Agronomic and physicochemical fruit properties of ‘Big Top’ nectarine budded on peach and plum based rootstocks in Mediterranean conditions

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Abstract

Agronomic and physicochemical fruit properties of ‘Big Top’ nectarine were evaluated in the Ebro Valley (Zaragoza, Spain), under replant and heavy-calcareous soil conditions typical of the Mediterranean area. Fruits were harvested at commercial maturity from trees budded on four peach-almond hybrids (*Prunus amygdalus* × *Prunus persica*): Adarcias, Felinem, GF 677 and Mayor; two *P. persica* × *Prunus davidiana* hybrids: Barrier and Cadaman; two hexaploid plums: Adesoto (*Prunus insititia*) and Tetra (*Prunus domestica*); and one almond-plum hybrid (*Prunus cerasifera* × *P. amygdalus*): Replantpac. Significant differences among the different rootstocks were found for most of the fruit quality traits analyzed at harvest maturity. The average of the four years of study showed that the brightest (high L* value) and most red colored skin fruits (high a* and b* values) were found on GF 677, while the lowest b* and h were recorded on Tetra and Felinem, respectively. Adesoto, GF 677 and Replantpac induced good fruit quality traits based on anthocyanins, Vitamin C, relative antioxidant capacity and/or total phenolic content (TPC). GF 677 also showed higher values on cumulative yield (CY) and yield efficiency (YE), with no significant differences with Replantpac for CY and Adesoto for YE. Barrier and Cadaman seem to delay maturity of ‘Big Top’ fruits based on flesh firmness (FF), titratable acidity (TA) and CIELAB parameters, and showed lower TPC and anthocyanins, which could be partly explained due to their worst adaptation to calcareous soil conditions. Results from this study underlined the important relationships between plant adaptability and fruit quality traits.

Keywords: skin color, vitamin C, total phenolic content, anthocyanins, antioxidant capacity

1. Introduction

The consistent adoption of new released cultivars by the fruit growers in the last two decades, among other factors like improvement in irrigation, fertilization, crop protection, postharvest technology, and certification and traceability techniques, allowed Spain to be the third largest peach producer worldwide, only surpassed by China and Italy. In addition, it is the second largest peach producer in the European Union, and the leader of exports in Europe (FAOSTAT, 2014). However, this has led growers to have no choice but to use replant soils, meaning soil and disease problems like root asphyxia, iron-chlorosis deficiency, waterlogging and soil-borne pathogens (Font i Forcada et al., 2014a; Mestre et al., 2015; Zarrouk et al., 2005), which affect the normal development of the tree. In order to solve that, and because the rootstock represents an important consideration for a productive orchard, particularly in orchard replanting situation (Bussi et al., 2002), breeding programs are very active in the release of new rootstocks, improving peach adaptability to the soil (Felipe, 2009; Pinochet, 2010; Moreno et al., 1994; 1995) and to different training systems, and improving peach fruit quality (Monet and Bassi, 2008). Therefore, the accurate evaluation of rootstocks responses to different growth conditions and the identification of the best scion-rootstock combination are of major importance to obtain high quality crops (Rato et al., 2008).

Several different species are commonly used as rootstocks for peaches. Peach-almond hybrids (*P. amygdalus* × *P. persica*), hexaploid plums (*P. domestica*, *P. insititia*) and peach seedlings rootstocks are largely used as rootstocks for peach trees in the Mediterranean countries (Byrne et al., 2012). Several cultivars budded on peach-almond hybrids and plum-based rootstocks, such ‘Catherina’, ‘Flavorcrest’, ‘Queen Giant’, ‘Redhaven’, ‘Suncrest’, ‘Tebana’ and ‘Tropic Snow’ have been studied under replant and Mediterranean soil conditions (Font i Forcada et al., 2013, 2014a; Layne, 1994; Marra et al., 2013; Orazem et al., 2011; Remorini et al., 2015). However, to the best of our knowledge, no study has been published with the aim of determining the fruit quality properties of one of the most appreciated nectarine cultivar grown in Spain, ‘Big Top’, under replant conditions. ‘Big Top’ is nowadays considered the reference

nectarine cultivar in Europe for fresh consumption, known as a slow-softening rate cultivar and appreciated for its early coloration resulting in greatly colored fruit, optimum fruit size, high sweetness, juiciness and flavor (Cano-Salazar et al., 2013). Moreover, besides its high quality for fresh consumption, ‘Big Top’ has been recently proved to have a good performance also prepared as fresh-cut product (Cefola et al., 2014). Modern consumers are increasingly interested in their personal health, and they expect food not only to be tasty and attractive but also safe and healthy. Consequently, it is important that peach growers acquire information about attributes and limitations of specific rootstocks and the effects of replant soil on tree growth and fruit quality. Therefore, the aim of this research was to study and compare tree growth, yield and physicochemical fruit properties of ‘Big Top’ cultivar on nine rootstocks in replant and heavy-calcareous soil conditions, typical of the Mediterranean area.

2. Materials and methods

2.1. Plant material and field trial

Nine *Prunus* rootstocks, including four *P. amygdalus* × *P. persica* hybrids: Adarcias, Felinem, GF 677 and Mayor; two *P. persica* × *P. davidiana* hybrids: Barrier and Cadaman; one *P. insititia* plum: Adesoto; one *P. domestica* plum: Tetra; and one *P. cerasifera* × *P. amygdalus* hybrid: Replantpac, were tested for ‘Big Top’ nectarine at the Experimental Station of Aula Dei (CSIC-Zaragoza, Spain). The genetic background and the origin of these rootstocks were already described by Mestre et al. (2015).

These rootstocks were budded with ‘Big Top’ nectarine cultivar during the summer of 1999, and trees were established in an experimental plot on March 2001. The trial was located in the Ebro Valley (North-Eastern of Spain), on a heavy and calcareous soil, with 28% total calcium carbonate, 8% active lime, water pH 8.4, and a clay-loam texture. It was established on a non-fumigated replant site, one year after uprooting an 8-year-old peach (‘Summergrand’ nectarine cv.) orchard that was budded on plums (*P. insititia*, *P. domestica*) and peach-almond rootstocks.

The experiment was established in a randomized block design with five single-tree replicates for each rootstock. Trees were planted at 5.5 m × 5.5 m and trained to a low density open-vase system. The wide tree row spacing was used to avoid any environmental effect on the adjacent trees in case of tree losses.

