Leaf mineral nutrition and tree vigor of 'Subirana' flat peach cultivar grafted on different *Prunus* rootstocks in a warm Mediterranean area

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ABSTRACT

Recent trends in peach orchards have focused on intensification and high density plantings using different *Prunus* rootstock genotypes with different vigor traits. This investigation aims to study the physiological behavior of different *Prunus* rootstocks in order to identify the most suitable rootstock under warm Mediterranean conditions. Field agronomic performance and foliar nutrient content of the flat peach cultivar 'Subirana' grafted on ten different *Prunus* rootstocks were studied on a heavy-textured and calcareous soil typical of the Mediterranean area during three successive years. Ten rootstocks: 'Garnem', 'PADAC 150', 'ADAGAF 04-03', 'PADAC 04-01', 'Rootpac® 70', 'PM 105 AD', 'AGAF 0301-04', 'Krymsk® 1', 'Krymsk® 86' and 'PAC 847', were considered. During the three monitoring years, vegetative growth, chlorophyll SPAD index, and leaf mineral status were determined. For mineral analysis, N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu and B were considered and the deviation from the optimum percentage (DOP) index was estimated for the diagnosis of the nutritional status of peach trees. Leaf chlorophyll content varied depending on the rootstock. 'PADAC 04-01' and 'ADAGAF 04-03' showed higher chlorophyll index. The lowest SPAD values were observed for the most dwarfing rootstock 'Krymsk® 1', which showed visual chlorosis symptoms, and lower leaf mineral contents compared to the other rootstocks, probably due to the bad adaptation to the heavy soil and warm conditions. Peach trees on *Prunus* rootstocks showed differences in leaf macronutrient and micronutrient content. Most of macronutrients ranged between deficient and optimum levels. All tested rootstocks induced a deficient N content and some of them also showed P and K deficiency. Better mineral situation was observed for some leaf macro and micronutrients contents, which fitted the optimum levels for Ca, Mg, Fe, Zn and B. The DOP index

ranged between -260 and -97 for 'Garnem' and 'Rootpac® 70', respectively. The most dwarfing rootstock 'Krymsk® 1' had a DOP value of -139, with less intensity of imbalances than the most invigorating one. 'Rootpac® 70', 'ADAGAF 04-03' and 'PADAC 04-01' had better adaptation under warm Tunisian conditions but high Σ DOP index. The most invigorating 'Garnem' had the highest imbalanced nutritional status, but continues to perform well under warm conditions. Interesting results were obtained with 'Rootpac® 70' showing one of the best balanced nutritional values (average Σ DOP index). However, the most dwarfing rootstock 'Krymsk® 1' presented the worst adaptation to the studied warm Mediterranean conditions, despite its low DOP value.

Keywords: Tree vigor; chlorophyll index; foliar mineral analysis; DOP

Abbreviation: TCSA: trunk cross sectional area; DOP: deviation from optimum percentage.

Introduction

Peach [*Prunus persica* (L.) Batsch] is the most important temperate and deciduous fruit tree grown in the world after apple. The viability of a peach orchard is linked to a proper cultivar and rootstock selection for a specific climate and soil conditions (Reig et al. 2018). During the last decade, a significant change has taken place in terms of the distribution of fruit type. Nectarine is now the most important fruit type, followed by melting peaches and non-melting peaches. An increase in flat peach production has been also accounted (Iglesias, Carbó and Bonany 2009), which is highly appreciated by consumers for its particular shape and taste. These fruit type productions were ensured by wide range of rootstocks. The rootstock choice represents one of the most important decisions for a productive peach orchard (Jiménez et al. 2011).

