

Plant growth, yield and fruit quality of ‘Lane Late’ navel orange on four citrus rootstocks

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Abstract

This study analyses the influence of four citrus rootstocks, *Citrus macrophylla* Wester, Gou Tou Chen (*Citrus* hybrid), *C. volkameriana* Ten. & Pasq. and Cleopatra mandarin (*C. reshni* Hort. ex Tan.), on growth, yield and fruit quality on Lane Late navel orange. Trees were grown in a plot in Alicante (Spain), where the soil is clay loam, with pH 8.5 and electric conductivity in the 1/5 extract: 0.643 mmhos cm⁻¹. Yield was weighed during four harvests, fruit quality was determined in 2007 and 2009. Cleopatra mandarin and Gou Tou Chen were found to be the most invigorating rootstocks for ‘Lane Late’ in heavy and calcareous soil. Trees on *C. macrophylla* rootstock produced the highest cumulative yield (328.81 kg tree⁻¹), without significant differences compared to trees on Cleopatra mandarin (292.41 kg tree⁻¹). Rootstock significantly affected fruit quality variables. *C. macrophylla* and *C. volkameriana* would appear to induce the highest fruit weight and ripening index.

Additional key words: fruit colour; fruit size; juice; organic acids; yield efficiency.

Resumen

Efecto del patrón sobre el crecimiento del árbol, la productividad y la calidad de la fruta, sobre el naranjo, variedad Lane Late

El presente estudio analiza la influencia de cuatro patrones de cítricos, *Citrus macrophylla* Wester, Gou Tou Chen (híbrido de *Citrus*), *C. volkameriana* Ten. and Pasq. y mandarino Cleopatra (*C. reshni* Hort. ex Tan.) en el tamaño del árbol, la productividad y la calidad de la fruta de la variedad ‘Lane Late’. Los árboles se cultivaron en una parcela en Alicante (España), donde el suelo es franco arcilloso, con pH 8,5 y conductividad eléctrica en el extracto 1/5: 0,643 mmhos cm⁻¹. La productividad de los árboles se determinó durante cuatro cosechas; la calidad de la fruta se analizó en 2007 y 2009. El mandarino Cleopatra y el Gou Tou Chen fueron los patrones más vigorosos para Lane Late en suelos pesados y calizos. Los árboles sobre el patrón *C. macrophylla* produjeron una mayor cosecha acumulada (328,81 kg árbol⁻¹), aunque sin diferencias significativas con los árboles injertados sobre mandarino Cleopatra (292,41 kg árbol⁻¹). El patrón afecta significativamente las variables de calidad del fruto. *C. macrophylla* y *C. volkameriana* inducen mayor peso del fruto, así como un mayor índice de madurez.

Palabras clave adicionales: ácidos orgánicos; color del fruto; eficiencia productiva; tamaño del fruto; zumo.

Introduction

Spain is one of the leading citrus producers supplying the fresh market world-wide. Salinity affects several areas of Castellón, Valencia and Alicante provinces

(produced mainly by NaCl) and most areas of Murcia (Pérez-Pérez *et al.*, 2009).

‘Lane Late’ navel orange is an important cultivar in Spain, which originated as a limb sport of Washington Navel orange in Australia and was first recorded in

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Abbreviations used: ABI (alternate bearing index), CI (colour index), CTV (*Citrus tristeza virus*), IVIA (Instituto Valenciano de Investigaciones Agrarias), RI (ripening index), TA (total acids), TCSA (trunk cross-sectional area), TSS (total soluble solids).

1950. It produces vigorous trees and has good productivity with high-quality fruits for fresh consumption. Fruits ripen in December, but are usually harvested in March in Spain when other navel oranges have already been harvested (Agustí, 2000).

Carrizo citrange [*C. sinensis* (L.) Osb. × *Poncirus trifoliata* (L.) Raf.] is currently the most important rootstock used in Spain, employed in over 80% of nursery production (Forner-Giner *et al.*, 2003). This rootstock is CTV (*Citrus tristeza virus*) tolerant, induces good productivity and fruit quality but is susceptible to salinity and lime-induced chlorosis (Newcomb, 1978). This makes it difficult to grow in calcareous soils due to salinity-related problems, thus requiring the search for alternatives. In Alicante province, soils are heavy and calcareous, with salinity problems, which hinder the use of Carrizo citrange rootstock.

