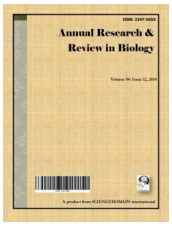

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Performance of 'Valencia Late' Sweet Orange (*Citrus sinensis*) on Different Rootstocks in the Gharb Region (Northwestern Morocco)

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Production and quality of citrus fruits depend largely on scion/rootstock compatibility. In order to find suitable combinations able to solve productivity problems of citrus at local scale, the performance of 'Valencia late' sweet orange (*Citrus sinensis*) on 14 rootstocks was studied under field conditions in the Gharb region (northwestern Morocco) through a field experiment. Total cumulative yield over five years of production was highest on Citrumelo 4475 (11) and PT B6 Z13 (5) compared to the other rootstocks. In terms of productivity, Citrumelo 4475 (11), *Citrus volkameriana* (25), *Citrus macrophylla* (24) and the Sunki mandarin x PT (16) and Sunki mandarin x PT (39) hybrids were the most efficient. Furthermore, this study revealed that the use of some rootstocks improved significantly juice content of Valencia late fruits. These included *Citrus volkameriana* (25), PT B6 CZ 24 (3), PT B6 CZ 13 (5), Cleopatra mandarin x CC (30), Sunki mandarin x PT (16), Citrumelo 4475 (11) and Citrumelo 1452 (41). Concerning juice quality, the study has identified rootstocks that enhanced both acid and

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sugar contents, namely Carrizo citrange (7), Sunki mandarin x PT (17), Citrumelo 1452 (41), Citrumelo 4475 (11), Sunki mandarin x PT (17), Sunki mandarin x PT (16) and PT B6 CZ 24 (3).

Keywords: Citrus; rootstock; Valencia late; growth; yield; production; fruit quality.

1. INTRODUCTION

'Valencia late' is the most important local sweet orange variety grown commercially in Morocco. The main rootstock used to grow this variety - as all other citrus varieties - is sour orange due to its wide adaptability to soil conditions and its acceptable resistance to *Phytophthora* diseases [1,2,3]. However, the susceptibility of this rootstock to tristeza - a deadly viral disease that recently ravaged several citrus orchards around the world - have called into question its use in the Mediterranean region. In addition, the resistance of sour orange to Phytophthora attacks is known to be affected under conditions of soil/irrigation water salinity [3,4]. Thus, the search for alternative rootstocks with satisfactory performance under these constraints is urgent and necessary to ensure continuity and development of citriculture in Morocco.

During the past decade, the threat of tristeza was behind the introduction of new rootstocks resistant or tolerant to this disease, but their behavior under Moroccan pedoclimatic conditions with local commercial orange scions is still unknown.

According to the literature, the rootstock may greatly alter the scion in citrus. It may dwarf or invigorate it; yields may be increased or decreased; fruit size may be altered; fruit quality can be affected; hardiness of the scion may also be influenced and maturity and precociousness of the scion are other considerations [5]. Fallahi et al. [6], 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 [7] reported that the yield and fruit quality of 'Shamouti' orange was markedly different when budded on different rootstocks. Similarly, significant effects of rootstocks on production and quality of citrus fruits were detected in several countries [8,9,10, 11,12,13,14,15,16,17,18,19]. However, these findings reveal many contradictions that were attributed to differences in climatic conditions, soil characteristics and plant material used. Indeed, although some rootstocks may show satisfactory results in some regions, it is not recommended to use or adopt them directly in another region without a thorough assessment of their behavior under local conditions.

Thus, this research was carried out to evaluate yield, production efficiency and fruit quality of 'Valencia late' sweet orange (*Citrus sinensis*) on 14 newly introduced rootstocks under agro-climatic conditions of the Gharb region (northwestern Morocco).