Tree decline was observed over the years as reported by Mestre et al. (2015). Consequently, four single-tree replications for Tetra, Mayor, GF 677, Cadaman, Barrier,

Adesoto and Adarcias, and three single-trees for Felinem were used in this study. In contrast, all trees budded on Replantac survived well to the end of the experiment. Guard rows were used to preclude edge effects. Cultural management practices, such as fertilization, winter pruning, and spring thinning, were conducted as in a commercial orchard. Open vase trees were pruned to strengthen existing scaffold branches and eliminate vigorous shoots, inside and outside the vase, that would compete with selected scaffolds or shade fruiting wood. Moderate-sized fruiting wood (0.3-0.6 m long) was selected. All trees were hand-thinned at 45-50 days after full bloom (DAFB) leaving approximately 20 cm between fruits. The plot was level-basin irrigated every 12 days during the summer.

2.2. Growth measurements and yield characteristics

For all the cropping years, starting in 2003, trunk girth, yield and number of fruits per tree were recorded. Trunk girth was measured each dormant season at 20 cm above the budding point, used to calculate trunk cross-sectional area (TCSA). At harvest, all fruits from each tree were counted and weighted to determine total yield per tree (kg/tree). Fruit weight (FW) was calculated considering the total number of fruits and total yield per tree. Average fruit weight (AFW) from 2009 to 2014 was also calculated. Cumulative yields (CY) per tree and yield efficiency (YE) of each scion-stock combination were computed.

2.3. Fruit physical and chemical properties

Over the last 4 years of study (2011-2014), 20 representative fruits were randomly hand-picked at commercial maturity time for each scion-rootstock combination. They were collected from shoots around the crown of the trees. Fruits were considered ripe when they no longer grew and exhibited the ground colour representative for 'Big Top' cultivar. Fruits were analysed for flesh firmness (FF), soluble solids content (SSC), titratable acidity (TA), skin colour parameters and antioxidant compounds.

FF was measured on two paired sides of each fruit, by removing 1 mm thick disk of skin from each side of the fruit, and using a penetrometer equipped with an 8 mm tip (Model FT-327). The two readings were averaged for each fruit and data were expressed in Newtons (N). SSC of juice extracted from 20 fruits was measured with a digital refractometer (Atago PR-101, Tokyo, Japan) and was expressed as °Brix. For TA, five grams of homogenized samples were diluted with 50 mL of distilled water, and microtitrated with 0.1 N NaOH to a pH end point of 8.2. The results were expressed as g malic acid per 100 g of fresh weight. Ripening index (RI) was determined as SSC/TA

ratio. Color determinations in the fruit equatorial zone were measured by the CIELAB L* (brightness or lightness; 0=black, 100=white), a* (red = positive values, green = negative values), b* (yellow = positive values, blue = negative values), C* (chroma) and h (hue angle degree; 0°=red-purple, 90°=yellow, 180°=bluish-green) using a colorimeter (Chroma Meter, CR-400 Konica Minolta, Japan).

After fruit quality analysis, in 2011 and 2012, fruits were peeled, and a portion of the mesocarp was removed from the middle of each opposite side and cut into small pieces. A composite sample for each tree of 5 g was built by mixing all pieces from all the selected fruits. This sample was frozen in liquid nitrogen and kept at -20 °C until analyzed. Total phenolics, anthocyanins, relative antioxidant capacity (RAC) and Vitamin C were evaluated according to Cantín et al. (2009), with some modifications. All samples were analyzed using a spectrophotometer Asys UVM 340 Microplate Reader (Biochrom Ltd, Cambridge, UK). Standard calibration curves were daily prepared. The Folin-Ciocalteu reagent at 0.25 N concentration was used to determine the total phenolic content (TPC). Absorbance was measured at 725 nm and the results were expressed as mg of gallic acid (3,4,5-trihydroxy-benzoic acid) equivalents (GAE) per 100 g FW. For determining anthocyanin content, spectrophotometric readings at 535 nm and 700 nm were taken against a blank cell filled with extraction solvent. Anthocyanins were expressed as mg of cyanidin-3-glucoside equivalents (C3GE) per kg of FW using a molecular weight of 494 and a molar extinction absorptivity coefficient $\epsilon = 25,965/\text{cm M}$. The relative antioxidant capacity (RAC) was determined using the 1,1-diphenyl-2-picrylhydrazyl (DPPH). Absorbance was measured at 515 nm and the results were expressed as μg of Trolox equivalents per g of FW. For vitamin C determinations, absorbance was determined at 525 nm and the results were expressed as mg of ascorbic acid (AsA) per 100 g of FW.

2.4. Data analysis

Statistical analysis was conducted using IBM SPSS, Statistics 23. The data was evaluated by two-way variance (ANOVA) analysis. When the F test was significant, means were separated by Duncan's multiple range ($P \leq 0.05$). The analyses of Pearson correlation and principal components analysis (PCA) were carried out to study correlations among vigor, yield, fruit quality traits and other agronomic parameters. PCA analysis was performed using Unscrambler X 10.3 software (CamoAsa, 2001).

3. Results and Discussion

3.1. Rootstock and year effect

The ANOVA analysis (Table 1) showed that rootstock and year significantly affected all evaluated traits, except for vitamin C, total phenolic content (TPC) and anthocyanins content, which were not significantly affected by the year, and TPC and soluble solids content, which were not significantly affected either by rootstock. These results suggested that vitamin C, TPC and anthocyanins contents appear to be less influenced by the prevailing environmental conditions over the growing season than the other traits evaluated. Font i Forcada et al. (2014a) also reported that year affected most of the traits evaluated in the ‘Catherina’ peach cultivar. The year-to-year variation in most of the traits may be explained by the differences in annual temperature and crop load over the different years of study. Statistically significant rootstock $\times$ year interactions were observed only for fruit weight and a* parameters. This could indicate that rootstocks had consistent effects on ‘Big Top’ nectarine and its fruit quality traits. Thus, owing to the non-significant rootstock $\times$ year interactions on the rest of the traits evaluated, the data from different years were also analyzed together. In addition, the significant effect of rootstock found on all traits, except for TPC and soluble solids content, agrees with previous works where the effect of rootstock on agronomic and fruit quality traits have been reported (Font i Forcada et al., 2013; 2014a).

3.2. The effect of rootstock on tree growth and yield

There was a significant effect of the rootstock on trunk-cross sectional area (TCSA), cumulative yield (CY) and yield efficiency (YE) at the sixteenth year after budding (2014). The plum rootstock Adesoto induced the lowest TCSA, while Cadaman and Replantpac showed the highest values (Table 2). An intermediate vigour was observed on the rest of the rootstocks.