Other citrus rootstocks include Cleopatra mandarin (*C. reshni* Hort. ex Tan.), which is tolerant to CTV, exocortis, xyloporosis, salt, cold and calcareous soils. However, despite being tolerant to these problems, trees on Cleopatra mandarin tend to grow slowly for the first few years after planting. Juice quality of fruits is excellent but fruit size is small, particularly with Valencia scions (Castle, 1987). Alternatively, trees on *C. volkameriana* are vigorous and bear precociously, but are more susceptible to *Phytophthora* spp. (Forner-Giner *et al.*, 2003).

Meanwhile, *C. macrophylla* Wester is a rootstock used in Spain usually for lemon trees in Spain. Trees on *C. macrophylla* are vigorous, precocious and fruit heavily but fruit has lower juice quality than trees on other rootstocks. Regarding tolerance traits, it is CTV-susceptible when used with orange but advantages include tolerance to salinity, iron chlorosis and *Phytophthora* spp. On the other hand, it is susceptible to cold and nematodes (Castle, 1987). Finally, Gou Tou Chen is probably a sour orange (*C. aurantium* L.) hybrid and used as citrus rootstock in China. Trials in Florida showed that trees grafted onto this rootstock are not very productive and fruit quality is low (Wutscher and Bowman, 1999).

The present study was carried out to evaluate vegetative growth, yield and fruit quality of 'Lane Late' navel orange grafted onto four commercial rootstocks used in Spain.

Material and methods

Plant material and field trial

C. macrophylla, Gou Tou Chen, *C. volkameriana* and Cleopatra mandarin were tested as rootstocks for

'Lane late' navel orange. Rootstock seeds were obtained from the rootstock germplasm bank at the IVIA (Instituto Valenciano de Investigaciones Agrarias).

All nursery processes were performed in an aphid-proof greenhouse, equipped with a cooling system, at temperatures ranging between 18°C and 27°C and relative humidity of about 80%. On May 28th 1996, one year after budding, the nursery trees were planted in a randomized block design with 14 single-tree replications for each scion-stock combination at the Experimental Station (38° 14' 56.47" N, 0° 41' 35.95" W) (pertaining to IVIA) in Elche, a village near Alicante, Spain. Tree spacing was 4.5 × 4 m. The plot was surrounded by buffer rows on all four sides.

The experimental station is located near the Mediterranean Sea (about 10 km). It has clay loam soil, with pH 8.5, CaCO₃ 44.4%, active calcium carbonate 17.1% and electric conductivity in the saturation extract at 25°C of 5.79 mS cm⁻¹.

Standard cultural practices for Lane Late orange were used with drip irrigation and chemical weed-control. Water pH was 8.0, while electrical conductivity was 0.8 mS cm⁻¹ up to 2005. From 2006 water pH was 7.8 with electrical conductivity ranging from 2.0 to 3.5 mS cm⁻¹ and 400 to 500 mg L⁻¹ of B. After the 6th year, the amounts of fertilization applied were: ammonium nitrate (33%) 2 kg tree⁻¹; mono-ammonium phosphate 0.5 kg tree⁻¹; KNO₃ 0.7 kg tree⁻¹; and iron chelate 10 g tree⁻¹ in springtime. After 3 years of cultivation, trees were hand-pruned annually after harvest.

Yield and quality variables

In January 2008, after being planted in the field for 12 years, tree height, canopy diameter, trunk girth at 10 cm above and below the budding union were measured for all the trees and scion/stock ratio was calculated. Canopy volume was calculated using Turrell's formula (1946).

In March, each tree was harvested. Yield (kg tree⁻¹) was monitored over a four-year period (2005/06 until 2008/2009).