Several rootstocks possessing diverse horticultural traits for stone fruit crops are being developed by different programs (Felipe et al. 1997; Loreti and Massai 2002; Beckman and Lang 2002). Rootstocks provide a technical tool for peach growers to increase productivity and improve efficiency via better tree survival, controlled tree vigor and increased fruit size, yield and quality (López-Ortega et al. 2016). Thus, the choice of rootstock becomes as economically important as the scion cultivar whenever peach trees must be grown on soils having high bulk density, coarse texture (sand), parasitic nematodes, root rot fungal pathogens, high pH or other orchard replant problems (Reighard and Loreti 2008). Peach-almond hybrids (*P. amygdalus* × *P. persica*) are largely used as rootstocks for peach trees in the Mediterranean countries. They are tolerant to lime induced iron-chlorosis and alkaline soils. They are also graft-compatible with peach and almond cultivars (Zarrouk et al. 2005).

In recent years, new selections of peach-almond hybrids rootstocks have also been developed with resistance to biotic stresses, such as root-knot nematodes (*Meloidogyne spp.*) (Pinochet 2009). Similarly, several plum rootstocks have also been released to be used for different stone fruit species (Moreno, Tabuenca and Cambra 1995). They adapt well to highly calcareous and heavy-textured soils, being tolerant to root asphyxia and iron chlorosis and resistant to root-knot nematodes. Dwarfing rootstocks for peaches are being also selected for reduced vigor, graft compatibility and sustained fruit production without reductions in fruit size and quality (Reighard and Loreti 2008). The adoption of high-density planting system in fruit tree orchards may only be possible through the use of less vigor or dwarfing rootstocks, combined with new cultivars to achieve a high and early yield. However, peach seedling and other *Prunus* species rootstocks have not been achieved satisfactorily owing to incompatibility, poor tree vigor or adaptation issues as under warm conditions (Ben Yahmed, Ghrab and Ben Mimoun 2016).

Previous studies with *Prunus* spp. have demonstrated the rootstock influence on fruit quality, tree vigor, yield efficiency, water relations, leaf gas exchange, plant size, bloom, harvest dates and fruit bud survival (Zarrouk et al. 2005; Font i Forcada, Gogorcena and Moreno 2014; Ben Yahmed et al. 2016). The rootstock also influences the mineral nutrient uptake as well as it affects the mineral contents in leaves of the cultivar (Zarrouk et al. 2005; Mestre et al. 2015). Selection of an appropriate graft combination seems to be crucial for the production of deciduous orchard species because the scion-rootstock interaction also influences water relations, leaf gas exchange, and plant size (Gonçalves et al. 2003). Different hypothesis have been suggested to explain the rootstock effects. Tree development, yield and fruit quality may be influenced by the rootstock of a deciduous fruit tree via

nutrient supply/water relations and hormonal balance (Solari and DeJong 2006; Sorce et al. 2002; Solari, Pernice and DeJong 2006).

The investigation of mineral status of fruit trees in relationship with scion-rootstock combinations has been scarce with few studies focusing on the mineral status of trees on *Prunus* rootstocks (Moreno et al. 1996; Rosati, DeJong and Southwick 1997) and even less for flat peaches grown under a warm climate. Under a warm climate, the agronomic performance of ten *Prunus* rootstocks grafted with the flat peach cultivar 'Subirana' was evaluated on heavy and calcareous soil conditions typical of the Mediterranean area (Ben Mimoun et al. 2013; Ben Yahmed et al. 2016). Thus, the present study investigated the nutritional status of ten scion-rootstock combinations. The objective was to look for the best rootstock with the smallest tree vigor and optimum nutritional status under warm Mediterranean conditions and high density orchards.

Material and methods

Experimental trial

This study was carried out in an experimental orchard situated in the region of Mornag (36° 41'N, 10° 15'E), the main fruit tree production area in northern Tunisia. Ten *Prunus* rootstocks were assessed: 'PADAC 150' (*P. insititia*), 'ADAGAF 04-03' [*P. cerasifera* x (*P. persica* x *P. dulcis*)] previously mentioned as PADAC 04-03 (Ben Yahmed et al. 2016), 'PADAC 04-01' [*P. cerasifera* x (*P. persica* x *P. dulcis*)], 'Rootpac® 70' [(*P. persica* x *P. davidiana*) x (*P. dulcis* x *P. persica*)], 'PAC 847' (*P. cerasifera* x *P. dulcis*), 'Krymsk® 86' (*P. cerasifera* x *P. persica*), 'Krymsk® 1' (*P. tomentosa* x *P. cerasifera*), 'AGAF 0301-04' (*P. cerasifera* x *P. persica*), 'PM 105 AD' (*P. insititia*) and 'Garnem' (*P. persica* x *P. dulcis*). Trees were planted at 2x6 m