Trees on Barrier and Cadaman induced the greatest cumulative yield (CY), although they were not significantly different from Adarcias, Felinem, GF 677, Mayor and Replantpac. TCSA was significantly and positively correlated with CY ($r = 0.85$, $P \leq 0.05$), in accordance with Layne (1994) who reported that cumulative yields are higher on the most vigorous rootstocks. The lowest cumulative yield was exhibited by the less vigorous rootstock Adesoto, although it did not differ from Tetra, Adarcias, Felinem and Mayor (Table 2).

Yield efficiency (YE) was greatest on GF 677, a rootstock with an intermediate vigour in this study, but not significantly different from the other rootstocks, except Mayor, Replantpac, Tetra and Cadaman (Table 2). Some authors (Alonso and Espada, 2011; Jiménez et al., 2011; Marra et al., 2013; Remorini et al., 2015) reported that higher

vigorous rootstocks induced lowest yield efficiency. Nevertheless, in this study a small negative correlation between YE and tree vigour was found ($r = -0.16$, $P \leq 0.05$). Lower value than expected is probably due to the high cumulative yield of some intermediate vigorous rootstocks, such as Barrier and GF 677. In contrast, De Salvador et al. (2002) reported the highest TCSA and CY on Barrier and GF 677 compared to other *Prunus* rootstocks such as Ishtara, Julior, Jaspi, Citation, Rubira, and some seedlings budded with ‘Suncrest’ peach cultivar and grown under Mediterranean climate.

Finally, average fruit weight (from 2009 to 2014) was significantly affected by rootstock. Barrier, with a medium TCSA, tended to produce higher fruit weight, as previously reported by several authors (Font i Forcada et al., 2013; Loreti and Massai, 2006; Orazem et al., 2011). Layne (1994) also observed largest fruits on intermediate-vigour rootstocks compared with more vigorous ones.

3.3. The effect of rootstock on physical and basic fruit quality properties

Rootstock was found to significantly affect the basic fruit quality traits: flesh firmness (FF), soluble solids content (SSC), titratable acidity (TA) and ripening index (RI) (Table 3).

The average of the four years of study shows that the greatest flesh firmness (FF) value was recorded on the peach $\times$ *P. davidiana* Barrier, although it did not differ significantly from Adarcias, Cadaman, GF 677 and Replantpac (Table 3). The tendency of Barrier to produce fruits with higher firmness was previously mentioned (Giorgi et al., 2005; Orazem et al., 2011; Remorini et al., 2008). In contrast, the plum rootstocks Adesoto and Tetra, and peach-almond hybrids Felinem and Mayor produced the softest fruit, although they did not differ significantly from the other rootstocks, except from Barrier and GF 677. The tendency of Tetra to produce softer fruits was also mentioned by Orazem et al. (2011).

Regarding soluble solids content (SSC), fruits from different rootstocks did not demonstrate significant differences in the average value for the four years of study, except for the first (2011) and second (2012) year when Mayor and Adesoto produced the highest SSC of fruits, respectively (Table 2). The tendency of Adesoto to induce higher SSC, individual (sucrose, fructose and sorbitol) and total sugars has already been showed (Orazem et al., 2011; Font i Forcada et al., 2014a). The SSC values obtained at harvest were similar to those reported by Iglesias and Echeverría (2009) for ‘Big Top’.

On average, the highest TA was induced by Barrier, although it did not differ from Cadaman and Replantpac. Similarly, the tendency of Barrier to produce fruits with

higher acidity was already mentioned (Giorgi et al., 2005). The lowest TA was exhibited by Adarcias, Felinem Mayor and Tetra (Table 3) although they did not differ from Adesoto, Felinem, GF 677 and Replantpac.

Nevertheless, small differences in the ripening index (RI) were found among rootstocks throughout the years of study (Table 3). Felinem and Mayor had the highest RI mean value, while Barrier and Cadaman induced the lowest one. Besides being mainly correlated with SSC, consumer acceptance is also dependent on the other fruit quality attributes such as TA (Crisosto et al., 2006), thus making fruit TA level an eligible target for breeders in order to meet consumers requirements (Di Vaio et al., 2015). Therefore, the effect of rootstock on these two parameters should also be taken into account for breeders and growers. Differences in SSC and TA on the same cultivar could change the consumer degree of liking, as reported by Iglesias and Echeverría (2009) who evaluated the effect of cultivar and harvest date on quality and fruit acceptance of six nectarine cultivars.

Significant differences were also found between rootstocks in L^* , a^* , b^* , C^* and h color parameters for 'Big Top' cultivar (Table 4). The average of the four years of study showed that the brightest (high L^* values) and most red and yellow colored skin (high a^* and b^* values) was found in fruits of 'Big Top' budded on GF 677, although not significantly different from Barrier, Cadaman, Mayor and Replantpac for L^* and b^* , and the rest of rootstocks but Adesoto for a^* values. In contrast, the lowest b^* was recorded on Adesoto, Felinem and Tetra, although not significantly different from several rootstocks (Table 4). Differences in ground color for the varying maturity occur in a^* (green-red), b^* (blue-yellow) and h coordinates, which increase a^* and b^* or decrease h values as maturity advances (Delwiche and Baumgardner, 1983; Ferrer et al., 2005).

It has been reported that the skin color of fruit influences consumer acceptance and sales (Liverani et al., 2002). Indeed, consumers associate intense color with better appearance and quality (Byrne et al., 2012; Iglesias and Echeverría, 2009). Surprisingly, high values were noted for Barrier rootstock fruit, since FF, SSC, TA and RI values could indicate lower ripeness of 'Big Top' fruits on this rootstock. 'Big Top' is known for its early intense red skin color development (Iglesias and Echeverría, 2009), which explained high color values on less mature fruit. Other authors (Génard et al., 1994; Font i Forcada et al., 2012; Ruíz and Egea, 2008) suggested that high h angle values could

indicate lower acidity. However, our results showed that ‘Big Top’ fruits from Barrier, Cadaman, GF 677 and Replantpac had higher h angle and TA values.

3.3. The effect of rootstock on phytochemical fruit compounds

Chemical analysis of fruits showed that rootstock had significant effect on ‘Big Top’ flesh. On average, small differences were found among rootstocks in the fruit Vitamin C content (Table 5). However, Tetra induced the lowest value for two years as well for the average of these two years. Among rootstocks, values of Vitamin C ranged from 2.3 mg AsA/100 g FW (Tetra, in 2011) to 10.9 mg AsA/100 g FW (Adarcias, in 2012). They were included within the range reported for peach flesh in the literature (Abidi et al., 2011; Cantín et al., 2009; Font i Forcada et al., 2013, 2014a; Gil et al., 2002; Tomás-Barberán et al., 2001) and those values (6-8 mg AsA/100 g of FW) reported in the USDA Food Composition Data (www.nal.usda.gov/fnic/foodcomp/).

