mineral content / rootstock crops / flooded land**

Influence du porte-greffe sur la teneur en éléments minéraux de la feuille et du fruit de l'oranger Washington navel.

Résumé — Introduction. De nombreux sols en Grèce ne bénéficient pas d'un bon drainage et ne sont donc pas suffisamment aérés. Le pays a donc besoin de porte-greffes adaptés à des sols inondables qui ne présenteraient pas les déficiences observées avec les porte-greffes d'orange amère les plus courants. L'influence de trois porte-greffes – l'orange amère (SO), le citrumelo Swingle (SC) et le citron Volkamer (VL) –, considérés comme tolérants à l'inondation, a été étudiée sur la qualité du fruit de l'oranger Washington navel et sur la concentration en éléments minéraux de son jus et sa pulpe. **Matériel et méthodes**. L'étude a été faite sur deux sites et pendant deux saisons. Les fruits ont été pesés à leur récolte ; leur teneur en jus et l'épaisseur de leur écorce ont été mesurées. Leur qualité a été évaluée en utilisant des techniques standard. Les macro- et microéléments de feuilles échantillonnées ont été analysés. **Résultats**. Les orangers greffés sur SC et VL ont donné des fruits plus gros et plus lourds que ceux sur SO qui a présenté, pour sa part, les plus fortes teneurs en jus, quelle que soit la saison. Les arbres greffés sur VL ont donné les fruits ayant les plus basses teneurs en acides totaux et en solides solubles totaux. Le potassium, dont la concentration a dépendu du lieu, de l'année et du porte-greffe, a été le principal élément trouvé dans la pulpe et le jus de l'orange Washington navel ; le calcium a eu la seconde place. **Discussion**. Finalement, d'un point de vue économique, SO et SC seraient les porte-greffes de la variété Washington navel les plus prometteurs. (© Elsevier, Paris)

Citrus **/ feuille / fruit / teneur en éléments minéraux / plante porte-greffe / terre inondée**

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1. introduction

The most commonly cultivated citrus variety in Greece is Washington navel orange: the Greek citrus industry produced 1.3 Mt in the 1996–1997 period, of which 1 Mt were Washington navel oranges.

Many reports have been published on the organic composition of orange juice in relation to rootstocks [1] and mineral intake [2], but studies on the effect of rootstocks on mineral composition of orange juice and pulp are limited [3, 4].

The new rootstocks developed in other regions of the world are not always found well adapted to the wet soils commonly used for citrus culture in Greece. Many soils exhibit poor drainage leading to inadequate soil aeration. Greece needs rootstocks for flooding soils that do not have the same deficiencies as the most common sour orange rootstocks. Troyer citrange is not adapted to wet soils and is considered to be a sensitive rootstock to flooding [5], while sour orange, Swingle citrumelo and Volkamer lemon are considered to be tolerant to flooding [6].

Therefore, this work was conducted to compare the compositional changes during two growing seasons that occur in Washington navel orange juice and pulp in relation to these three rootstocks, adapted to humid soils.

The rootstocks included in these trials have been tested previously for tolerance to phytophthora [7].

2. materials and methods

Fifteen oranges per tree were harvested at maturity in the end of December of 1994 and 1995 from 10-year-old Washington navel orange (*Citrus sinensis*) trees grafted on Swingle citrumelo (*Citrus paradisi* × *Poncirus trifoliata*), sour orange (*Citrus aurantium*), and Volkamer lemon (*Citrus volkameriana*), planted in two loamy-soiled locations (*table I*) at a spacing of 5 × 6 m (four plots, three trees per plot) in the region of the Aghia village (Chania, Crete). The experimental area has an average annual rainfall of 920 mm occurring mainly during the period from mid-September to mid-April. Mean maximum temperatures range from 23 °C in January to 36 °C in July and mean minimum temperatures from 2 °C to 10 °C for the same months. The relative humidity varies between 65% and 80% and is inversely related to temperature.

The soil of location 1 presents a better field infiltration which affects the water balance in comparison with the soil of location 2.

The trees received the recommended horticultural management and fertilization of 1 kg per tree of the fertilizer Acidam produced by Eurozolf Srl. Co., with the title 0N-0P-0K-50S-15C and 1.5 kg of calcium nitrate with 15.5% total N.

At harvest, the fruit were weighed and the juice content and the rind thickness measured. Analytical analyses of internal quality were conducted using standard procedures:

Table I.
Soil characterization of the two loamy locations used for comparing the compositional changes that occur in Washington navel orange juice and pulp in relation to three rootstocks adapted to humid soils.