2. MATERIALS AND METHODS

Table 1 presents the rootstocks that were tested in the present study. Rootstock seeds were obtained from Citrus Research Center, INRA Corse station France. One-year-old seedlings were T-budded in 1997, then field planted in 1999 in the Gharb region, more precisely at Citrus Experimental Station, Tazi, Morocco (Latitude, 358N; Longitude, 328E). The budwood used was collected from a single tree, raised and certified to be free of viral diseases by Citrus Research Center, INRA Morocco. The experiment was laid out in a randomized complete block design with four replications. Plot size consisted of one tree and tree spacing was 6m x 6m. The soil at the station has a clay texture, a pH of 7.5 and a conductivity of 1.5 dS/m. The climate of the study region is of type Csa according to the Köppen classification (hot-summer Mediterranean climate) with an annual mean temperature of 19.2℃ and an annual rainfall of about 570 mm.

Yield was recorded annually for each tree from 2005 to 2010. In each year, 10 fruits per tree were randomly harvested during the January–March period and analyzed for juice content, brix and acid concentration. Brix was measured using a laboratory refractometer. Total acidity (TA), expressed as percent citric acid, was determined by titration with NaOH [20].

Height and diameter of the canopy were measured annually after harvest, as well as trunk circumference. Canopy volume was calculated using the one half prolate spheroid formula: V = 0.5236HD2 (H = canopy height, D = canopy

diameter) [21]. Trunk circumference was measured 15 cm above the bud union and converted to trunk cross-sectional area (TCSA). Yield efficiency was estimated as the ratio of total cumulative yield to canopy volume estimated in 2010.

Table 1. List of the rootstocks used in the experiment

Codes	Rootstocks
3	*Poncirus trifoliata*. B6 CZ 24
6	Sunki mandarin x P.T. B2 38581
5	P.T B 6 C Z 13
7	Carrizo citrange 28608
11	Citrumelo 4475 B2 G3
16	Sunki mandarin x P.T. 30591
17	Sunki mandarin x P.T. 30588
18	Cleopatra mandarin x P.T. 30584
23	Gou-Tou SRA 506
24	*Citrus macrophylla*
25	*Citrus volkameriana* 28613
30	Cleopatra mandarin x C.C. 30577
34	Sour orange P6 R26 A16
39	Sunki mandarin x P.T. 330590
41	Citrumelo 1452 B6 C

Data were analyzed using SAS procedures. The analysis of variance was performed to examine rootstock effects on yield and fruit quality characteristics. Means were compared using Duncan's New Multiple Range Test.

3. RESULTS

3.1 Height Growth

12 years after planting, trees of Valencia late showed variable heights depending on the rootstock used. The highest values were recorded in trees grafted on *C. volkameriana*, Sunki mand x PT, Citrumelo 1452, Carrizo citrange, *Citrus macrophylla* and Cleop mand x PT. This rootstock group was followed by Citrumelo 4475, Sunki mand x PT and sour orange. By contrast, trees on the Sunki mand x PT (17) hybrid resulted in the lowest height (2.1 m) (Table 2).

Canopy volume, expressed in m^3, varied significantly depending on the rootstock used. *Citrus volkameriana* and Cleop mand x CC enhanced canopy volume at a higher extent (28.82 and 26.85 m^3, respectively) compared with the other rootstocks. On the other hand, the lowest canopy volume (9.27 m^3) was recorded in trees grafted on Sunki mand x PT (17).

Regarding canopy diameter, Table 2 shows that some rootstocks resulted in high values (3.72 to 3.50 m), such as *Citrus volkameriana*, Gou-Tou sour orange (23), *Citrus macrophylla* (24) and Carrizo citrange (7). By contrast, the smallest diameter (2.90 m) was recorded on the Sunki mand x PT (17) hybrid. As for sour orange, canopy diameter was about 3.50 m, which was not significantly different from the values obtained on *Citrus volkameriana* and its group (25) (Table 2).