Cumulative yield (kg tree⁻¹) was calculated for 2005/06 through 2008/09 (four-year cumulative yield). Yield efficiency (kg m⁻³) was estimated as the ratio of cumulative yield to canopy volume. The alternate bearing index (ABI) was calculated by dividing the difference between two consecutive harvests by the sum of two yields × 100% for the four harvests. An index

exceeding 50% corresponded to a tree in alternate bearing, while an index below 50% indicated that the tree is in regular bearing.

Fruit quality was determined for the 2006/07 and 2008/09 harvests. After the harvest, 25-fruit samples were taken randomly per tree to determine the physical and chemical characteristics. Fruit weights were taken with a digital balance (Sartorius, model BL-600, 0.01 g accuracy). Fruit diameter (D), fruit height (H) and peel thickness were measured with an electronic digital slide gauge (Mitutoyo, model CD-15 DC, England, 0.01 mm accuracy) and fruit shape index (D/H) was calculated.

The juice was extracted with an electric squeezer and juice percentages (w/w) were calculated.

The chemical analyses were determined using three juice samples for each scion/stock combination. The pH was measured with a pH-meter (Crison, model microPH 2001). Total soluble solids (TSS) were measured with a hand-held refractometer (Atago Co., model N-1, Tokyo, Japan, 0.2°Brix accuracy) and expressed as degrees Brix at 20°C. The method to analyse titratable acidity (TA) was based on neutralisation (0.1 N NaOH) to pH 8.1 and values were expressed as g citric acid 100 g⁻¹, since this is the dominant organic acid in orange. The ripening index (RI) was calculated as the ratio of total soluble solids/titratable acidity.

Colour determinations were made for fruit skin on four opposite faces in the equatorial zone and for juice. The CIELAB L^* (brightness or lightness; 0 = black, 100 = white), a^* ($-a^*$ = greenness, $+a^*$ = redness) and b^* ($-b^*$ = blueness, $+b^*$ = yellowness) colour variables were measured using the chromatometer CR-300 (Minolta, Ramsey, NJ). Colour index (CI) was calculated using the following formula (Jimenez-Cuesta *et al.*, 1981) $CI = 10^3 a^*/L^*b^*$.

Individual organic acids and sugars were also determined using three juice samples for each scion/stock combination. The juice was centrifuged at 15,000 rpm for 20 min. One millilitre of the extract was filtered through a 0.45 µm Millipore filter and then injected into a Hewlett-Packard HPLC series 1100. The elution system consisted of 0.1% phosphoric acid with a flow rate of 0.5 mL min⁻¹. The organic acids were eluted through a Supelco column [Supelcogel™ C-610H column (30 cm × 7.8 mm)] and Supelguard column (5 cm × 4.6 mm, Supelco, Inc., Bellefonte, PA, USA) and detected by absorbance at 210 nm. For sugar determinations, the same HPLC, elution system, flow rate and columns were used. Sugars were detected with

a refractive index detector (HP 1100, G1362A). A standard curve of pure organic acids (oxalic, citric, tartaric, malic, acetic, fumaric, succinic and L-ascorbic acids) purchased from Sigma (Poole, Dorset, UK) was used for quantification. Similarly, a standard curve of pure sugars (glucose, maltose, fructose, sucrose and sorbitol) purchased from Sigma (Poole, Dorset, UK) was used for quantification. Results for both individual organic acids and sugars were expressed as (%).

Statistical analysis

Statistical analyses were performed using SPSS 18.0 for Windows. A basic descriptive statistical analysis was followed by an analysis on variance for mean comparisons. The method used to discriminate among the means (multiple range test) was the Fisher's least significant difference (LSD) procedure at 95.0% confidence level. The relationship between quality and yield variables was examined using a bilateral Pearson correlation.

Results and discussion

Vegetative growth

No statistical differences were found for tree height, canopy diameter and canopy volume among rootstocks (Table 1). In a study on 'Navelina' orange, Forner-Giner *et al.* (2003) found similar tree height and canopy volume on *C. volkameriana* and Cleopatra mandarin. But, in a study on 'Marisol' Clementine, Bassal (2009) stated that Cleopatra mandarin induced lower tree height as compared with Carrizo citrange and 'Swingle' citrumelo.