spacing and budded with a flat peach cultivar 'Subirana' in 2007. Initially, ten replications (trees) were used for each rootstock. The trial was established in 2008. Trees were drip irrigated on a loamy-clay soil (21.2% loam, 37.4% clay, 41.4% silt) having a pH of 8.4, EC of 411 $\mu\text{S cm}^{-1}$, and 34.1% of CaCO_3 (see description in Table 1). The experimental orchard was subjected to standard cultural practices for production. The production area is characterized by a warm Mediterranean climate with average annual rain-fall and ETo of 450 and 1240 mm, respectively, and frequent warm winter each 3-4 years (Ghrab et al. 2014a).

Table 1

Growth parameter

Trunk girths were measured during the dormant season at 20 cm above the graft union and the trunk cross-sectional area (TCSA) was determined.

Chlorophyll index (SPAD)

The chlorophyll (Chl) content per unit leaf area measured as SPAD units was estimated in the field, using a SPAD 502 meter (Minolta Co., Osaka, Japan) as described in other *Prunus* rootstocks studies (Jiménez et al. 2007; Mestre et al. 2015; Mestre et al. 2017; Reig et al. 2018). Measurements were carried out 120 days after full bloom (DAFB) on thirty leaves per tree, from extension shoots located all around the crown during three successive years (2012, 2013 and 2014).

Leaf mineral analysis

Leaf mineral contents were determined on three trees per rootstock during three successive years (2012-2014). Samples were obtained and analyzed at 120 DAFB

each year. Leaf samples were collected from extension shoots around the crown of trees. The mineral composition of the dried leaf tissue of the three trees was measured using the methods of C.I.I, Pinta and DeWaele (1975). Total nitrogen (N) was determined by Kjeldahl analysis (Gerhardt Vapodest); phosphorus (P) was analyzed spectrophotometrically by the phospho-vanadate colorimetric method (Hewlett Packard 8452A); potassium (K) by atomic emission spectroscopy; and calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), sodium (Na) and zinc (Zn) by atomic absorption spectroscopy (Perkin-Elmer 1100).

Deviation from optimum percentage (DOP)

The DOP index was estimated for the diagnosis of the nutritional status of trees (Montañés et al. 1993). This index provides similar information to the Diagnosis and Recommendation Integrated System (DRIS) (Sanz 1999). The DOP index was calculated from leaf analysis at 120 DAFB by the following mathematical expression:

$$DOP = \frac{C \times 100}{C_{ref}} - 100$$

Where C is the nutrient content in the sample to be studied, and C_{ref} is the nutrient content considered as optimum, both values given on a dry matter basis. The C_{ref} has been taken from optimum values proposed by Leece, Cradock and Carter (1971).

The ΣDOP is obtained by adding the values of DOP indices irrespective of sign. The larger was the ΣDOP , the greater was the intensity of imbalances among nutrients.

Data analysis

For statistical analysis, the software Statgraphics for Windows was used (version 4.1; Microsoft Corp., Redmond, WA, USA). The data were expressed as means. An

ANOVA was used to detect differences between averages. When F values were significant, means were separated by Duncan's multiple range ($p \leq 0.05$).

Principal components analysis (PCA) was performed using the collected data (TCSA, SPAD, DOP) in addition to previous published data on yield and fruit quality (Ben Yahmed et al. 2016).

Results

Vigor characteristics

Tree growth, as measured by TCSA, was significantly affected by rootstocks (Table 2). 'Garnem' showed the highest values of TCSA (213.9 cm²) over the three years of measurements, followed by 'Rootpac® 70' (167.3 cm²), 'ADAGAF 04-03', 'AGAF 0301-04' and 'PADAC 150', while the lowest value was noted for 'Krymsk® 1' (23.7 cm²). The other rootstocks induced intermediate tree vigor.