3.2 Rootstock/Scion Compatibility

The rootstock/scion compatibility is evaluated using the 'Scion diameter / Rootstock diameter' ratio, also known as compatibility index. A quotient of 1 generally indicates that the combination is compatible [22,23]. In this study, *C. macrophylla* (24), Carrizo citrange (7), Sunki mand x PT (30) and sour orange (34) gave very close ratios to 1, which shows a good compatibility of these rootstocks with the Valencia late variety. The Citrumelo group, including Citrumelo 4475 (11) and Citrumelo 1452 (41), showed values ranging from 0.72 to 0.77, while Gou-Tou sour orange (23) resulted in the lowest ratio (0.62). It is also clear from Table 3 that all the rootstocks resulted in higher ratios than 0.5, which ranks the compatibility of all combinations studied as acceptable.

3.3 Production

The production of Valencia late (in kg/tree) varied significantly over time and depending on rootstocks. Regardless of the season, trees on Citrumelo 4475 (11), *Citrus volkameriana* (25), Sunki mand x PT (39), *Citrus macrophylla* (24) and Sunki mand x PT (16) resulted in a significant production. Other rootstocks also enhanced production of Valencia late trees, but to a lower extent, namely Citumelo 1452 (41) and Carrizo citrange (7). On the other hand, the lowest production was recorded on sour orange rootstock (34) (Table 4).

3.4 Cumulative Production and Production Efficiency

The cumulative production of Valencia late between 2005 and 2010 (CP) varied significantly depending on rootstocks. Trees on Citrumelo 4475 (11) and *Citrus volkameriana* (25) were ranked first with a production of 1024 and 1000 kg/tree respectively. These were followed by trees on PT B6-CZ13 (5), Sunki mand x PT (39), *Citrus macrophylla* (24) and Citrumelo 1452 (41)

with a CP ranging from 829 to 917 kg/tree. Trees on sour orange, used as control, cumulated only 731.78 kg/tree over the years of production, which was much lower than the results obtained on the aforementioned rootstocks (Table 5).

Production efficiency (PE), expressed in kg per m^3 of tree canopy, was highest on Citrumelo 4475 (11) (50.36 kg/m^3) and PT B6 Z13 (5) (49.05 kg/m^3) and moderate on *C. volkameriana* (25), Sunki mand x PT x (39) and Citrumelo 1452 (41). Trees on sour orange (34) resulted in relatively low PE (34.22 kg/m^3), while the lowest PE was recorded on Sunki mand x PT (17) and Carrizo citrange (7) with corresponding values of 30.15 and 29.5 kg/m^3, respectively (Table 5).

Table 2. Effect of different rootstocks on growth parameters of Valencia late

Rootstocks	Height growth (m)	Canopy volume (m^3)	Canopy diameter (m)
Citrumelo 4475	3.40 b	20.60 b	3.40 ab
*C. volkaméria*na	3.92 a	28.82 a	3.72 a
P.T. B 6 C Z 13	3.27 c	17.70 d	3.22 bc
Sunki mand x PT	3.87 a	24.47 b	3.45 ab
Gou-Tou SRA 506	3.20 c	22.90 b	3.70 a
C. macrophylla	3.80 a	24.42 b	3.50 ab
Carrizo citrange	3.90 a	25.00 b	3.55 ab
Sunki mand x PT16	3.37 b	23.00 b	3.60 ab
Cleop mand x PT 18	3.72 a	25.62 b	3.60 ab
P.T. B 6 C Z24	3.40 b	19.02 c	3.27 abc
Cleop mand x C.C (30)	3.85 a	26.85 a	3.62 ab
Citrumelo 1452	3.67 a	19.40 d	3.17 bc
Sunki mand x P.T6	3.40 b	20.00 c	3.37 ab
Sour orange	3.40 b	21.80 c	3.50 ab
Sunki mand x PT17	2.10 d	9.275 e	2.90 c
P	<.0001	<.0001	<.0001

**Rootstocks followed by the same letter are not significantly different at 5% level (Duncan test)*

Table 3. Graft compatibility of different rootstocks with the Valencia late variety