TCSA (trunk cross sectional area) is usually considered to be highly correlated with tree weight and canopy volume (Westwood and Roberts, 1970). *C. macrophylla* trees had the lowest TCSA and Gou Tou Chen and Cleopatra mandarin had the highest TCSA with significant differences. Similar TCSA values were obtained on *C. volkameriana* with 'Clementine' mandarin (Georgiou, 2002).

The ratio between scion and rootstock trunk girth is used as an indicator of the scion/rootstock affinity, whereas values close to 1 are associated with very good affinity (Bisio *et al.*, 2003). The highest affinity was found with *C. volkameriana* (0.94) without significant differences with *C. macrophylla* and Cleopatra mandarin

Table 1. Effect of citrus rootstocks on tree height, canopy diameter, canopy volume, trunk cross sectional area (TCSA) and scion: rootstock ratio of 'Lane Late' orange

	<i>C. macrophylla</i>	Gou Tou Chen	<i>C. volkameriana</i>	Cleopatra m.
Tree height (m)	2.01 ^a	2.18 ^a	2.04 ^a	2.15 ^a
Canopy diameter (m)	3.29 ^a	3.36 ^a	3.34 ^a	3.59 ^a
Canopy volume (m ³)	11.57 ^a	13.1 ^a	12.16 ^a	14.68 ^a
TCSA (cm ²)	150.18 ^c	312.88 ^a	245.34 ^b	311.81 ^a
Scion: stock ratio	0.88 ^a	0.79 ^a	0.94 ^a	0.88 ^a

Mean separation within columns by LSD test ($p \leq 0.05$). In each row, values with the same letter are not significantly different.

(0.88). Similar results were obtained by Bassal (2009) for Cleopatra mandarin.

Yield

In the 2005/2006 season, trees on Cleopatra mandarin and *C. macrophylla* produced a significantly higher yield (117.98 and 102.48 kg tree⁻¹, respectively) than trees on all other rootstocks. During 2006/2007 trees on *C. macrophylla* also produced a significantly higher yield (93.05 kg tree⁻¹) than other rootstocks. In 2007/2008, all rootstocks gave similar yields without significant differences. During 2008/2009, the results were similar to the 2006/2007 season, with *C. macrophylla* rootstock yielding most. In general, for all the years under study, *C. macrophylla* proved to be the most productive rootstock, differing significantly from the rest, with the exception of Cleopatra mandarin, which was also a very productive rootstock, but on alternate years.

Trees on *C. macrophylla* rootstock produced the highest cumulative yield (328.81 kg tree⁻¹) (Table 2), with no significant differences with trees on Cleopatra

mandarin (292.41 kg tree⁻¹). By contrast, in a study on 'Marisol' Clementine, Bassal (2009) reported that Cleopatra mandarin was the least productive rootstock. Tuzcu *et al.* (2004) reported that 'W. Navel' orange trees budded on Carrizo citrange produced the highest fruit yield while the lowest corresponded to Cleopatra mandarin. On the other hand, Mourão Filho *et al.* (2007) found that fruit yield of 'Fallglo' and 'Sunburst' mandarin trees was not affected by the rootstock.

The highest yield efficiency corresponded to trees on *C. macrophylla* (5.69 kg m⁻³) with significant differences as compared to other rootstocks. The lowest yield-efficient trees were those grafted onto Gou Tou Chen (1.42 kg m⁻³), but differences with Cleopatra mandarin were not significant (2.22 kg m⁻³). *C. volkameriana* had an intermediate yield efficiency (2.86 kg m⁻³). Similar results were reported by Forner-Giner *et al.* (2003) on 'Navelina' orange, who found that trees on *C. volkameriana* had similar yield efficiency, but lower yield efficiency on Cleopatra mandarin. In this respect, in a study on 'Marisol' Clementine Bassal (2009) found that all studied rootstocks had a similar yield efficiency. These results are in accordance with Georgiou and Gregoriou (1999) on 'Shamouti' orange,

Table 2. Yield, cumulative yield (calculated for 2005/06 through 2008/09), trunk diameter, yield efficiency and alternate bearing index (ABI) of 'Lane Late' orange grafted on four rootstocks