Regarding total phenolic content (TPC), no significant differences were observed at the average of the two years. However, ‘Big Top’ fruits from Felinem tended to have the highest TPC. The TPC values varied from 8.4 mg GAE/100 g FW (Barrier, in 2011) to 17.1 mg GAE/100 g FW (Felinem, in 2011) or 13.5 mg GAE/100 g FW (Adesoto, in 2012). Nonetheless, these values were about twice lower than those reported by Orazem et al. (2011) and Font i Forcada et al. (2014a) for different peach cultivars.

Concerning anthocyanins content the highest value was induced by GF 677, but it did not differ significantly from the other rootstocks, except for Barrier (Table 5). The anthocyanins content varied greatly among rootstocks and years ranging from 0.42 mg C3GE/kg FW (Cadaman, in 2012) to 1.29 mg C3GE/Kg FW (GF 677, in 2011) or 1.25 mg C3GE/Kg FW (Adesoto, in 2012). The anthocyanins content was in the range previously reported for peach flesh (Font i Forcada et al., 2013, 2014a; Zhao et al., 2015). C3GE was identified as the main anthocyanin compound in peaches and it is responsible for the red color in these fruits (Tomás-Barberán et al., 2001).

No significant correlation was obtained between anthocyanins and RAC in this study, as reported by Cantín et al. (2009) and Font i Forcada et al. (2014 a,b) in peaches and nectarines, probably due to their lower content compared with strawberries, raspberries and plums (Gil et al., 2002). Nevertheless, due to the increasing evidence of the benefit of anthocyanins to human nutrition and health, to know which rootstock induces more anthocyanin content to a given cultivar is also important.

Significant differences were found in the average of relative antioxidant capacity (RAC) values for the two studied years (Table 5). Barrier induced the highest value, although

no significant differences were found with the other rootstocks except for Adarcias. In contrast, Barrier rootstock budded with ‘Suncrest’ peach had the lowest antioxidant capacity compared to other *Prunus* rootstocks (Giorgi et al., 2005). Among rootstocks, values of RAC ranged from 316.1 μg Trolox/g FW (Felinem, in 2011) to 359.3 μg Trolox/g FW (GF 677, in 2011), being in the range previously reported (Font i Forcada et al., 2013, 2014a; Orazem et al., 2011).

Some works (Cefola et al., 2014; Font i Forcada et al., 2014a; Gil, 2002; Orazem et al., 2011) reported that, in general, fruits with higher TPC showed higher antioxidant capacity. Similarly, a moderate positive correlation between RAC and TPC was found in this study ($r = 0.42$, $P \leq 0.05$). In contrast, there was no significant correlation between RAC and ascorbic acid content, as reported by Drogoudi and Tsipouridis (2007), suggesting that antioxidants other than ascorbic acid may mostly contribute to the total antioxidant capacity in peach fruit, as phenolic compounds (Abidi et al., 2011; Cantín et al., 2009; Gil et al., 2002).

In spite of fruits were harvested with the same visual characteristics of maturity, some rootstocks might delay (Barrier and Cadaman) or advance (Tetra) maturity based on FF, SSC, TA, CIELAB parameters and RI results, in good agreement with De Salvador et al. (2002) and Orazem et al. (2011). In addition, rootstocks that seem to delay fruit maturity (Barrier and Cadaman) had also fruits with lower total phenolic content (TPC) and anthocyanins. A high negative correlation between TPC and FF ($r = -0.62$, $P \leq 0.05$), and low negative correlations between TPC and TA ($r = -0.38$, $P \leq 0.05$) and between anthocyanins and TA ($r = -0.34$, $P \leq 0.05$) have been found in this study. Barrier and Cadaman have been also reported to show wider imbalanced nutritional values (ΣDOP index, deviation from optimum percentage) and lower Fe leaf mineral concentrations than the other rootstocks in this growing conditions (Mestre et al., 2015). It could also contribute to explain lower fruit ripeness for those two rootstocks. In contrast, Adesoto, Felinem, GF 677 and Replantpac induced good fruit quality traits based on anthocyanins, Vitamin C, RI, RAC and/or TPC values.

3.3. Principal component analysis

A principal component analysis (PCA) was performed to understand how agronomical and fruit quality traits contribute to the variability among different rootstocks budded with ‘Big Top’ nectarine cultivar (Figure 1). Leaf mineral nutrients (Ca, Cu, Fe, K, Mg, Mn, N, P, Zn), ΣDOP index and root and crown suckering (SCK) values were

previously reported by Mestre et al. (2015). Principal components 1 (PC1) and 2 (PC2) accounted for 37 % and 17 %, respectively, of the total variability (Fig. 1).

The traits that revealed to be main sources of variability in the first principal component corresponded to b^* , CY, Σ DOP, FF, h, L^* , Mg and TCSA, while in the second principal component corresponded to AFW, a^* , C^* , P, Mn, TA, RI and YE. Rootstocks on the negative side of PC1 corresponding to Barrier, Cadaman, GF 677 and Replantpac induced, in general, higher b^* , CY, FF, h, L^* and Mg values. Adesoto, Felinem and Tetra showed the contrary. Mayor, with low values of AFW, TA and YE induced high values of a^* and Mn.

Normally, research into rootstock effect on plant physiology is mainly focused on plant adaptability, size and fruiting (Giorgi et al., 2005). However, in the last few years fruit quality has achieved an important role in plant adaptability. These results underline the important relationships between plant adaptability and development and the major factors of fruit quality and nutritional value. Besides, for each rootstock type, a better combination of plant training and cultivation system can help to increase the YE and fruit size, while retaining their adaptability and quality. In this case, Replantpac and GF 677 rootstocks appear suitable for peach production when planting on marginal soils or under replanting conditions, while Adarcias, Adesoto and Tetra rootstocks may be more convenient for reducing excessive growth of peach cultivars in fertile soils and to increase planting density (Mestre et al., 2015). Replantpac is a recently new released plum based rootstock (Pinochet, 2010), and further studies with more peach cultivars should be performed to have a better knowledge of this rootstock in different scenarios.

4. Conclusions

This study is likely to represent the first data on the fruit quality and the antioxidant compounds of 'Big Top' budded on different rootstocks under replant conditions. The results indicated that the rootstock assessed displayed different characteristics.