Rootstocks	Rootstock diameter (cm)	Scion diameter (cm)	Compatibility index
Citrumelo 4475	73.66 ab	54.50 bc	0.70 ed
*C. volkaméria*na	73.62 ab	66.00 a	0.87 ab
P.T. B 6 C Z 13	66.77 bcd	47.27 c	0.70 ed
Sunki mand x PT	65.50 dc	53.25 bc	0.80 bdc
Gou-Tou SRA 506	74.77 a	47.50 c	0.62 e
C. macrophylla	54.00 ef	48.75 c	0.90 a
Carrizo citrange	70.25 abc	62.50 ab	0.92 a
Sunki mand x PT16	58.12 e	45.25 c	0.77 dc
Cleop mand x PT 18	66.00 dc	54.00 c	0.72 ed
P.T. B 6 C Z24	65.27 dc	54.00 bc	0.82 bc
Cleop mand x C.C (30)	59.87 de	53.25 bc	0.90 a
Citrumelo 1452	67.62 bc	54.12 bc	0.77 dc
Sunki mand x P.T6	68.00 abc	52.00 c	0.77 dc
Sour orange	50.25 gf	49.30 c	0.97 a
Sunki mand x PT17	47.00 g	44.50 c	0.90 a
P	<.0001	<.0001	<.0001

**Rootstocks followed by the same letter are not significantly different at 5% level (Duncan test)*

Table 4. Effect of different rootstocks on production of Valencia late trees (Kg/tree)

	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010
Citrumelo 4475 (11)	215.66 a	139.33 ab	183 a	227.10 a	260.00 a
*C. volkaméria*na *(25)*	170.75 b	151.50 a	191 a	230.70 a	256.43 a
P.T. B 6 C Z 13 (5)	170 b	144.75 a	161.68 b	178.68 b	200.00 b
Sunki mand x PT (39)	160.75 c	133.00 ab	172.33 b	211.83 a	239.38 a
Gou-Tou SRA 506 (23)	136 d	146.00 a	146.38 c	146.75 c	167.50 c
C macrophylla (24)	133.75 de	134.75 ab	144.23 c	153.90 c	273.13 a
Carrizo citrange (7)	128.75 e	113.25 c	145.55 c	178.03 b	189.48 c
Sunki mand x PT (16)	118 f	119.50 c	151.10 c	182.65 b	217.20 a
Cleop mand x PT (18)	112.75 gf	97.75 c	112.63 d	127.58 d	151.25 c
P.T. B 6 C Z 24 (3)	111.25 g	124.25 c	144.68 c	165.00 b	196.68 b
Cleop mand x C.C (30)	110 g	124.50 c	145.23 c	166.28 b	182.50 b
Citrumelo 1452 (41)	109 g	127.00 c	165.45 b	204.00 a	223.68 a
Sunki mand x P.T (6)	108 g	122.00 c	146.55 c	170.88 b	190.63 b
Sour orange (34)	75 h	118.25 c	154.30 c	182.65 b	201.25 b
Sunki mand x PT (17)	47 i	34.25 d	53.68 d	65.65 e	68.13 d
P	<.0001	<.0001	<.0001	<.0001	<.0001

**Rootstocks followed by the same letter are not significantly different at 5% level (Duncan test)*

Table 5. Effect of rootstock on cumulative production and production efficiency of Valencia late trees in kg/m^3 of tree canopy

Rootstocks	CP (Kg/tree)	PE (Kg/m^3)
Citrumelo 4475 (11)	1024.93 a	50.36 a
C. volkameriana (25)	1000.33 a	35.82 b
P.T. B 6 C Z 13 (5)	855.00 b	49.05 a
Sunki mand x PT (39)	917.08 b	38.95 b
Gou-Tou SRA 506 (23)	742.63 c	32.40 c
C macrophylla (24)	839.55 b	34.77 c
Carrizo citrange (7)	754.90 c	29.50 c
Sunki mand x PT (16)	788.40 c	35.80 c
Cleop mand x PT (18)	601.88 d	24.12 d
P.T. B 6 C Z 24 (3)	741.93 c	40.80b
Cleop mand x C.C (30)	728.18 d	28.75c
Citrumelo 1452 (41)	829.23 b	43.10 b
Sunki mand x P.T (6)	738.20 c	37.02b
Sour orange (34)	731.78 c	34.22c
Sunki mand x PT (17)	269.10 e	30.15 d
P	<.0001	<.0001