	<i>C. macrophylla</i>	Gou Tou Chen	<i>C. volkameriana</i>	Cleopatra m.
Yield (kg tree ⁻¹)				
2005/06	102.48 ^{ab}	84.81 ^b	79.85 ^b	117.98 ^a
2006/07	93.05 ^a	31.23 ^c	56.17 ^{bc}	61.14 ^b
2007/08	67.22 ^a	67.29 ^a	61.03 ^a	79.95 ^a
2008/09	66.06 ^a	18.93 ^b	37.35 ^b	33.32 ^b
Cumulative yield (kg tree ⁻¹)	328.81 ^a	202.26 ^c	234.42 ^{bc}	292.41 ^{ab}
Trunk diameter (cm)	13.75 ^c	19.77 ^a	17.55 ^b	19.82 ^a
Yield efficiency (kg m ⁻³)	5.69 ^a	1.42 ^c	2.86 ^b	2.22 ^{bc}
ABI (%)	16.18 ^c	51.87 ^a	23.15 ^b	34.35 ^b

Mean separation within columns by LSD test ($p \leq 0.05$). In each row, values with the same letter are not significantly different.

Georgiou (2000) on 'Nova' mandarin and Georgiou (2002) on 'Clementine' mandarin in Cyprus.

The ABI differed significantly among some of the studied rootstocks. Gou Tou Chen exhibited alternate bearing (51.87%). Cleopatra mandarin (34.35%) and *C. volkameriana* (23.15%) showed a relatively low ABI without statistical differences between them. *C. macrophylla* (16.18%) was the rootstock with most uniform productivity. These results are in disagreement with those obtained by Georgiou and Gregoriou (1999) on 'Shamouti' orange and Mourão Filho *et al.* (2007) on 'Fallglo' and 'Sunburst' mandarin, for which alternate bearing was reported not to be rootstock-dependent. However, Georgiou reported in 2000 on 'Nova' mandarin and in 2002 on 'Clementine' mandarin, that trees on all rootstocks displayed relatively strong ABI.

Fruit quality variables

As most fruits are destined for fresh consumption, fruit size, juice content and TSS/TA ratio are of great importance in Spain (Forner-Giner *et al.*, 2003).

Rootstock was found to significantly affect fruit quality variables (Table 3). Trees on *C. volkameriana* gave the heaviest and largest fruit (242.9 g), whereas trees on Gou Tou Chen and Cleopatra mandarin gave lighter and smaller ones. By contrast, Bassal (2009) reported on 'Marisol' clementine and Gregoriou and Economides (1993) on 'Shamouti' orange that trees on sour orange, Carrizo citrange and 'Swingle' citrumelo produced similar fruits in weight and size. Meanwhile, Tuzcu *et al.* (2004) found that the fruit weight of 'W. Navel' orange on sour orange was similar to that on Carrizo citrange and Cleopatra mandarin. Forner-Giner *et al.* (2003) found on 'Navelina' orange that the trees

on *C. volkameriana* produced heavier fruit than those on Cleopatra mandarin.

Fruits from *C. volkameriana* and Cleopatra mandarin had a more spherical shape index (1.02) than fruits from *C. macrophylla* (1.04). Conversely, Bassal (2009) did not find significant differences for shape index among all rootstocks studied.

The fruits with the thickest rind produced the lowest amount of juice. Fruits from *C. volkameriana* and *C. macrophylla* had the thickest rind and those on Gou Tou Chen and Cleopatra mandarin had the thinnest. On the other hand, fruits from *C. volkameriana* and *C. macrophylla* had the lowest juice content. These results are in accordance with García-Sánchez *et al.* (2006), who found that fruits of 'Clemenules' mandarin on Carrizo citrange had a higher juice percentage and lower peel percentage than those on Cleopatra mandarin. To the contrary, statistically significant differences in fruit peel thickness and juice content were not found among rootstocks by Bassal (2009) on 'Marisol' clementine, Gregoriou and Economides (1993) on 'Ortanique' tangor, Tuzcu *et al.* (2004) on 'W. Navel' and Mourão Filho *et al.* (2007) in Fallgo and Sunburst mandarins.

