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Artigo/Article

Adaptation of two citrus cultivars grafted on forner alcaide Nº 517 to super high-density system and evaluation of mechanized harvesting

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SUMMARY

Adaptation of two citrus cultivars, Valencia Delta Seedless (VDS) and Valencia Late Frost (VLF) grafted on Forner Alcaide nº 517, to super high-density groves with mechanical harvesting was evaluated in southwest of Spain. Regarding to crop development, both cultivars showed a similar behavior regard to tree growth, good affinity with the rootstock and chlorophyll content in leaf (SPAD units). However, differences were obtained in phenological development and internal quality of the fruit. So, VDS showed a more advanced phenology, while VLF obtained a better-quality juice: higher titratable acidity content with a lower maturity index. On the other hand, it was identified a great potential of the mechanical harvesting in both cultivars, with significant fruit detachment percentages (about 90% or more) and above 8 kg of fruit retention force (FRF). However, VDS obtained a better response to the harvesting equipment evaluated (New Holland BRAUD 9090X DUAL, over-row continuous canopy shaking harvester). So, VDS recorded higher fruit detachment percentages (95-100%) as well as lower levels of physiological and physical damage. Finally, the differences between cultivars, both efficiency of the fruit detachment and tree damage could respond to differences in the structure of the tree and rigidity of the branches.

Index terms: super-intensive, dwarfing citrus rootstocks, harvesting efficiency, tree damage, alteration fruits.

Adaptação de duas cultivares de citros enxertadas em Forner Alcaide Nº 517 em sistema de plantio super-adensado e avaliação da colheita mecanizada

RESUMO

A adaptação de duas cultivares de citros, Valencia Delta Seedless (VDS) e Valencia Late Frost (VLF) enxertadas em Forner Alcaide nº 517, foi avaliada em pomares com alta densidade de plantio e colheita mecânica, no sudoeste da Espanha. Em relação ao desenvolvimento das culturas, ambas as cultivares apresentaram comportamento semelhante em relação ao crescimento da planta, boa afinidade com o porta-enxerto e bom conteúdo de clorofila na folha (unidades SPAD). Entretanto, foram obtidas diferenças no desenvolvimento fenológico e na qualidade interna da fruta.

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Assim, a VDS mostrou uma fenologia mais tardia, enquanto a VLF obteve um suco de melhor qualidade: maior teor de acidez titulável com menor índice de maturação. Por outro lado, foi identificado um grande potencial de colheita mecânica em ambas as cultivares, com porcentagens significativas de desprendimento de frutas (cerca de 90% ou mais) e acima de 8 kg de força de retenção de frutos (FRF). No entanto, a VDS obteve melhor resposta ao equipamento de colheita avaliado (New Holland BRAUD 9090X DUAL, colhedora por agitação contínua da copa). Assim, a VDS registrou maiores porcentagens de desprendimento de frutos (95-100%), bem como menores níveis de danos fisiológicos e físicos. Finalmente, as diferenças entre as cultivares, tanto a eficiência do desprendimento da fruta quanto os danos das plantas podem responder às diferenças na estrutura das plantas e à rigidez dos ramos.

Termos de indexação: super-adensado, porta-enxertos ananicantes, eficiência de colheita, danos nas plantas, alterações nas frutas.

INTRODUCTION

Most citrus crops, regardless of fruit destination, are hand-harvested. Nevertheless, in citrus crops oriented to industry juice, the challenge is the integral mechanization of crop aimed to reduce the principal production costs and obtain a greater profitability. In this sense, super high-density groves with mechanical harvesting emerge as an interesting strategy for citrus destined to juice industry.

In the last decades, trends have been directed to increase the density of plantation, reducing the distance between trees within the same row. Despite the fact that the more usual tree spacing in a traditional citrus orchard is 6 m × 4 m, in the last years citrus orchards have been established with high-density spacing (7 m × 3 m or 7 m × 2.5 m), mainly destined to juice industry, with a wider distance between rows to allow big harvesting equipments to get in, and higher density planting to maintain grove yields. In this way, arise the super high-density system with reduced vigour trees, narrower tree spacing (around 4 m × 1.5 m) and trees performance with mechanical hedge pruning in order to reach a high degree of mechanization.