The plum based Replantpac seemed to be one of the most adapted rootstock in replant and heavy-calcareous soil conditions, inducing vigorous trees with higher cumulative yield, and good fruit quality based on anthocyanins, Vitamin C, relative antioxidant capacity and/or total phenolic content (TPC) of 'Big Top' fruits. Further studies with more peach cultivars should be performed to have a better knowledge in different scenarios of its agronomical and fruit quality performance. The plum Adesoto and the peach-almond hybrids Felinem and GF 677 also induced good fruit quality based on anthocyanins, Vitamin C, relative antioxidant capacity and/or total phenolic content

(TPC) with lower (Adesoto) or intermediate vigorous trees. Nevertheless, susceptibility to waterlogging and/or some soil pathogens should be considered in the case of peach-based rootstocks.

Finally, comparing the results from this study to other studies on replant conditions the impact of the same rootstock on agronomical and physicochemical traits mainly depend on the cultivar. Therefore, further studies should involve more cultivars to establish if the impact of the rootstock on these traits is similar and constant.

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6. References

Abidi, W., Jiménez, S., Moreno, M.A., Gogorcena, Y., 2011. Evaluation of antioxidant compounds and total sugar content in a nectarine [*Prunus persica* (L.) Batsch] progeny. *Int. J. Mol. Sci.* 12, 6919–6935.

Alonso, J.M., Espada, J.L., 2011. Influence of the rootstock on the agronomic performance of ‘Jesca’ peach under replant conditions. *Acta Hort.* 903, 489–494.

Bussi, C., Besset, J., Girard, T., 2002. Effect of peach or hybrid rootstocks on growth and cropping of two cultivars of peach trees (Emeraude and Zephyr). *Fruits* 57 (4), 249–255.

Byrne, D.H., Raseira, M.B., Bassi, D., Piagnani, M.C., Gasic, K., Reighard, G.L., Moreno, M.A., Pérez, S., 2012. The peach. In: Badenes, M.L., Byrne, D.H. (Eds.), *Fruit Breeding, Handbook of Plant Breeding* 8. Springer Science + Business Media, pp. 505–569.

CamoASA, 2001. The unscrambler 9.6 user manual. CamoASA, Oslo.

Cano-Salazar, J., López, M.L., Echeverría, G., 2013. Relationships between the instrumental and sensory characteristics of four peach and nectarine cultivars stored under air and CA atmospheres. *Postharvest Biol. Technol.* 75, 58–67.

Cantín, C., Moreno, M.A., Gogorcena, Y., 2009. Evaluation of the antioxidant capacity, phenolic compounds, and vitamin C content of different peach and nectarine [*Prunus persica* (L.) Batsch] breeding progenies. *J. Agric. Food Chem.* 57, 4586–4592.

405 Cefola, M., Pace, B., Sergio, L., Baruzzi, F., Gatto, M.A., Carito, A., Linsalata, V.,
 406 Cascarano, N.A., Di Venere, D., 2014. Postharvest performance of fresh-cut 'Big Top'
 407 nectarine as affected by dipping in chemical preservatives and packaging in modified
 408 atmosphere. *Int. J. Food Sci. Technol.* 49, 1184–1195.
 409 Crisosto, C.H., Crisosto, G.M., Echeverría, G., Puy, J., 2006. Segregation of peach and
 410 nectarine (*Prunus persica* (L.) Batsch) cultivars according to their organoleptic
 411 characteristics. *Postharv. Biol. Technol.* 39, 10–18.
 412 Delwiche, M.J., Baumgardner, R.A., 1983. Ground color measurements of peach. *J.*
 413 *Am. Soc. Hortic. Sci.* 108 (6), 1012–1016.
 414 De Salvador, F.R., Ondradu, G., Scalas, B., 2002. Horticultural behavior of different
 415 species and hybrids as rootstocks for peach. *Acta Hort.* 592, 317–322.
 416 Di Vaio, C., Marallo, N., Graziani, G., Ritieni, A., Di Matteo, A., 2015. Evaluation of
 417 fruit quality, bioactive compounds and total antioxidant activity of flat peach cultivars.
 418 *J. Sci. Food Agric.* 95, 2124–2131.
 419 Drogoudi, P.D., Tsipouridos C.G., 2007. Effects of cultivar and rootstock on the
 420 antioxidant content and physical characters of clingstone peaches. *Sci. Hortic.* 115, 34–
 421 39.
 422 FAOSTAT, 2014. <<http://faostat.fao.org>>.
 423 Felipe, A.J., 2009. Felinem, Garnem, and Monegro almond x peach hybrid rootstocks.
 424 *HortScience* 44, 196–197.
 425 Ferrer, A., Remón, S., Negueruela, A.I., Oria, R., 2005. Changes during the ripening of
 426 the very late season Spanish peach cultivar Calanda. Feasibility of using CIELAB
 427 coordinates as maturity indices. *Sci. Hortic.* 105, 435–446.
 428 Font i Forcada, C., Gogorcena, Y., Moreno, M.A., 2012. Agronomical and fruit quality
 429 traits of two peach cultivars on peach-almond hybrid rootstocks growing on
 430 Mediterranean conditions. *Sci. Hortic.* 140, 157–163.
 431 Font i Forcada, C., Gogorcena, Y., Moreno, M.A., 2013. Fruit sugar profile and
 432 antioxidants of peach and nectarine cultivars on almond x peach hybrid rootstocks. *Sci.*
 433 *Hortic.* 164, 563–572.
 434 Font i Forcada C., Gogorcena, Y., Moreno, M.A., 2014a. Agronomical parameters,
 435 sugar profile and antioxidant compounds of “Catherine” peach cultivar influenced by
 436 different plum rootstocks. *Int. J. Mol. Sci.* 15(2), 2237–2254.