Locations	Soil analysis of the orchards				
	Calcium carbonate ($CaCO_3$) mg·kg^{-1}	pH	Electrical conductivity (dS·m^{-1})	Phosphorus (μg·g^{-1})	Potassium (μg·g^{-1})
Site 1	1.5	6.8	2.956	210	160
Site 2	1.5	7.8	2.652	230	240

– the total soluble solids were determined by measuring the refractive index at 20 °C;

– titratable acids (total acids) were determined by direct titration of a 10-mL aliquot to pH 8.1;

– ascorbic acid was determined by a modified version of the 2,6-dichloroindophenol method [8];

– sodium and potassium were determined by flame spectroscopy using a Bruno Langl MGd flame spectrometer, while magnesium, calcium and iron were determined by atomic absorption method using a Perkin-Elmer 403 atomic absorption spectrometer [9].

Leaf samples were collected in September and analyzed for macro- and microelements. Nutrient concentration of leaves was determined with the analytical procedures currently used at the Edaphological Institute of Lycovrissis (Athens), according to the procedures of Embleton et al. [10].

The experimental design was a split-plot with two plots of each rootstock and four replications. Statistical analysis was conducted using the F-test, and Duncan's multiple range test was employed for mean separation.

3. results and discussion

Fruit quality was significantly influenced by the rootstocks and location (*table II*). The trees grafted on Swingle citrumelo and Volkamer lemon had larger and heavier fruits than those on sour orange. Rind thickness varied with the season, but not with location. Fruit from trees on Volkamer lemon generally had thicker rind than fruit from trees on sour orange or Swingle citrumelo (*table II*).

Fruit from trees on sour orange had the highest juice content for the two seasons. Trees on Volkamer lemon produced fruit with the lowest total soluble solids and total acids. Total soluble solids and acids varied between seasons and location.

Table II.
Fruit quality of Washington orange trees grafted on three rootstocks and grown for two seasons, on two locations.

Rootstock season	Fruit weight (g)		Rind thickness (mm)		Juice content (%)		Total soluble solids (%)		Total acids (%)		Brix/acid ratio		Vitamin C (mg 100 mL^{-1})	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Sour orange														
1993–1994	206.0d	135.5f	5.70b	5.70b	42.62b	41.87bc	10.37ab	10.87a	0.86de	0.98bc	12.03de	11.16de	55.0cd	53.0d
1994–1995	273.7b	244.0c	7.58a	7.12a	45.50a	33.25b	9.87bc	9.95bc	1.05b	0.92cd	9.47f	10.78ef	60.0a	56.5de
Volkamer lemon														
1993–1994	241.0c	272.5b	7.10a	7.40a	34.75ef	32.75f	8.40e	9.80c	0.61h	0.64h	13.77bc	15.32a	50.0e	50.0e
1994–1995	300.4a	251.0c	7.50a	7.20a	34.75ef	32.25f	8.55e	8.25e	0.75fg	0.55h	11.29de	15.01ab	48.5e	49.12e
Swingle citrumelo														
1993–1994	266.5b	190.0e	6.20b	6.20b	36.52de	32.10f	9.27cd	9.82bc	0.74g	0.83ef	12.57cd	11.88de	57.0bc	59.0ab
1994–1995	316.5a	305.0a	6.20b	6.10b	39.50c	33.75ef	9.37cd	8.80de	1.17a	0.72g	7.98g	12.20de	57.12bc	56.75bc

For a same quality parameter, means within the columns followed by the same letter do not differ at the 95% level (Duncan's multiple-range test).

Table III.
Leaf analysis of Washington navel orange trees grafted on three rootstocks for two seasons on two locations.

Rootstock season	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Calcium (%)		Magnesium (%)		Zinc ($\mu g \cdot g^{-1}$)		Manganese ($\mu g \cdot g^{-1}$)	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Sour orange														
1993–1994	2.7abc	2.7abc	0.119de	0.121de	1.14a	0.79b	4.25cd	4.6c	0.186bcd	0.210bc	14.25fg	20.25ef	17.5e	14.2e
1994–1995	2.9a	2.9a	0.122d	0.120de	0.79b	0.63b	5.26b	6.2a	0.175bcd	0.187bcd	24.00de	37.00ab	90.0a	62.5b
Volkamer lemon														
1993–1994	2.6bc	2.7abc	0.100e	0.122d	0.98ab	1.03a	3.00f	3.7de	0.201bcd	0.210bc	14.25fg	20.10ef	17.6e	16.6e
1994–1995	2.5cd	2.8ab	0.105e	0.118de	0.70b	1.17a	3.00f	6.2a	0.212b	0.175bcd	25.47cde	31.00 bc	50.0bc	55.0 bc
Swingle citrumelo														
1993–1994	2.6bc	2.5cd	0.150b	0.115de	1.20a	1.22a	3.25ef	3.8de	0.290a	0.160d	15.20fg	10.22g	18.2e	16.2e
1994–1995	2.7abc	2.3d	0.160a	0.130c	1.17a	0.97ab	3.45ef	5.6b	0.300a	0.162cd	28.00cd	38.00a	35.0d	50.0bc

For a same nutrient, means within the columns followed by the same letter do not differ at the 95% level (Duncan's multiple-range test).