Mechanical harvesting has been evaluated and commercialized in the Florida citrus industry since 1958 (Florida Department of Citrus, 2000). Mechanical harvesting against hand harvesting can report substantial costs savings (Roka, 2004).

The first plantations in super high-density system was carried out at the beginning of 90's in olive orchards. The success of this system resides mainly in the integral mechanized harvesting; an earlier production with high and steady yield and a great quality oil (Arenas & Hervalejo, 2012).

Currently, the harvesting systems most widely used are trunk vibrators and canopy shakers. However, in super high-density system is the over-row continuous canopy shaking harvester, similar to grape harvester (Gregoire, New-Holland or Pellenc), the best alternative.

In this sense, in Andalusia is carrying out a project to develop a new technology in super high-density system in citrus orchards. From 2009 several experimental fields have been established in Andalusia with super-intensive citrus groves (3.5-4.0 m × 1-2 m). The acquired experience throughout these years indicates that the success of super high-density system resides on the design of the plantation, shape of the trees, plant material selection (rootstocks and cultivars) and crop management (Arenas & Hervalejo, 2012; Arenas et al., 2012). However, it is necessary to continue developing this way of plantation system.

Along these lines, the present study shows the results obtained regarding to the adaptation of the citrus groves to super high-density systems, evaluating the agronomic behavior of different citrus cultivars on Forner Alcaide nº 517 and their response to mechanical harvesting by over-row continuous canopy shaking harvester, similar to grape harvester.

MATERIALS AND METHODS

Plant material and experimental design

The experimental plot was located in Alcalá del Río (Seville, Spain) under a typical continental Mediterranean climate and variable precipitation regimes. The soil is loam (25% clay, 32% sand and 43% silt), with an alkaline pH (8.7), low levels in organic matter (1.5%), without problems of active $CaCO_3$ (4.8%) or salinity (0.12 mS cm^{-1}). Well-irrigated water, applied by drip irrigation system, with a neutral pH (7.1), slight salinity (1.46 mS cm^{-1}) and moderate levels of bicarbonates (7.74 meq L^{-1}).

The experimental plot was planted in 2012 with two orange cultivars (*Citrus sinensis* L. Osbeck), Valencia Delta Seedless and Valencia Late Frost, on Forner-Alcaide nº 517 (FA-517). Tree spacing was 3 m × 1 m.

The trees show a structure in hedge, performed by mechanical pruning, with black nets in the tree row and individual insulated cover. The trees were hedged, topped and skirted by a disc-saw pruning machine several times in the year.

The experimental plot has two rows of VLF and two rows of VDS. In each row, 6 trees were randomly selected; it means 12 trees per cultivar which different measurements were carried out.

Samples

Climate data were downloaded during 2014-2015 season from the agroclimatic station located in IFAPA Las Torres (RIA).

Assessment of the different citrus cultivars adaptation to super high density systems:

Tree vegetative growth

In March 2015 total height (TH; m), skirt height (SH; m), canopy longitudinal diameter (LD; m) and cross diameter (CD; m), cultivar trunk diameter (CVD; mm) and rootstock diameter (RD; mm) were measured. Affinity between rootstock and cultivar was determinated by the ratio RD/TD, more affine when the ratio is closer to 1. Volume canopy was calculated by Turrell method (Turrell, 1946): CV (m^3) = 0.5238 × (TH- SH) × [(LD + TD)/2]^2.

Leaf chlorophyll content index (SPAD)

It is an index related to the tree nutritional status. An indicator of chlorophyll content is SPAD units, a proportional numerical value of chlorophyll amount in leaves.

In March 2015, SPAD measurements were performed by the SPAD-502 Plus meter on four leaves randomly selected at the beginning of the trial, two leaves from east-facing and other two from west-facing of the canopy tree.

Phenology

A weekly monitoring of the most frequent phenological stages was carried out in each randomly selected tree at the beginning of the trial, distinguishing between canopy tree orientations (east and west). BBCH scale was used (Agustí et al., 2001).