**Rootstocks followed by the same letter are not significantly different at 5% level (Duncan test)*

3.5 Juice Content

Trees on *C. volkameriana* (25) and Sunki mand x PT (39) produced the juiciest fruits (respectively 57.54 and 56.20%). These were followed by trees on PT B6 CZ 24 (3), sour orange (34), PT B6 CZ 13 (5), Carrizo citrange (7), Cleop mand x CC (30), Sunki mand x PT (16), Citrumelo 4475 (11), *C. macrophylla* (24), Cleop mand x PT (18) and Citrumelo 1452 (41) with averages ranging from 53 to 49%. On the other hand, fruits grown on Sunki mand x PT (17) and Sunki mand x PT (6) had the lowest juice content (43.65%) (Table 6).

3.6 Titratable Acidity

As shown in Table 6, trees on Carrizo citrange (7), Sunki mand x PT (17) and Citrumelo 1452 (41) produced the most acidic fruits. This group resulted in a percentage of citric acid ranging from 1.19 to 1.35. Similarly, the rootstocks PT B6 CZ 24 (3), PT B6 CZ 13 (5), Cleop mand x PT (18), Sunki mand x PT (16) and Citrumelo 4475 (11) favored acidity but to a lower extent than the first group. As for fruits obtained on the other rootstocks, acidity average was between 0.88 and 0.79. We should note that, in this regard, trees on sour orange showed similar behavior to

that of trees on *Citrus macrophylla* and *Citrus volkameriana* (Table 6).

3.7 Sugar Content

Brix values, expressing sugar content of the fruits, varied significantly depending on the rootstock used. Fruits produced on Carrizo citrange (7), Sunki mand x PT (6), Cleop mand x PT (18) and sour orange (34) resulted in the highest values (11.97 to 13.2 °Brix). These were followed by those produced on PT B6 CZ 24 (3), PT B6 CZ 13 (5), Sunki mand x PT (17), Sunki mand x PT (16), Citrumelo 4475 (11) and Citrumelo 1452 (41) with average values ranging from 11.03 to 11.77 °Brix. By contrast, the lowest brix values were recorded in fruits grown on *C. volkameriana* (25), Sunki mand x PT (39) and *C. macrophylla* (24) (Table 6).

3.8 Fruit Maturity Index

The analysis of data related to fruit maturity (Table 6) showed that the use of some rootstocks, namely Sunki mand x PT (6), Cleop mand x CC (30), sour orange (34) and Sunki mand x PT (39) increased significantly the E/A ratio and encouraged therefore early fruit maturity, whereas other rootstocks such as Carrizo citrange (7), Citrumelo 1452 (41) and PT B6 CZ 13 (5) favored low E/A ratios and late fruit maturity. Between the two extremes, a third group consisting of *C. volkameriana* (25) yielded fruits with moderate E/A index.

4. DISCUSSION

The rootstock plays an important role in citriculture since it affects several production features, both qualitative and quantitative. In addition, it plays a very important role in resistance or tolerance to biotic and abiotic constraints [24].

This study which was conducted in the perspective of searching alternative rootstocks for sour orange in the Gharb region highlighted agronomic importance of some rootstock varieties that proved, after 5 years of field experimentation, to be efficient and well adapted to local conditions.