The pH values were quite similar for each scion/stock throughout the study without differences (Table 4).

Total soluble solids (TSS) ranged from 10.5% to 11.4%. Fruits from trees on Cleopatra mandarin had the highest TSS values while Gou Tou Chen had the lowest. Similar results were obtained by Bassal (2009) on 'Marisol' grafted onto Cleopatra mandarin that induced the highest TSS. Verdú (1993) found that 'Clemenules' on Cleopatra mandarin had higher TSS too. It is worthy to note that the high yield shown by *C. macrophylla* when compared with other rootstocks, did not significantly affect its TSS.

The lowest total acid (TA) percentage was found on fruit of *C. volkameriana* without significant differen-

Table 3. Fruit weight, diameter, height, peel thickness and juice of 'Lane Late' orange grafted on four citrus rootstocks

	<i>C. macrophylla</i>	Gou Tou Chen	<i>C. volkameriana</i>	Cleopatra m.
Fruit weight (g)	235.09 ^{ab}	207.38 ^c	242.9 ^a	215.18 ^{bc}
Fruit diameter (mm)	79.92 ^a	75.66 ^c	77.39 ^b	76.34 ^{bc}
Fruit height (mm)	76.76 ^a	73.46 ^b	75.8 ^a	73.59 ^b
Shape index (D/H)	1.04 ^a	1.03 ^{ab}	1.02 ^b	1.02 ^b
Peel thickness (mm)	6.08 ^b	4.77 ^c	6.55 ^a	5.09 ^c
Juice (%)	44.24 ^b	47.95 ^a	44.81 ^b	46.39 ^{ab}

Mean separation within columns by LSD test ($p \leq 0.05$). In each row, values with the same letter are not significantly different.

Table 4. Total soluble solids (TSS), total acid (TA), pH and ripeness index (RI) of 'Lane Late' orange grafted on four rootstocks

	<i>C. macrophylla</i>	Gou Tou Chen	<i>C. volkameriana</i>	Cleopatra m.
pH	4.0 ^a	3.9 ^a	4.0 ^a	3.9 ^a
TSS (%)	10.6 ^{ab}	10.5 ^b	10.7 ^{ab}	11.4 ^a
TA (%)	0.66 ^{ab}	0.73 ^a	0.58 ^b	0.75 ^a
RI	16.0 ^{ab}	14.4 ^b	18.3 ^a	15.2 ^b

Mean separation within columns by LSD test ($p \leq 0.05$). In each row, values with the same letter are not significantly different.

ces with *C. macrophylla*. The highest acidity was induced by Cleopatra mandarin and Gou Tou Chen. By contrast, some authors found that the effects of rootstock on fruit juice acidity were non-significant (Tuzcu *et al.*, 2004; Demirkese *et al.*, 2005; García-Sánchez *et al.*, 2006).

The ratio between the soluble solid content measured in °Brix and the titratable acidity determined as a percentage of citric acid content in the fruit juice is the most widely used method to estimate citrus fruit maturity level. Fruits of trees on *C. volkameriana* and *C. macrophylla* showed the highest ripeness index (RI). Cleopatra mandarin induced the lowest values (15.2) with significant differences compared to *C. volkameriana*. However, Tuzcu *et al.* (2004) on 'W. Navel' orange, Demirkese *et al.* (2005) on 'Rhode Red Valencia' orange and Kaplankiran *et al.* (2005) on 'Okitsu' Satsuma mandarin reported that the effects of rootstocks on RI were not statistically significant.