Yield

In March 2015, before mechanical harvesting test, the fruits from each randomly selected tree were counted. A fruit sample was collected from each of these trees in order to obtain the fruit mean weight (kg).

Yield (kg $tree^{-1}$) was estimated multiplying the number of fruits from each tree by the average weight of each fruit (kg).

Fruit quality

In February and March 2015 were collected fruits samples from the two citrus cultivars. The subplot with each citrus cultivar was divided in three repetitions, collecting a fruit sample per citrus cultivar and repetition. Each sample consisted in 8 fruits collected from 4 trees and from two mainly cardinal directions of the canopy tree (east and west).

In each sample, the fruit quality was determined, analysing both external quality parameters: color index (CI), weight (W, g), equatorial diameter (ED, mm), height (H, mm), shape (D/H), peel thickness (PT, mm); and internal quality parameters: juice percentage (% J), titratable acidity (TA, g L^{-1}), total soluble solids (TSS, º Brix) and maturity index (MI=TSS/TA). In relation to internal fruit quality also were evaluated several fruit physiological alterations, such as creasing and disintegration of the central axis, which were determined by a 4-point rating scale: 0 = absent alteration in the fruit, 1 = mild alteration, 2 = moderate alteration, 3 = severe alteration.

A colorimeter (Konica Minolta CR300, Ramsey, NJ, USA) was used to measure fruit colour on three locations around the equatorial plane of the fruits. The Hunter parameters "a", "b" and "L" were used to calculate the Colour index (C.I.) according to Jiménez-Cuesta et al. (1981): C.I. = a × 100/ (L × b), where "L" indicates lightness and "a" and "b" are the chromaticity coordinates. ED, H and PT were determined to each fruit by a digital calliper. TSS was measured by a digital refractometer

(Atago, Palette PR100) and expressed as degrees Brix at 25 °C and TA was determined by titration of 5 ml of juice with 0.1N NaOH using phenolphthalein as indicator.

Evaluation of mechanical harvesting in super high density citrus groves

In 2015, March 24th, a trial of mechanical harvesting was carried out to evaluate the detachment fruit capacity and its effects on tree integrity. The mechanical harvesting equipment tested was the New Holland BRAUD 9090X DUAL, an over-row continuous canopy shaking harvester, similar to grape harvester. Working parameters tested were 2.5 km h^{-1} and 440 r.p.m.

Fruit Retention Force (FRF)

Defined as the tension force needed to remove the stem from the fruit, decreases with ripening fruit, and it depends on the cultivar. Before fruit harvesting, FRF was determined for each citrus cultivar. FRF was measured on 24 fruits using a dynamometer with an adapted attachment to citrus fruits.

Fruit detachment percentage

Before and immediately after mechanical harvesting test, the fruits from each randomly selected tree were counted. Fruit detachment percentage was calculated according to the equation: Fruit detachment (%) = (nº $fruits_i$ – nº $fruits_f$) × 100/ nº $fruits_i$; where: nº $fruits_i$: tree fruits before mechanical harvesting and nº $fruits_f$: fruits remained on the tree after mechanical harvesting.

Tree damages

Mechanical damage: immediately after mechanical harvesting, a visual checking of the integrity trees was carried out, establishing a 3-point rating scale according to the severity of the damage: 0 = no apparent damages, 1 = slight scratches on the tree bark, 2 = broken bark, 3 = broken or fallen branches.

Physiological damage: One month after and before mechanical harvesting test SPAD units were measured on the randomly selected trees at the beginning of the trial.

Physiological damages were determined based on the comparison of SPAD units obtained in each date.

Statistical analysis

The data were statistically analysed using STATISTICA 6.0 software package (Statsoft Inc. U.S.A.) by analysis of variance procedures (ANOVA) with LSD calculated to separate means.