Table 2

Leaf chlorophyll index

The chlorophyll index (SPAD) presented high inter and intra annual variations (Table 3). Over the three-years, 'Subirana' grafted on 'Krymsk® 1' was significantly different from trees on the other rootstocks. Trees budded on the most dwarfing rootstock 'Krymsk® 1' showed the lowest SPAD with a decreasing tendency over the three years. On average, SPAD values ranged between 35.3 and 43.7 for 'Subirana' grafted on 'Krymsk® 1' and 'ADAGAF 04-03', respectively. The lowest (32.4) and the highest (46.7) SPAD values were obtained in 2014 for 'Krymsk® 1' and 'PADAC 150', respectively (Table 2). Furthermore, the medium vigor rootstock 'ADAGAF 04-03' induced increasing SPAD values of grafted trees with the highest SPAD value in

average. 'Garnem' and 'Rootpac® 70', inducing the highest tree vigor, performed high SPAD values (>41 units).

Table 3

Leaf mineral content and DOP

Foliar analysis of the flat peach trees revealed high variation of nutritional mineral status among *Prunus* rootstocks (Table 4). Most of macro mineral elements were ranged between deficient and optimum levels (Leece, Cradock and Carter 1971). Leaf macronutrients contents of trees budded on *Prunus* rootstocks were in the range of 2.21-2.75, 0.13-0.15, and 1.63-2.12% for N, P and K, respectively. All tested rootstocks induced a deficient N content and some of them P and K deficiency in comparison to optimum levels. Better mineral situation was observed for some leaf macro and micronutrients contents, which fit the optimum levels for Ca, Mg, Fe, Zn and B. Excessive levels of Cu ($\geq 20 \text{ mg kg}^{-1}$) were observed for all rootstocks except for 'Garnem'. Some rootstocks induced excessive Na contents while Mn deficiency was also found in other cases.

The vigorous rootstock 'Garnem' induced N, P, Na, Mn and Cu deficiency, whereas 'Rootpac® 70' performed a better nutritional status with only N, K and Cu deficiency. Trees on the less vigorous rootstock 'Krymsk® 1' showed N, P, K, Mn and Cu deficiencies. The lowest leaf N content was noted for 'Krymsk® 1' with visual deficiency symptoms. Five rootstocks ('ADAGAF 04-03', 'Rootpac® 70' and 'AGAF 0301-04', 'PADAC 04-01', 'Rootpac® 70' and 'PAC 847') induced normal leaf P levels. All rootstocks showed low leaf K contents, with the exception of 'AGAF 0301-04', 'Garnem' and 'AGAF 0301-04' which presented normal leaf K values. Regarding the DOP index, high variation was observed for 'Subirana' trees on the assessed *Prunus* rootstocks. However, no significant differences were observed

between rootstocks. This index ranged between -260 and -97 for ‘Garnem’ and ‘Rootpac® 70’, respectively. In spite of the negative values in absolute terms, trees on ‘Rootpac® 70’ seems to be more nutritional balanced than those on the other rootstocks. The vigorous rootstock ‘Garnem’ showed the highest intensity of imbalances among nutrients with higher average Σ DOP values. The most dwarfing rootstock ‘Krymsk® 1’ had a DOP value of -139, with less intensity of imbalances than the invigorating one.

Table 4

Principal component analysis

A principal component analysis (PCA) was used to determine the relative importance of the different physiological parameters and the variability within the studied *Prunus* rootstocks grown on a calcareous soil and warm Mediterranean conditions. PCA was performed using the collected data (TCSA, SPAD and DOP) in addition to previous published data on tree vigor (canopy and root volumes) yield and fruit quality (Ben Yahmed et al. 2016). Data analysis revealed two main components (PCs) explaining 68.7% of the variability observed between the studied rootstocks (Figure 1). Two distinct groups were visualized and differentiated by parameters related to tree vigor (TCSA, canopy and root volumes), yield and fruit characteristics (weight and diameter of fruits, cumulative yield) and leaf characteristics (SPAD) on one hand, and rate of tree mortality, buds abscission and ripening index and DOP index on other hand (Figure 1). The invigorating rootstocks ‘Garnem’, ‘Rootpac® 70’, ‘ADAGAF 04-03’ and ‘PADAC 04-01’ formed the first group (Figure 1). Within this group, two subgroups were also identified according to tree vigor, chlorophyll index and fruit quality traits. ‘Garnem’ formed alone a subgroup of the most vigorous rootstocks with different fruit quality traits and highest TCSA. The second subgroup included