437 Font i Forcada, C., Gradziel, T.M., Gogorcena, Y., Moreno, M.A., 2014b. Phenotypic
 438 diversity among local Spanish and foreign peach and nectarine [*Prunus persica* (L.)
 439 Batsch] accessions. *Euphytica* 197, 261–277.
 440 Génard, M., Souty, M., Holmes, S., Reich, M., Breuils, L., 1994. Correlations among
 441 quality parameters of peach fruit. *J. Sci. Food. Agric.* 66, 241–245.
 442 Gil M., Tomás-Barberán, F.A., Hess-Pierce, B., Kader, A.A., 2002. Antioxidant
 443 capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach,
 444 and plum cultivars from California. *J. Agric. Food Chem.* 50 (17), 4976–4982.
 445 Giorgi, M., Capocasa, F., Scalzo, Murri, G., Battino, M., Mezzetti, B., 2005. The
 446 rootstock effects on plant adaptability, production, fruit quality, and nutrition in the
 447 peach (cv. ‘Suncrest’). *Sci. Hortic.* 107, 36–42.
 448 Iglesias, I., Echeverría, G., 2009. Differential effect of cultivar and harvest date on
 449 nectarine color, quality and consumer acceptance. *Sci. Hortic.* 120, 41–50.
 450 Jiménez, S., Pinochet, J., Romero, J., Gogorcena, Y., Moreno, M.A., Espada, J.L., 2011.
 451 Performance of peach and plum based rootstocks of different vigour on a late peach
 452 cultivar in replant and calcareous conditions. *Sci. Hortic.* 129, 58–63.
 453 Layne, R.E.C., 1994. *Prunus* rootstocks affect long-term orchard performance of
 454 ‘Redhaven’ peach on brookston clay loam. *HortScience* 29 (3), 167–171.
 455 Liverani, A., Giovannini, D., Brandi, F., 2002. Increasing fruit quality of peaches and
 456 nectarines: the main goals of ISF-FO (Italy). *Acta Hort.* 592, 507–514.
 457 Loreti, F., Massai, R., 2006. Bioagronomic evaluation of peach rootstocks by the Italian
 458 MiPAF targeted project. *Acta Hort.* 713, 295–302.
 459 Marra, F.P., Lo Bianco, M., La Mantia, L. Caruso, T., 2013. Growth, yield and fruit
 460 quality of ‘Tropic Snow’ peach on size-controlling rootstocks under dry Mediterranean
 461 climates. *Sci. Hortic.* 160, 274–282.
 462 Mestre, L., Reig, G., Betrán, J.A., Pinochet, J., Moreno, M.A., 2015. Influence of
 463 peach-almond hybrids and plum-based rootstocks on mineral nutrition and yield
 464 characteristics of ‘Big Top’ nectarine in replant and heavy-calcareous soil conditions.
 465 *Sci. Hortic.* 192, 475–481.
 466 Monet, R., Bassi, D., 2008. Classical genetics and breeding. In: Layne, D.R., Bassi, D.
 467 (Eds.). *The peach: Botany, Production and Uses*. CAB International, Wallingford (UK),
 468 pp. 61–84.
 469 Moreno, M.A., Tabuenca, M.C., Cambra, R., 1994. Performance of Adafuel and
 470 Adarcias as peach rootstocks. *HortScience* 29, 1271–1273.

Moreno, M.A., Tabuenca, M.C., Cambra, R., 1995. Adesoto 101, a plum rootstock for peaches and other stone fruits. HortScience 30, 1314–1315.

Orazem, P., Stampar, F., Hudina, M., 2011. Quality analysis of ‘Redhaven’ peach fruit grafted on 11 rootstocks of different genetic origin in replant soil. Food Chem. 124, 1691–1698.

Pinochet, J., 2010. ‘Replantpac’ (Rootpac® R), a Plum–almond hybrid rootstock for replant situations. HortScience 45, 299–301.

Rato, A.E., Agulleiro, A.C., Barroso, J.M., Riquelme, F., 2008. Soil and rootstock influence on fruit quality (*Prunus domestica* L.). Sci. Hortic. 3, 218–222.

Remorini, D., Tavarini, S., Degl’Innocenti, I., Loreti, F., Massai, R., Guidi, L., 2008. Effect of rootstock and harvesting time on the nutritional quality of peel and flesh of peach fruits. Sci. Hortic. 361–367.

Remorini, D., Fei, C., Loreti, F., Massai, R., 2015. Observations on nine peach rootstocks grown in a replant soil. Acta Hort. 1085, 131–138.

Ruíz, D., Egea, J., 2008. Phenotypic diversity and relationships of fruit quality traits in apricot (*Prunus armeniaca* L.) germplasm. Euphytica 163, 143–158.

Tomás-Barberán, F.A., Gil, M.I., Cremin, P., Waterhouse, A.L., Hess-Pierce, B., Kader, A.A., 2001. HPLC-DAD-ESIMS analysis of phenolic compounds in nectarines, peaches, and plums. J. Agric. Food Chem. 49, 4748–4760.

Zarrouk, O., Gogorcena, Y., Gómez-Aparisi, J., Betrán, J.A., Moreno, M.A., 2005. Influence of almond x peach hybrids rootstocks on flower and leaf mineral concentration, yield and vigour of two peach cultivars. Sci. Hortic. 106, 502–514.

Zhao, X., Zhang, W., Yin, X., Su, M., Sun, C., Li, X., Chen, K., 2015. Phenolic composition and antioxidant properties of different peach [*Prunus persica* (L.) Batsch] cultivars in China. Int. J. Mol. Sci 16, 5762–5778.

Table 1

ANOVA analysis of the effect of rootstock and year on agronomic and fruit quality traits in ‘Big Top’ cultivar for the average of the years of study.

Source of variation ^a	Rootstock	Year	Rootstock × Year
Trunk cross-sectional area (TCSA)	***	***	ns
Yield (Y)	***	***	ns
Cumulative yield (CY)	***	***	ns
Yield efficiency (YE)	***	**	ns
Fruit weight (FW)	**	***	*
Flesh firmness (FF)	***	***	ns
Soluble solids content (SSC)	ns	***	ns
Titrateable acidity (TA)	***	***	ns
Ripening index (RI)	**	***	ns
L*	***	***	ns
a*	**	***	*
b*	***	***	ns
C*	***	***	ns
h*	***	***	ns
Vitamin C	**	ns	ns
Total phenolics	ns	ns	ns
Anthocyanins	*	ns	ns
Relative antioxidant capacity (RAC)	*	**	ns

^a Data were evaluated by two-way variance (ANOVA); *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$; ns, not significant.

Table 2

Trunk cross-sectional area (TCSA), cumulative yield (CY) and yield efficiency (YE) of the ‘Big Top’ nectarine budded on different *Prunus* rootstocks, at the sixteenth year after budding (2014). Mean values (2009–2014) of fruit weight (FW).