RESULTS AND DISCUSSION

Assessment of the different citrus cultivars adaptation to super high-density systems

Tree vegetative growth

Significant differences were not observed in the tree vegetative growth between cultivars (p>0.05). VDS and VLF showed similar tree height and canopy volume

Table 1. Effect of citrus cultivars on Forner Alcaide nº 517, on total height (TH) and canopy volume (CV) of tree

	TH(m)	CV (m^3)
VDS	2.2 ± 0.07 ns	1.4 ± 0.07 ns
VLF	2.2 ± 0.05 ns	1.6 ± 0.08 ns

ns: no significant differences between citrus cultivar (p>0.05); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Table 2. Effect of citrus cultivars on Forner Alcaide nº 517, on rootstock diameter (RD), cultivar diameter (CD) and affinity ratio (CD/RD)

	RD(m)	CD (m)	CD/RD
VDS	52.1 ± 1.3 ns	49.1 ± 1.2 ns	0.95 ± 0.01 ns
VLF	53.7 ± 1.2 ns	47.8 ± 1.3 ns	0.89 ± 0.02 ns

ns: no significant differences between citrus cultivar (p>0.05); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

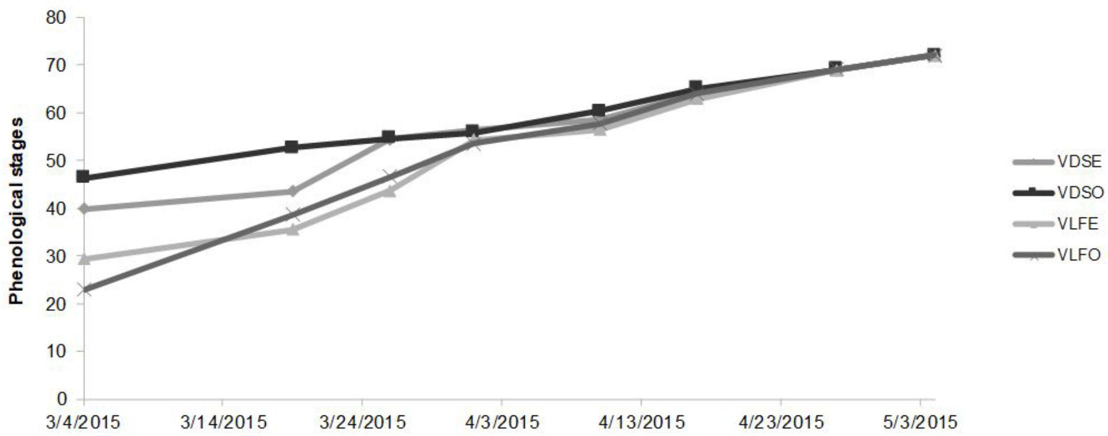

Figure 1. Phenological evolution of citrus cultivar on Forner Alcaide nº 517, in both canopy tree orientations, according to BBCH scale.VDS: Valencia Delta Seedless; VLF: Valencia Late Frost; E: east-facing; W: west-facing.

(Table 1). Nevertheless, VLF reached a slightly higher canopy volume.

In relation to trunk diameter, both rootstocks (RD) and cultivars (CD), significant differences were not observed. Both citrus cultivars showed a good affinity with Forner Alcaide nº 517 (CD/RD close to 1) (Table 2).

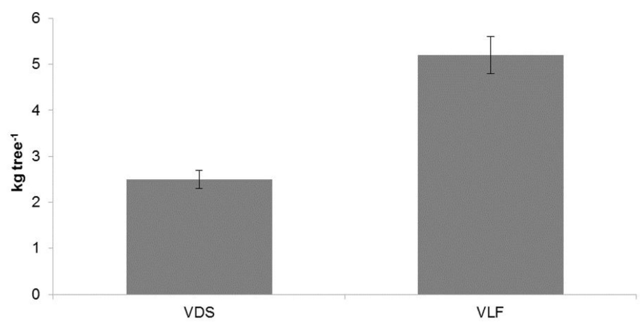

Figure 2. Effect of citrus cultivar on Forner Alcaide nº 517, on total yield (kg tree^{-1}). Different letters indicate significant differences between citrus cultivars ($p<0.05$). VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Leaf chlorophyll content index (SPAD)

The citrus cultivar had no significant effect on leaf chlorophyll content index, showing very similar SPAD values, close to 75.