Volkamer lemon induced significant lower concentrations of the vitamin C content in comparison with the rootstocks sour orange and Swingle citrumelo (*table II*).

The leaf mineral status according to Embleton et al. [10] was optimal (*table III*). Rootstocks affected leaf mineral concentration of Washington navel orange trees. With sour orange, calcium concentration was increased, while, with Swingle citrumelo, potassium concentration was increased (*table III*). Leaf mineral concentration of the other elements did not indicate effects due to rootstocks. Leaf manganese and zinc levels were higher in the second season than those in the first season, due to Acidam fertilizer [11].

Potassium was the most abundant element in Washington navel orange pulp and juice (*tables IV, V*). The levels of this element showed the widest variability. This observation was confirmed by Hopkins and Walkley [12]. Its concentration was found within a range of 911 to 1780 $\mu g \cdot g^{-1}$ for pulp and 990 to 1830 $\mu g \cdot L^{-1}$ for juice. Potassium concentration in the pulp was higher than in the juice of fruit from sour orange in both seasons. Potassium content was higher in 1995 than in 1994 (*tables IV, V*). There is no correlation between leaf and fruit potassium levels [13].

The sodium concentration in the juice was higher than in the pulp for location 1 and lower for location 2. However, for both cases, pulp showed higher potassium/sodium ratios than juice.

Magnesium level was found to be from 84 to 103.78 $\mu g \cdot g^{-1}$ for pulp and from 81.25 to 102.7 $\mu g \cdot L^{-1}$ for juice (*tables IV, V*). Magnesium levels in the juice were similar to those of calcium, while in the pulp, magnesium content was 50% lower than that of calcium. Similar results were found by Nikdel and Nagy [14].

Calcium is the second most abundant element in Washington navel orange. Calcium concentration ranged from 178.6 to 283.9 $\mu g \cdot g^{-1}$ for pulp and from 59.05 to 104.42 $\mu g \cdot L^{-1}$ for juice. Calcium content in the pulp was higher than that in the juice, probably due to the low solubility of calcium salts with organic

Table IV.
Ranges of element contents in orange pulp, according to three different rootstocks and two locations on the region of Chania (Greece).

Rootstock season	Potassium ($\mu g \cdot g^{-1}$)		Sodium ($\mu g \cdot g^{-1}$)		Magnesium ($\mu g \cdot g^{-1}$)		Calcium ($\mu g \cdot g^{-1}$)		Iron ($\mu g \cdot g^{-1}$)	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Sour orange										
1993–1994	1 516 b	1 754 a	4.1 g	14.1 cd	103.8 a	103.2 a	246.1 c	212.8 e	0.83 d	0.38 i
1994–1995	1 074 d	1 780 a	6.7 f	15.2 b	95.2 cd	98.3 bc	253.7 c	178.6 f	0.87 c	0.38 i
Volkamer lemon										
1993–1994	1 295 c	1 264 c	3.2 g	14.9 bc	93.1 d	87.1 e	287.5 a	212.3 e	1.19 a	0.44 h
1994–1995	911 e	1 323 c	3.2 g	11.5 e	84.0 e	92.3 d	279.8 b	215.8 e	0.96 b	0.38 i
Swingle citrumelo										
1993–1994	1 780 a	1 364 c	3.2 g	13.2 d	98.0 bc	95.9 cd	242.0 d	210.7 e	0.74 f	0.31 j
1994–1995	1 476 b	1 343 c	3.9 g	16.9 a	101.5 ab	94.0 cd	283.9 ab	211.3 e	0.78 e	0.62 g

For a same element, means within the columns followed by the same letter do not differ at the 95% level, (Duncan's multiple-range test).

Table V.
Ranges of element contents in orange juice, according to three different rootstocks and two locations in the region of Chania (Greece).