Rootstock	TCSA (cm ²)	CY (kg tree ⁻¹)	YE (kg cm ⁻²)	FW (g)
Adarcias	234.4 ab	201.0 abc	0.86 bc	192.5 ab
Adesoto	180.4 a	162.2 a	0.90 bc	192.4 ab
Barrier	297.6 abc	277.9 c	0.93 bc	213.5 b
Cadaman	380.5 c	291.8 c	0.77 ab	203.6 ab
Felinem	252.4 abc	206.1 abc	0.82 abc	189.4 ab
GF 677	266.0 abc	270.3 bc	1.02 c	204.2 ab
Mayor	323.6 bc	202.0 abc	0.62 a	179.4 a
Replantpac	371.2 c	269.4 bc	0.73 ab	202.4 ab
Tetra	232.1 ab	174.6 ab	0.75 ab	200.2 ab

For each rootstock, means followed by the same letter in each column are not significantly different at $P < 0.05$ according to Duncan's Multiple Range Test.

Table 3

The effect of rootstocks and year on fruit quality attributes of the ‘Big Top’ nectarine.

Character	Rootstock	2011	2012	2013	2014	Average
FF (N)	Adarcias	44.3 bcd	55.4 ab	50.6 a	46.6 a	51.2 ab
	Adesoto	40.8 abc	56.6 ab	36.8 a	44.0 a	46.1 a
	Barrier	50.1 d	63.5 b	53.6 a	51.8 a	56.3 b
	Cadaman	45.0 cd	58.7 ab	45.6 a	47.8 a	50.7 ab
	Felinem	38.2 ab	56.4 ab	40.7 a	48.4 a	46.5 a
	GF 677	45.0 cd	57.2 ab	53.7 a	49.9 a	53.3 ab
	Mayor	37.7 a	59.3 ab	40.1 a	44.0 a	46.6 a
	Replantpac	45.7 cd	57.9 ab	46.6 a	47.8 a	51.9 ab
	Tetra	39.5 abc	53.1 a	38.6 a	41.0 a	45.8 a
SSC (° Brix)	Adarcias	11.8 ab	15.7 ab	12.4 a	11.9 a	12.9 a
	Adesoto	12.9 ab	16.8 b	14.1 a	11.3 a	13.6 a
	Barrier	10.7 a	16.1 ab	12.5 a	12.2 a	12.5 a
	Cadaman	10.8 a	14.5 a	12.1 a	11.7 a	12.3 a
	Felinem	11.9 ab	14.5 a	13.9 a	11.3 a	12.6 a
	GF 677	11.5 ab	14.8 a	11.9 a	12.0 a	12.5 a
	Mayor	14.2 b	15.0 ab	13.2 a	12.3 a	13.5 a
	Replantpac	12.3 ab	15.9 ab	12.7 a	12.0 a	12.7 a
	Tetra	12.6 ab	14.6 a	12.0 a	11.4 a	12.5 a
TA (g malic/100 g FW)	Adarcias	0.78 ab	0.58 a	0.70 a	0.58 a	0.64 a
	Adesoto	0.87 abc	0.64 ab	0.57 a	0.54 a	0.65 ab
	Barrier	1.06 bc	0.72 b	0.75 a	0.65 a	0.79 c
	Cadaman	1.13 c	0.63 ab	0.67 a	0.64 a	0.76 bc
	Felinem	0.85 abc	0.60 a	0.54 a	0.58 a	0.61 a
	GF 677	0.88 abc	0.58 a	0.65 a	0.57 a	0.67 ab
	Mayor	0.66 a	0.57 a	0.61 a	0.55 a	0.61 a
	Replantpac	0.95 abc	0.57 a	0.65 a	0.60 a	0.70 abc
	Tetra	0.80 ab	0.57 a	0.58 a	0.55 a	0.62 a
RI	Adarcias	15.4 abc	27.3 a	17.8 a	20.8 a	20.5 abc
	Adesoto	14.8 abc	26.7 a	25.6 a	21.0 a	21.9 bc
	Barrier	10.6 ab	22.7 a	16.7 a	18.9 a	16.6 a
	Cadaman	9.5 a	23.2 a	18.6 a	18.6 a	17.2 ab
	Felinem	13.3 abc	25.9 a	18.4 a	21.3 a	23.5 c
	GF 677	19.9 bc	24.7 a	27.7 a	20.3 a	19.4 abc
	Mayor	21.6 c	26.6 a	21.8 a	22.6 a	22.5 c
	Replantpac	13.0 abc	29.0 a	19.8 a	20.3 a	19.4 abc
	Tetra	16.8 abc	26.1 a	21.9 a	21.1 a	21.7 bc

For each year and trait, means followed by the same letter in each column are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Abbreviations: FF, flesh firmness; SSC, soluble solids content; RI, ripening index; TA, titratable acidity.

Table 4

Effect of rootstocks on chromatic parameters of ‘Big Top’ nectarine cultivar from the thirteenth (2011) to the sixteenth (2014) year after budding.