Phenology

VDS showed an earlier bloom than VLF (Figure 1). Nevertheless, from mid-April both citrus cultivars manifested similar phenological development. Similar results were reported by Martínez-Ferri et al. (2005).

Similar phenological behavior was obtained from both canopy tree orientations, being the east-facing more delayed than west-facing, from March to April.

Yield

VLF (5.3 kg tree^{-1}) obtained a significantly higher yield than VDS (2.5 kg tree^{-1}), about the double (Figure 2).

In late March were recorded strong precipitations that together with the more sensitive phenological stage of VDS, could have contributed to the lower yield registered by this cultivar.

Fruit Retention Force (FRF)

VDS showed a slightly higher FRF, no significant differences, than VLF, both cultivars with values close to 9 kg. These results are agreed with those obtained by Romero-Rodríguez (2011) and Hervalejo et al. (2012).

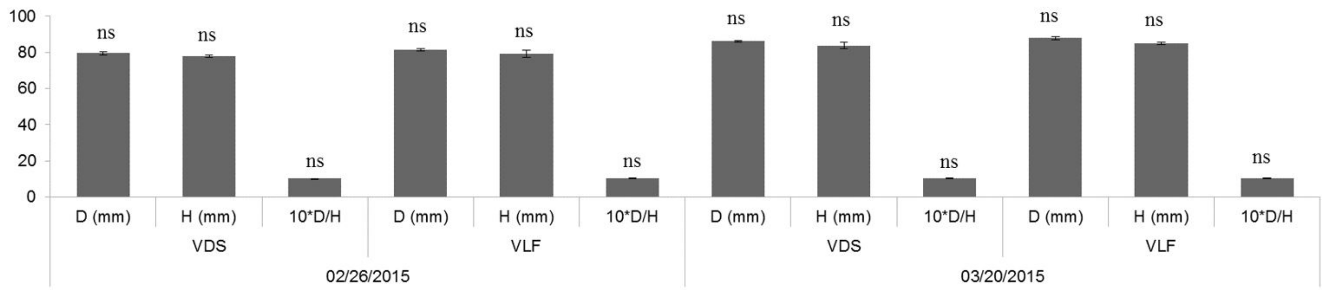

Figure 3. Effect of citrus cultivars on Forner Alcaide nº 517, on diameter (D), height (H) and shape (D/H). ns: no significant differences between citrus cultivar (p>0.05); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Fruit quality

External quality parameters

VLF showed a greater fruit size than VDS, no significant differences in none sampling dates (Figure 3). Regarding the fruit shape (D/H), both citrus cultivars showed a similar spherical shape (~1), no significant differences. It was observed that VLF obtained greater weight fruits than VDS (257.4 g *vs.* 243.4 g obtained in February and 312.6 g *vs.* 302 g in April). These results are agreed with a previous work carried out by Romero-Rodríguez et al. (2014), where VDS showed very similar weight. Overall, the fruits registered a weight increase from the first to the second sampling date.

In relation to the peel thickness significant differences between citrus cultivars were not observed, showing a increase up to 20% and reaching values close to 9.5 mm. According to the results obtained in others works (Hervalejo et al., 2010), these values are high for VDS.

Although without significant differences, VLF showed a higher fruit colour (Table 3). Nevertheless, both citrus cultivars suffered a slight greening of the fruits, showing CI with almost two units less in the second sampling dates.

Table 3. Effect of citrus cultivar on Forner Alcaide nº 517, on fruit colour index

	CI	
	02/26/15	03/20/15
VDS	12.82± 0.50 ns	10.79 ± 0.36 ns
VLF	13.42 ± 0.35 ns	11.52 ± 0.33 ns

ns: no significant differences between citrus cultivar (p>0.05); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Internal quality parameters

Regard to the juice content, significant differences between citrus cultivars (Table 4) were not observed, registering both juice contents above 41%. It is an acceptable value to juice industry. These values are coherent with those reported by Romero-Rodríguez et al. (2014). In relation to organoleptic characteristics, VLF showed a greater juice quality, showing a slightly higher content in total soluble solid (Table 5), in both cases above 11º Brix. These values