Colour is considered one of the most important external factors of fruit quality, as fruit appearance greatly influences consumers. A coloured fruit on the tree is

always ripe, thus the risk of selecting immature fruit due to colour is highly improbable, unless they are artificially de-greened. In temperate countries, this non-destructive method can be applied in the field as well as in the industry to accurately show the apparent maturation degree of the fruit (Olmo *et al.*, 2000). The fruits with best external colour (Table 5) were produced on *C. macrophylla* and *C. volkameriana* (colour index, 1.82 and 1.83 respectively) and the worst on Gou Tou Chen (1.16). Similar results were obtained with juice colour, which showed the best colour index with significant differences with the other rootstocks. Fruits of trees grafted on Cleopatra mandarin and Gou Tou Chen were more luminous in colour (higher L* parameter). On the other hand, trees grafted onto *C. macrophylla* and *C. volkameriana* produced fruit with the most intense orange coloured skin (higher a* parameter). All rootstocks had attractive orange fruits with CI higher than 1. Similar values of L*, a* and b* were obtained on 'Hamlin' and 'Earlygold' by Lee and Castle (2001).

Sugars are the major components of citrus juice soluble solids and sweetness of orange juice is intrinsic

Table 5. Effect of citrus rootstocks on fruit colour of 'Lane Late' orange

	<i>C. macrophylla</i>	Gou Tou Chen	<i>C. volkameriana</i>	Cleopatra m.
<i>Peel</i>				
L*	71.39 ^c	73.82 ^a	72.13 ^b	73.24 ^a
a*	12.26 ^a	8.31 ^c	12.26 ^a	10.74 ^b
b*	96.66 ^{ab}	98.33 ^a	95.64 ^b	92.78 ^c
CI	1.82 ^a	1.16 ^c	1.83 ^a	1.60 ^b
<i>Juice</i>				
L*	41.18 ^{ab}	39.67 ^c	41.61 ^a	40.76 ^b
a*	-8.26 ^c	-7.81 ^b	-8.14 ^{bc}	-3.83 ^a
b*	32.18 ^a	29.52 ^b	30.51 ^b	13.74 ^c
CI	-6.23 ^a	-6.67 ^{bc}	-6.41 ^{ab}	-6.88 ^c

Mean separation within columns by LSD test ($p \leq 0.05$). In each row, values with the same letter are not significantly different.

Table 6. Organic acids and sugars of ‘Lane Late’ orange grafted on four citrus rootstocks

	<i>C. macrophylla</i>	Gou Tou Chen	<i>C. volkameriana</i>	Cleopatra m.
Sucrose (%)	4.02 ^b	4.18 ^{ab}	3.73 ^b	4.56 ^a
Glucose (%)	1.66 ^a	1.42 ^{ab}	1.35 ^b	1.50 ^{ab}
Fructose (%)	1.57 ^a	1.28 ^b	1.17 ^b	1.42 ^{ab}
Total sugars (%)	7.25 ^a	6.88 ^{ab}	6.26 ^b	7.48 ^a
Citric acid (%)	0.97 ^b	1.09 ^a	0.89 ^c	1.06 ^a
Malic acid (%)	0.29 ^a	0.29 ^a	0.29 ^a	0.31 ^a
Ascorbic acid (%)	0.047	0.058	0.044	0.059
Total acids (%)	1.31 ^{ab}	1.43 ^a	0.24 ^b	0.43 ^a

Mean separation within columns by LSD test ($p \leq 0.05$). In each row, values with the same letter are not significantly different.

sic to its sugar composition. Sucrose is present in the largest amounts in orange juice (Kelebek *et al.*, 2009).

The highest content of total sugars was found on *C. macrophylla* and Cleopatra, differing from *C. volkameriana*. The major sugars were sucrose, glucose and fructose. Sucrose was the sugar present at the highest concentration, ranging from 55 to 61% of total sugars and followed by glucose and fructose. Similar results were obtained by Kelebek *et al.* (2009) on ‘Kozan’ orange in Turkey and Albertini *et al.* (2006) on ‘Salustiana’ orange.

The rootstock influenced the total organic-acid content (Table 6). The lowest total acid values were obtained on *C. volkameriana* and *C. macrophylla*. The major organic acid in ‘Lane Late’ navel orange was citric acid (0.89–1.15%). Malic acid was not affected by rootstock, with values between 0.29 and 0.31%. Similar results were found by Nisperos-Carriedo *et al.* (1992) with calamondin and Kelebek *et al.* (2009) on ‘Kozan’ orange. The highest ascorbic acid values were recorded in ‘Lane Late’ trees grafted on Gou Tou Chen and Cleopatra mandarin.