‘Rootpac® 70’, ‘PADAC 04-01’ and ‘ADAGAF 04-03’, with higher chlorophyll index and better fruit quality. For the second group, the most dwarfing rootstock ‘Krymsk® 1’ presented a separate subgroup with lowest SPAD values, and showing leaf yellowing, a reduction of growth, and premature defoliation. ‘Krymsk® 86’, ‘AGAF 0301-04’, ‘PAC 847’, ‘PM 105 AD’ and ‘PADAC 150’ formed the second subgroup with different DOP index and fruit quality traits.

Figure 1

Discussion

Recent trends in fruit tree orchards focusing on intensification, high-density plantings and mechanization were accompanied by selection programs of rootstocks that promote reduced or moderate tree vigor (Connor et al. 2014). Our work focused on evaluation of ten *Prunus* rootstocks for further selection of potential candidates to be used under warm areas. It revealed that the tested rootstocks induced contrasting tree vigor and leaf chlorophyll content (SPAD). Among the ten rootstocks, ‘Garnem’ and ‘Krymsk® 1’ were the most and least vigorous rootstocks, respectively. The less vigorous ‘Krymsk® 1’ induced a reduction of 90% in TCSA compared to ‘Garnem’ and had the lowest root and canopy volumes as previously reported under warm conditions (Ben Yahmed et al. 2016). In the Mediterranean area, the poor tree growth induced by ‘Krymsk® 1’ was also reported (Zarrouk et al. 2006; Jiménez et al. 2011). Rootstocks affected the leaf chlorophyll content based on the SPAD readings. The most dwarfing rootstock ‘Krymsk® 1’ performed the lowest SPAD values, showing visual leaf yellowness, especially when compared with more vigorous rootstocks. Similar visual symptoms were observed on almond trees grafted on the dwarfing rootstock ‘Rootpac® 20’ in the same area (Ben Yahmed, Ghrab and Ben Mimoun

2016). SPAD readings were used as an indicator of iron chlorosis in fruit trees (Jiménez et al. 2008; El-Jendoubi et al. 2012). In our investigation, SPAD values were within the standards reported in heavy-calcareous soils (Zarrouk et al. 2005; Jiménez et al. 2011; Mestre et al. 2015) for the *Prunus* rootstocks. Zarrouk et al. (2006) reported that low SPAD values may be associated with the blockage of carbohydrate assimilates and nitrogen uptake in scion leaves. These observed anomalies associated to less vigorous and dwarfing rootstocks could be explained by adaptation problems to warm climatic conditions or scion-rootstock incompatibility. In a similar warm area, the most dwarfing rootstock 'Rootpac® 20' suffered from inadequate chilling, resulting in bad adaptation (Ben Yahmed, Ghrab and Ben Mimoun 2016). Ghrab et al. (2014b) found that the rootstock could have an impact in reducing the effect of warm winter on flowering and fruiting of peach and that trees grafted on the less vigorous one were more affected.

The scion-rootstock interaction was reported to be also governed by nutritional status. Peach trees on different *Prunus* rootstocks showed differences in leaf content of macronutrients and micronutrients. Leaf N values were slightly lower than the optimum for all rootstocks, explained mainly by the type of soil (calcareous), as documented in previous studies for similar soil conditions (Mestre et al. 2017; Mestre et al. 2015; El-Jendoubi et al. 2012). Differences in leaf major nutrients between rootstocks are likewise attributable to the inherent capacity of the rootstock to absorb nutrients (Meland 2010; Mestre et al. 2015; Mestre et al. 2017).