Character	Rootstock	2011	2012	2013	2014	Average
L*	Adarcias	36.2 abc	37.6 a	35.6 a	35.9 bcd	36.3 ab
	Adesoto	34.5 a	39.4 ab	34.8 a	36.2 bcd	36.0 a
	Barrier	39.6 c	39.7 ab	34.4 a	34.7 abc	37.6 ab
	Cadaman	37.8 abc	41.1 ab	35.1 a	35.7 abcd	37.5 ab
	Felinem	35.6 ab	38.7 a	34.0 a	34.4 ab	35.6 a
	GF 677	37.0 abc	42.8 b	36.6 a	36.6 cd	38.2 b
	Mayor	38.7 bc	40.9 ab	34.6 a	35.6 abcd	37.6 ab
	Replantpac	37.7 abc	39.2 ab	36.4 a	37.3 d	37.5 ab
	Tetra	36.4 abc	38.0 a	33.9 a	33.9 a	35.7 a
a*	Adarcias	33.5 ab	33.7 ab	32.5 bc	35.5 a	33.8 ab
	Adesoto	32.3 a	33.1 a	27.1 a	35.7 a	32.2 a
	Barrier	34.0 ab	33.3 a	31.4 bc	33.7 a	33.3 ab
	Cadaman	34.3 ab	33.5 a	32.5 bc	34.4 a	33.8 ab
	Felinem	34.8 b	34.9 ab	30.6 ab	33.2 a	33.7 ab
	GF 677	33.5 ab	34.2 ab	34.8 c	34.5 a	34.1 b
	Mayor	35.2 b	35.6 b	33.0 bc	34.4 a	34.6 b
	Replantpac	34.2 ab	34.5 ab	33.7 bc	35.0 a	34.4 b
	Tetra	33.3 ab	34.1 ab	30.4 ab	34.1 a	33.0 ab
b*	Adarcias	15.2 abc	15.6 a	14.2 a	14.9 abc	15.0 ab
	Adesoto	12.8 a	17.8 ab	12.5 a	15.0 abc	14.2 a
	Barrier	19.1 c	18.6 abc	12.9 a	13.6 ab	16.6 abc
	Cadaman	17.2 abc	20.2 abc	13.8 a	14.3 abc	16.5 abc
	Felinem	17.9 bc	22.5 c	16.4 a	13.1 a	14.2 a
	GF 677	14.2 ab	17.7 ab	11.9 a	15.8 bc	17.7 c
	Mayor	18.0 bc	20.5 bc	11.9 a	14.6 abc	17.1 bc
	Replantpac	17.6 bc	18.4 abc	11.9 a	16.6 c	16.9 bc
	Tetra	15.3 abc	16.5 ab	11.9 a	12.5 a	14.2 a
C*	Adarcias	37.1 ab	37.4 a	36.0 bcd	38.6 a	37.2 abc
	Adesoto	34.8 a	36.9 a	30.7 a	38.9 a	35.5 a
	Barrier	39.3 b	38.6 ab	34.2 abc	36.5 a	37.6 abc
	Cadaman	38.7 b	39.5 ab	36.0 bcd	37.4 a	38.0 bc
	Felinem	38.5 b	41.4 b	38.8 d	38.3 a	36.8 abc
	GF 677	37.7 ab	39.5 ab	33.2 abc	36.4 a	38.9 c
	Mayor	39.9 b	41.4 b	36.0 bcd	37.5 a	39.0 c
	Replantpac	38.9 b	39.6 ab	37.6 cd	39.1 a	38.7 c
	Tetra	37.0 ab	38.1 ab	32.7 ab	36.4 a	36.2 ab
h	Adarcias	23.9 abc	24.3 a	22.3 a	22.2 abc	23.3 abc
	Adesoto	21.1 a	28.8 abc	23.2 a	22.4 abc	23.2 ab
	Barrier	28.9 c	28.4 abc	21.4 a	21.4 abc	25.8 bc
	Cadaman	26.1 abc	30.6 bc	21.9 a	22.1 abc	25.4 bc
	Felinem	27.3 bc	32.7 c	23.7 a	23.9 bc	21.3 a
	GF 677	21.7 ab	26.2 ab	16.2 a	21.7 abc	26.5 cd
	Mayor	26.3 abc	29.4 abc	21.1 a	22.4 abc	25.4 bc
	Replantpac	26.7 abc	27.6 abc	23.8 a	24.7 c	25.5 bc
	Tetra	23.9 abc	25.2 ab	19.7 a	19.8 abc	22.5 ab

For each year and trait, means followed by the same letter in each column are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Abbreviations: a*, greenness/redness; b*, blueness/yellowness; C*, chroma; h, lightness' angle; L*, lightness.

Table 5

Effect of rootstock on phenolics, anthocyanins, vitamin C and antioxidant capacity (RAC) of ‘BigTop’.

Character	Rootstock	2011	2012	Average
Vitamin C (mg AsA/100 g FW)	Adarcias	5.1 ab	10.9 c	8.0 b
	Adesoto	9.4 b	6.5 ab	8.0 b
	Barrier	5.3 ab	6.0 ab	5.7 ab
	Cadaman	6.8 b	5.4 ab	6.1 b
	Felinem	7.0 b	5.2 ab	6.1 ab
	GF 677	6.9 b	7.3 bc	7.1 b
	Mayor	5.8 ab	6.6 ab	6.2 ab
	Replantpac	5.4 ab	8.3 bc	6.9 b
	Tetra	2.3 a	2.7 a	2.5 a
Total phenolics content (mg GAE/100 g FW)	Adarcias	8.9 a	10.7 a	9.7 a
	Adesoto	12.1 ab	13.5 a	12.5 a
	Barrier	8.4 a	9.2 a	8.7 a
	Cadaman	8.6 a	8.8 a	8.7 a
	Felinem	17.1 b	12.8 a	15.4 a
	GF 677	8.9 a	11.3 a	10.1 a
	Mayor	12.6 ab	9.3 a	11.7 a
	Replantpac	9.9 a	11.9 a	10.8 a
	Tetra	8.7 a	11.4 a	9.6 a
Anthocyanins (mg C3GE/kg FW)	Adarcias	0.58 a	0.76 ab	0.67 ab
	Adesoto	0.84 ab	1.25 c	1.04 ab
	Barrier	0.60 a	0.46 a	0.53 a
	Cadaman	0.80 ab	0.42 a	0.61 ab
	Felinem	1.06 ab	0.94 bc	1.00 ab
	GF 677	1.29 b	0.69 ab	1.44 b
	Mayor	1.02 ab	0.81 abc	0.92 ab
	Replantpac	0.61 a	0.83 abc	0.73 ab
	Tetra	0.87 ab	0.93 bc	0.90 ab
Relative antioxidant capacity (µg Trolox/g FW)	Adarcias	322.2 a	338.4 a	330.3 a
	Adesoto	326.9 a	344.3 a	335.6 ab
	Barrier	361.1 a	358.6 a	359.9 b
	Cadaman	320.8 a	349.9 a	335.4 ab
	Felinem	316.1 a	346.6 a	331.3 ab
	GF 677	359.3 a	342.4 a	350.8 ab
	Mayor	337.9 a	353.6 a	345.8 ab
	Replantpac	332.3 a	351.4 a	339.9 ab
	Tetra	337.7 a	345.9 a	341.8 ab

For each trait, means followed by the same letter in each column are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test.

Abbreviations: AsA, acid ascorbic; C3GE, cyaniding 3-glucoside equivalents; FW, fresh weight; GAE, gallic acid equivalents.

Figure 1. Principal component analysis for agronomic, fruit quality and leaf traits evaluated on different *Prunus* rootstocks budded with ‘Big Top’ nectarine cultivar.

Abbreviations: a*, greenness/redness; AFW, average fruit weight; ANTHOC, anthocyanins content; AY, average yield; b*, blueness/yellowness; C*, chroma; Cu, copper; CY, cumulative yield; DOP, deviation from optimum percentage index; FF, flesh firmness; Fe, iron; FW, fruit weight; h, lightness’ angle; K, potassium; L*, lightness; Na, sodium; Mg, magnesium; Mn, manganese; N, nitrogen; P, phosphorus; RAC, relative antioxidant capacity content; SCK, root and crown suckering; TPC, total phenols content; TCSA, trunk cross sectional area; Vit. C, vitamin C content; YE, yield efficiency; Zn, zinc.

Data (leaf mineral elements) from this table were partially presented in Mestre et al. (2015).