Table 4. Effect of citrus cultivars on Forner Alcaide nº 517, on juice acidity content (Juice %)

	Juice %	
	02/26/15	03/20/15
VDS	41.1± 1.9 ns	41.8 ± 1.3 ns
VLF	42.9 ± 0.9 ns	41.2 ± 0.3 ns

ns: no significant differences between citrus cultivar (p>0.05); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Table 5. Effect of citrus cultivars on Forner Alcaide nº 517, on sugar juice content (TSS ºBrix)

	TSS (ºBrix)	
	02/26/15	03/20/15
VDS	11.27 ± 0.47 ns	11.40 ± 0.26 ns
VLF	11.63 ± 0.24 ns	11.57 ± 0.09 ns

ns: no significant differences between citrus cultivar (p>0.05); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

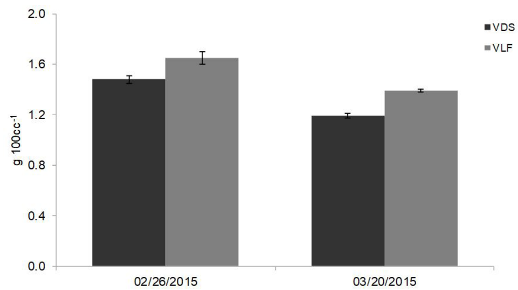

Figure 4. Effect of citrus cultivar on Forner Alcaide nº 517, on titratable acidity (g $100cc^{-1}$). Different letters indicate significant differences between citrus cultivars ($p<0.05$); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

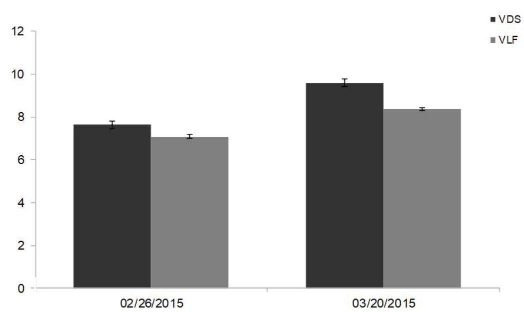

Figure 5. Effect of citrus cultivar on Forner Alcaide nº 517, on maturity index (TSS/TA). Different letters indicate significant differences between citrus cultivars ($p<0.05$); ns: no significant differences between citrus cultivar; VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Table 6. Effect of citrus cultivars on Forner Alcaide nº 517, on creasing and disintegration of the central axis of the fruit

	02/26/15	03/20/15
Creasing	0 ±	0 ±
	0 ±	0 ±
Disintegration	0.7 ± 0.4 ns	0.6 ± 0.2 ns
	0.8 ± 0.3 ns	1.1 ± 0.1 ns

ns: no significant differences between cultivars to each parameter and sample date ($p>0.05$); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

were very similar to studied in 2013-2014 season by Romero-Rodríguez et al. (2014), who did not find significant differences between them. Regarding titratable acidity (Figure 4), VLF had significantly higher values in both sampling dates. The greater acidity in VLF resulted in a lower maturity index (TSS/TA), significant in the second sampling date (Figure 5).

Finally, regard to internals physiological alterations of the fruit none of the two cultivars showed important levels (Table 6). None of the fruits showed creasing alterations, such as it was obtained in other trials (Hervalejo et al., 2010); on the contrary, disintegration of the central axis of the fruit, without significant differences between the cultivars, reached a moderate level, maximum in the second sampling date, although only on the VLF cultivar. The disintegration values were lower than values observed (0.7) by Hervalejo et al. (2010), where VDS registered values above 1.3 in the same date. VLF neither had an important disintegration.

Evaluation of mechanical harvesting in super high density citrus groves

Fruit detachment percentage

The harvester machine experimented a greater work efficiency in VDS than in VLF (Table 7), showing VDS a higher fruit detachment percentage (100%) than VLF (84.7%).