4.1 Tree Vigor

In terms of tree vigor, we showed in this study that certain rootstocks enhanced height growth of Valencia late trees to a higher extent than sour orange. This was indeed the case of *C. volkameriana* (25), Sunki mand x PT (39), Citrumelo 1452 (41), Carrizo citrange (7), *Citrus macrophylla* (24) and the Cleop mand x PT (18) hybrid. By contrast, trees on Sunki mand x PT (17) recorded the lowest height (2.1 m). Similarly, a study that was conducted on a clay loamy soil in Cuba showed a high vigor of Valencia trees on *Citrus volkameriana* [23,25,26]. Continella et al. [9] reported that 'Comune' clementine resulted in a higher canopy volume when grafted on *Citrus macrophylla* and *Citrus volkameriana* than when associated with sour orange.

Table 6. Results of juice quality analyses

Rootstocks	% juice	% citric acid	°Brix	E/A
Sunki mand x P.T (6)	43,45 c	0,88 c	12,13 a	13,86 a
P.T. B 6 C Z 24 (3)	51,31 b	1,03 b	11,40 b	11,07 c
Carrizo C. (7)	49,87 b	1,19 a	11,97 a	10,13 c
P.T. B 6 C Z 13 (5)	48,57 b	1,10 b	11,13 b	10,20 c
C. macrophylla (24)	51,78 b	0,90 c	10,63 c	11,85 c
Cleop mand x C.C. (30)	51,23 b	0,84 c	11,27 b	13,53 a
Cleop mand x PT (18)	49,93 b	1,12 b	13,20 a	11,85 c
Sunki mand x PT (17)	43,65 c	1,29 a	11,77 b	9,12 d
Sunki mand x PT (16)	52,88 b	1,04 b	11,43 b	10,99 c
Citrumelo 4475 (11)	53,11 b	1,01 b	11,03 b	11,01 c
Citrumelo 1452 (41)	50,74 b	1,35 a	11,57 b	8,80 e
Sour orange (34)	49,99 b	0,91 c	12,20 a	13,38 a
C. volkameriana (25)	57,54 a	0,79 c	9,63 c	12,22 b
Sunki mand x PT(39)	56,20 a	0,80 c	10,93 c	13,72 a

**Rootstocks followed by the same letter are not significantly different at 5% level (Duncan test)*

4.2 Diameter and Volume of the Canopy

The use of *Citrus volkameriana* (25) and Carrizo citrange (7) resulted in the highest volume and diameter of the canopy as compared to the other rootstocks. These results are consistent with the work of Forner-Giner et al. [27], which reported a large canopy volume of Navelina orange trees on Carrizo citrange. However, in other studies using the Nova mandarin variety, trees on sour orange displayed a larger canopy volume than those grafted on Carrizo citrange [28,29].

4.3 Graft Compatibility

In our study, sour orange (34), *Citrus macrophylla* (24), Carrizo citrange (7) and Sunki mand x PT showed very close 'Scion diameter / Rootstock diameter' ratios to 1. This indicates the good grafting affinity of these rootstocks with the variety studied [22,23]. Similar findings were reported by Georgiou [30] in clementine and mandarin. In the same sense, Georgiou and Gregoriou [31] and Gregoriou [28] reported a good compatibility of Valencia late and Nova mandarin, respectively, with sour orange.

4.4 Production

The highest production of Valencia late (in kg/tree) was recorded on Citrumelo 4475 (11), *Citrus volkameriana* (25), Sunki mand x PT (39), *Citrus macrophylla* (24) and Sunki mand x PT (16). Similarly, Zekri and Al-Jaleel [32] reported a high large-scale production of Valencia late trees on *Citrus macrophylla* and *Citrus volkameriana* after seven years of observations. However, in contrast to our results, these authors reported a poor production of Swingle Citrumelo. This fact may be explained by the use of an alkaline substrate in these experiments, which was not the case of our orchard test.