Rootstock season	Potassium ($\mu g \cdot L^{-1}$)		Sodium ($\mu g \cdot L^{-1}$)		Magnesium ($\mu g \cdot L^{-1}$)		Calcium ($\mu g \cdot L^{-1}$)		Iron ($\mu g \cdot L^{-1}$)	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Sour orange										
1993–1994	1 238 e	1 690 b	9.3 gf	8.2 gh	92.1 bc	94.62 abc	79.45 d	84.72 c	0.75 a	0.63 c
1994–1995	1 387c	1 830 a	15.0 b	11.6 d	97.8 ab	90.32 bcd	81.77 cd	59.05 g	0.74 a	0.50 e
Volkamer lemon										
1993–1994	990 g	1 302 cd	11.4 de	13.3 c	91.6 bcd	81.25 e	98.90 b	83.25 cd	0.42 fg	0.35 g
1994–1995	1 130 f	1 529 c	10.3 ef	12.5 cd	82.6 de	86.77 cde	104.42 a	67.75 e	0.56 d	0.38 g
Swingle citrumelo										
1993–1994	1 323 cd	1 642 b	8.5 gh	8.0 h	95.0 abc	87.75 cde	82.00 cd	64.07 ef	0.70 b	0.38 g
1994–1995	1 522 c	1 628 b	14.7 b	17.7 a	102.7 a	89.00 bcde	67.92 e	63.40 f	0.63 c	0.44 f

For a same element, means within the columns followed by the same letter do not differ at the 95% level (Duncan's multiple-range test).

acids. Fruit obtained from trees on Volkamer lemon had a high calcium concentration during the course of the experiment.

Iron concentrations in orange juice from Volkamer lemon were lower compared to the results obtained with the other rootstocks. This may be a characteristic of Volkamer lemon since it shows iron deficiency in the leaves during the winter, but iron is higher in the pulp for location 1 in Volkamer

lemon. Among the two locations, the iron concentration is lower at location 2, where the soil is more flooded.

The ranges of potassium, magnesium and iron concentrations in the juice were similar to those reported by Nagy [15].

4. conclusion

The most abundant element of Washington navel orange in pulp and juice was potassium. A Duncan's multiple-range test at 95% confidence limit showed a significant difference of fruit quality, depending of the location, season and rootstock.

On the basis of these results, sour orange and Swingle citrumelo are promising as potential commercial rootstocks for the Washington navel variety in Greece, particularly for water-holding soils. Swingle citrumelo grows more vigorously on flooded soils than in well-drained soils [16]. Volkamer lemon is a vigorous rootstock which shows a low concentration of soluble solids per fruit, but produces more soluble solids per tree [17]. Volkamer lemon deserves further evaluation as potential commercial rootstock. Sour orange in Greece is a popular rootstock because of its many attributes related to yield and juice quality. However, it has one major weakness which is its high susceptibility to *Citrus* tristeza virus [18].

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Influencia del portainjertos en el contenido en elementos minerales de la hoja y del fruto del naranjo Washington Navel.

Resumen — Introducción. Existen numerosos suelos en Grecia que al no tener un buen drenaje no están aireados. Por ello, el país necesita portainjertos adaptados a suelos inundables, que no presenten las deficiencias observadas con los portainjertos más usuales de naranja amarga. Se estudió la influencia de tres portainjertos -naranja amarga (SO), el citrumelo Swingle (SC) y el citrus Volkameriana (VL)-, que presentan una tolerancia a la inundación, en la calidad del fruto del naranjo Washington Navel y la concentración en elementos minerales de su zumo y pulpa. **Material y métodos**. El estudio se llevó a cabo en dos terrenos y durante dos estaciones. Los frutos se pesaron al recolectarse y se midió el contenido en jugo y el espesor de las cortezas. Se evaluó su calidad mediante una serie de técnicas estándares. Se analizaron los macro y microelementos de las hojas muestreadas. **Resultados**. Los árboles injertados en SC y VL dieron frutos de mayor tamaño y más pesados que los injertados en SO que tenían, a su vez, el mayor contenido en jugo fuera cual fuera la estación considerada. Los árboles injertados en VL dieron los frutos con los contenidos más bajos en ácidos totales y en sólidos solubles totales. El potasio, cuya concentración dependió del lugar, del año y del portainjerto, fue el principal elemento hallado en la pulpa y en el jugo de la naranja Washington Navel seguido por el calcio. **Discusión**. Cabe concluir diciendo que desde un punto de vista económico SO y SC parecen los portainjertos más prometedores de la variedad Washington Navel. (© Elsevier, Paris)

***Citrus* / hojas / frutas / contenido mineral / plantas para patrón / tierras inundablas**