Table 7. Pearson product moment correlations (p value) between quality and yield variables of ‘Lane Late’ orange

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
(1) TCSA	1																						
(2) Yield	–0.6474	1																					
(3) Cumulative yield	ns	0.8187	1																				
(4) Yield efficiency	–0.8107	0.9011	0.6248	1																			
(5) Fruit weight	–0.6043	ns	ns	ns	1																		
(6) Fruit diameter	–0.5438	ns	ns	0.5286	ns	1																	
(7) Fruit height	ns	ns	ns	ns	ns	0.9144	1																
(8) Peel thickness	ns	ns	ns	ns	ns	ns	ns	1															
(9) Juice	ns	–0.5497	–0.6729	ns	ns	ns	ns	–0.5372	1														
(10) L*	0.6489	–0.6279	ns	–0.7031	ns	ns	ns	–0.7293	ns	1													
(11) a*	ns	0.5422	ns	0.5359	ns	ns	ns	0.7860	ns	–0.9258	1												
(12) b*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	1											
(13) CI	ns	0.5422	ns	ns	ns	ns	ns	0.8058	ns	–0.8936	0.9917	ns	1										
(14) pH	ns	ns	ns	ns	ns	ns	ns	0.6442	ns	–0.7146	0.6850	ns	0.6705	1									
(15) TSS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	1								
(16) TA	ns	ns	ns	ns	ns	ns	ns	–0.6955	0.5859	0.6576	–0.7225	ns	–0.7456	–0.7545	ns	1							
(17) RI	ns	ns	ns	ns	ns	ns	ns	0.6279	–0.6276	–0.5349	0.6505	ns	0.6791	0.6151	ns	–0.9146	1						
(18) Sucrose	ns	ns	ns	ns	ns	ns	ns	–0.6602	ns	ns	ns	ns	ns	ns	ns	ns	ns	1					
(19) Glucose	ns	0.5934	0.6107	0.5430	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.5195	1				
(20) Fructose	ns	0.5674	0.6320	0.5155	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.5820	0.9870	1			
(21) Citric acid	ns	–0.5239	ns	ns	ns	ns	ns	–0.7405	0.6628	ns	–0.5484	ns	–0.5631	ns	ns	0.6474	–0.6501	0.5631	ns	ns	1		
(22) Malic acid	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.6039	ns	ns	ns	1	
(23) Ascorbic acid	0.6216	–0.5889	ns	–0.5677	–0.5255	ns	ns	–0.8442	ns	0.6849	–0.6754	ns	–0.6876	–0.7294	ns	0.7247	–0.7135	ns	ns	ns	0.5889	ns	1

Significant at $p \leq 0.05$. ns: not significant.

Correlation analysis

Variable interdependence was investigated by correlation analysis (Table 7). Seventy-two pairs of variables were highly correlated. Yield efficiency was negatively correlated with TCSA ($r = -0.8107$, $p \leq 0.05$). As expected, yield was positively correlated with cumulative yield ($r = 0.8187$) and yield efficiency ($r = 0.9011$). Fruit height and fruit diameter had a highly positive correlation ($r = 0.9144$). A negative correlation was found between a^* and TA ($r = -0.7225$) and a positive correlation between a^* and CI ($r = 0.9917$). TA was strongly correlated with RI ($r = -0.9146$) and with pH ($r = -0.7545$). Fructose and glucose were positively correlated too ($r = 0.9870$).

Conclusions

The results of this study show how different rootstocks influence vegetative growth, yield and fruit quality of 'Lane Late' orange. Cleopatra mandarin and Gou Tou Chen proved the most invigorating rootstocks for 'Lane Late' in growing conditions with heavy and calcareous soil. *C. macrophylla* showed a tendency to induce higher yield and yield efficiency. *C. macrophylla* and *C. volkameriana* appear to induce the highest fruit weight, fruit diameter and ripening index.

The results of this trial can be of interest to assess other orange varieties and even in other regions with similar agro-climatic conditions, especially in the Mediterranean area.

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