4.5 Production Efficiency

The cumulative production between 2005 and 2010 was highest on Citrumelo 4475 (11) and *Citrus volkameriana*. This result is in agreement with several studies that reported a high cumulative production of Valencia late trees on *Citrus volkameriana* rootstock [6,11,19,33,34]. Similar findings were also reported by the study of Continella et al. [9], in which combinations of 'Comune' clementine with *C. macrophylla* and sour orange were the most productive over 12 years. By contrast, other works revealed no significant differences among Cleopatra mandarin, sour orange, Carrizo citrange, *Citrus volkameriana*, rough lemon, *Citrus macrophylla* and *Citrus taiwanica* in terms of cumulative production [35,36]. Concerning the performance of Citrumelo roostocks, Al-Jaleel and Zekri [37] noted a slight loss of production when trees were grafted on Swingle Citrumelo, whereas other authors reported a high productivity on this rootstock [8,13,33,38,39,40].

Carrizo citrange was ranked second in our study in terms of cumulative production. Al-Jaleel and Zekri [41] also noted that orange trees are more productive on Carrizo citrange than on Swingle Citrumelo and Cleopatra mandarin. Kaplankiran et al. [42] and Demirkeser et al. [43] reported a significant increase in production of Satsuma and Valencia late trees, respectively, when grafted on Carrizo citrange rootstock as compared to those grafted on sour orange, which is consistent with our findings. On the other hand, the works of Georgiou [30] reported a low production of clementine in the presence of Citrumelo, sour orange and Carrizo citrange. For their part, Filho et al. [44] reported no effect of rootstock at all on the production of mandarin trees. The contradictions observed between these different works could be attributed to other factors than the rootstock such as the variety, tree age, climatic conditions and soil characteristics.

Production efficiency, expressed in kg per m^3 of canopy, was highest in Citrumelo 4475 (11) (50.36 kg/m^3) and PT B6 Z13 (5) (49.05 kg/m^3). These results support the work of Roose [45], which showed that Citrumelo rootstocks enhanced production efficiency of 'Fallglo' mandarin in California and that of Georgiou [28] who obtained similar results in Cyprus using the Nova mandarin variety. In general, high production efficiency coupled with low vigor encourages the use of such rootstocks in high density plantings [19]. This was the case of PT B6 Z13 (5) and Citrumelo 4475 (11) in our study.

4.6 Fruit Weight

Rootstock had a significant effect on the weight of Valencia late fruits, which was more pronounced on PT B6 Z13 (5), Sunki mand x PT (6) and *C. volkameriana* (25). Zekri and Al-Jaleel [46] noted similar observations when grafting Valencia late on *Citrus macrophylla* and *Citrus volkameriana*. Similar findings were also reported in numerous citrus varieties [8,11,19,23,26,39, 47,48,49].

4.7 Juice Content

Rootstock significantly affected juice content of Valencia late fruits. The highest percentage was observed in fruits obtained on *Citrus volkameriana*, followed by those produced on PT B6 CZ 24 (3), PT B6 CZ 13 (5), Cleop mand x CC (30), Sunki mand x PT (16), Citrumelo 4475 (11) and Citrumelo 1452 (41) with a juice content varying from 53 to 50%. According to the literature, the effect of rootstock on juice content of scion fruits is a controversial issue. Gregoriou and Economides [15], using the Ortanique variety, showed no effect of sour orange, Carrizo citrange and Swingle Citrumelo on juice content of the fruits. Tuzcu et al. [50] showed no significant difference between sour orange and Carrizo citrange with regard to juice content of Navel orange fruits. Furthermore, Filho et al. [44] reported no relationship between the nature of the rootstock and juice content of scion fruits. In contrast to these reports, the study of García-Sánchez et al. [29] showed that clementine produced juicier fruits on Carizzo citrange than on Cleopatra mandarin. Fellahi et al. [6] reported that fruits produce less juice when grown on Troyer citrange compared to those obtained on *Citrus macrophylla* and *Citrus volkameriana*.