Tree damage

Mechanical damage: VLF showed more sensitive to the mechanical harvesting than VDS (Table 8). VDS suffered a mild damage (1), while VLF suffered a moderate damage (1.5).

Physiological damage: Comparing SPAD measurements done immediately before and one month later from the mechanized harvested trial (Table 9), it was observed a greater sensitivity to the mechanized harvested in VLF.

Table 7. Effect of citrus cultivars on Forner Alcaide nº 517. on fruit detachment percentage and work equipment parameters (advance speed and shaker frequency)

Variety	Frequency (rpm)	Speed (km h^{-1})	Detached fruit %
VDS	440	2.5	100
VLF	440	2.5	84.7

ns: no significant differences ($p>0.05$); VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Table **8.** Effect of citrus cultivars on Forner Alcaide nº 517, on tree mechanical damages (0-1: mild, 1-2: moderate and 2-3: severe)

Variety	Frequency (rpm)	Speed (km h^{-1})	Damage
VDS	440	2.5	1
VLF	440	2.5	1.5

VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

Table **9.** Effect of citrus cultivars on Forner Alcaide nº 517, on SPAD values in two sampling dates

	SPAD			
	Frequency (rpm)	Speed (km h^{-1})	03/20/15	04/27/15
VDS	440	2.5	75.6 ns	75.89 ns
VLF	440	2.5	79.36 b	72.36 a

Different letters indicate significant differences between cultivars to this campaign ($p<0.05$); ns: no significant differences between cultivars; VDS: Valencia Delta Seedless; VLF: Valencia Late Frost.

VLF showed damages levels (mechanical and physiological), higher than VDS, suffering breaks of branches and a decreased in chlorophyll content in leaves. A relation between physical and physiological damages was not found, it means that the decrease in the chlorophyll of leaves probably was not due to the broken branches. The differences found in the detachment efficiency and the damage caused to the tree, between cultivars, could be a response to the differences in the structure and the rigidity of the branches.

A more rigid structure of the tree could transmit a worst vibration of the equipment to the fruit, causing a lower fruit detachment, and a lower adaptation of the equipment to the aerial part of the tree, producing broken branches. A lower absorb of equipment beating by aerial part of the branches could cause damages at the root tip level which explain the physiological damages found along a month.

CONCLUSIONS

Objective i. Evaluation of different citrus rootstocks adaptation to super high-density systems

Significant differences were not obtained, between cultivars, regard to the tree growth. Both cultivars showed means values of 2.2 m of height and 1.5 m^3 of canopy and a good affinity with the rootstock, Forner Alcaide nº 517. Likewise, regard to leaf chlorophyll content, both cultivars showed similar SPAD values (~75). On the contrary, differences between cultivars in the phenological development, yield and internal quality of the fruits were obtained.

VDS showed an earlier beginning in flowering than VLF, reaching a full flowering stage between late March and early April. The strong precipitations recorded in late March (2014) together with the phenological differences between cultivars (more sensitive phenological stage in VDS) could be responsible to the lower yield registered in VDS, which was almost the half from obtained in VLF (5 kg $tree^{-1}$).

In fruits of both cultivars, only were observed significant differences in the juice organoleptic quality and in the internal maturity of the fruit. VLF registered a higher quality juice with a greater content in total acids. The higher acids content translates into a lower maturity index in VLF. Despite of differences found in the internal maturity of the fruits, the fruit retention force was similar in both cultivars (>8 kg).

Objective ii. Evaluation of mechanical harvesting in super high density citrus orchards

This trial showed a great potential of the mechanical harvesting, with over-row continuous canopy shaking harvester, in super high density citrus orchards. Significant fruit detachment percentages (about 90% or more) were obtained, showing on VDS higher percentages.

In the other hand, VLF showed damages levels (mechanical and physiological), higher than VDS, suffering breaks of branches and a decreased in chlorophyll content in leaves.

These differences found between cultivars, both in the detachment efficiency and the damage caused to the tree, may be because the differences in the structure and the rigidity of the branches. In this sense, it would be interesting to study the tree structure and/or the rigidity of branches in both cultivars, as well as transmission of the vibration to the fruit.

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