4.8 Titratable Acidity

Juice total acidity is an important element in determining the quality of citrus fruits and their harvest period. In this study, acid content was higher in fruits obtained on Carrizo citrange (7), Sunki mand x PT (17) and Citrumelo 1452 (41) as compared to those obtained on sour orange, *Citrus macrophylla* and *Citrus volkameriana*. Similar results were found by Zekri and Al-Jaleel [32] in trees of Valencia late grafted on *Citrus volkameriana*, Carrizo citrange and Swingle Citrumelo.

Trees on *Citrus volkameriana* bore more acidic fruits than to those produced on sour orange. This result coincides with the findings of Continella et al. [47], Fellahi et al. [6], Fallahi and Rodney [14], Wutscher and Bistline [51] and Wutscher et al. [52]. According to Verdú [53], fruits of "Clemenules" mandarin produced on Swingle Citrumelo are more acidic than those produced on sour orange. By contrast, other authors reported no effect of rootstock on juice acidity [29,42,43,50] and [54]. Such observations could be related to climatic conditions, including low temperatures and precipitation.

4.9 Sugar Content

The flavor and taste of citrus fruits depend on their sugar content, acidity and the presence of aroma. Overall, the highest values were observed when using Carrizo citrange (7), Sunki mand x PT (6), Cleop mand x PT (18), sour orange (34) and to a lower extent Poncirus and Citrumelo rootstocks. On the other hand, the lowest values were recorded in fruits grown on *Citrus volkameriana* (25) and *Citrus macrophylla* (24). This result is consistent with the work of Zekri and Al-Jaleel [29], which showed a higher sugar concentration in fruits grown on sour orange and Carrizo citrange as compared to those grown on *Citrus macrophylla* and *Citrus volkameriana*. Similar results were also reported by other workers [6,11,14,35,40,47,50,52].

Also, we showed in our study that fruits produced on Swingle citrumelo tended to accumulate more sugars than those produced on *Citrus volkameriana* (4.25 °Brix of difference). The low sugar concentrations recorded on *Citrus macrophylla* and *Citrus volkameriana* are probably related to tree vigor. Indeed, vigorous rootstocks are reported to induce an alteration of fruit internal quality [37].

4.10 Fruit Maturity Index

Fruit maturity, expressed as the E/A ratio, was influenced by the nature of the rootstock. In general, fruits obtained on mandarin and *Poncirus trifoliata* hybrids had high E/A ratios and presented a potential for early maturity. In this sense, Nadori et al. [55] reported that Cleopatra mandarin stimulated early maturity of Caddoux clementine.

5. CONCLUSION

This study was conducted in order to evaluate the effect of various rootstocks on yield, yield efficiency, tree size and fruit quality of the local orange variety 'Valencia late' under the conditions of the Gharb region (northwestern morocco).

Based on statistical analyses of data collected during five years of experimentation, it appears that rootstock affects all these parameters and therefore conditions success and profitability of Valencia late fruits.

Among the rootstock accessions studied, Citrumelo 4475 (11), *Citrus volkameriana* (25),

Sunki mandarin x PT (39), *Citrus macrophylla* (24) and Sunki mandarin x PT 16 proved to be the most efficient in terms of productivity. These could be implicated in strategies for solving productivity problems of Valencia late at local scale.

This study also enabled to identify emerging rootstocks with high production efficiency, which could be used in high density plantings to improve the yield per unit area, such as Citrumelo 4475 (11) and PT B6 Z13 (5).

Concerning fruit internal quality, this study has identified rootstocks that improved significantly juice content, including *Citrus volkameriana* (25), PT B6 CZ 24 (3), PT B6 CZ 13 (5), Cleopatra mandarin x CC (30) Sunki mandarin X PT (16), Citrumelo 4475 (11) and Citrumelo 1452 (41), while other rootstocks have enhanced both acidity and brix, namely Carrizo citrange (7), Sunki mandarin x PT (17), Citrumelo 1452 (41), Citrumelo 4475 (11), Sunki mandarin x PT (17), Sunki mandarin x PT (16) and PT B6 CZ 24 (3).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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