Trees grafted on the most dwarfing rootstock 'Krymsk® 1' showed leaf N, P and K deficiency. The interaction between N and K is well known in crop growth due to potassium effects on nitrate absorption and reduction from the soil solution (Reig et al. 2018). The same effect on leaf mineral content was also induced by less

305 invigorating rootstocks for peach (Zarrouk et al. 2005), cherry (Moreno et al. 2001;
306 Jiménez et al. 2004), apricot (Rosati, DeJong and Southwick 1997) . It was
307 concluded that dwarfing rootstocks could be less efficient in the absorption of some
308 nutrients from the soil. The reduction of nutrient uptake capacity in rootstock could be
309 associated to their reduced root volume (Ben Yahmed et al. 2016) as previously
310 reported for apple dwarfing rootstocks (Webster 2004). Their smaller root system and
311 the graft union with twisted xylem vessels that act as filters could influence the
312 balance of different solutes reaching the scion cultivar. Differences were not
313 observed among rootstocks for leaf P content and values were close to sufficiency.
314 Mineral analysis showed leaf K deficiency levels for most rootstocks compared to
315 norms (Leece, Cradock and Carter 1971) except for 'Garnem', 'PADAC 04-01' and
316 'AGAF 0301-04'. Lower leaf K content was associated with heavier cropping
317 rootstocks for cherry (Nielsen and Kappel 1996) and apple trees (Fallahi et al. 1984),
318 as more K is required by growing fruits. However, in our case, 'AGAF 0403-01' and
319 'Garnem' showed higher cumulative yield (Ben Yahmed et al. 2016) and sufficiency
320 levels of leaf K as compared to the other rootstocks. Ca contents were in the
321 optimum range for *Prunus* rootstocks (Leece, Cradock and Carter 1971) except for
322 'AGAF 0403-01' where value was close to sufficiency. Previous studies indicate that
323 a better rootstock performance could be due to a more favorable nutritional status
324 (Moreno et al. 1996; Jiménez et al. 2007), a factor that has a positive effect on yield
325 and fruit quality (Jiménez et al. 2007; Cantín et al. 2010). In the last case, a higher
326 content for that macro element (Ca) was associated with lower yield and agronomic
327 performance of cherry trees (Moreno et al. 2001). Both rootstock and crop load can
328 alter leaf mineral contents of the budded scion (Obreza and Morgan 2008).

Magnesium content was within the sufficiency levels (Leece, Cradock and Carter 1971) for all *Prunus* rootstocks, which showed also adequate or slightly higher Na content as previously reported in peaches (Zarrouk et al. 2005). Leaf Fe, Zn and B micronutrients were in the optimum range (Leece, Cradock and Carter 1971) and not significantly affected by the rootstock species in contrast to other studies (Mestre et al. 2015). However, significant differences among rootstocks were observed for leaf Mn, with deficient contents showed for 'Garnem', PADAC 04-01', 'PM 105 AD', 'AGAF 0301-04', 'PAC 847' and 'Krymsk® 1'. Mn deficiency was also reported for peach and cherry trees growing in compact and calcareous soils (Moreno et al. 2001; Jiménez et al. 2004; Zarrouk et al. 2005) probably due to its insolubilization in this type of soil. El-Jendoubi et al. (2012) reported higher leaf Mn variation for peach (10-112) with an average value of 39.8, which was in the range of the normal levels (Leece, Cradock and Carter 1971). Furthermore, increased Ca in the soil or an excess of phosphoric acid fertilization might decrease or block Mn uptake (Johnson and Uriu 1989). Measurements of iron contents showed optimum levels for all rootstocks. Jiménez et al. (2008) observed that the most tolerant rootstocks to iron-chlorosis in the orchard trial were the peach-almond hybrids (*P. dulcis* x *P. persica*). However, plum based rootstocks did also appear to be more tolerant to iron-chlorosis than other peach-based rootstocks as *P. persica* x *P. davidiana* (Mestre et al. 2015). Considering that Fe chlorosis is usual in peach trees in our growing conditions, the use of almond-peach hybrids as tolerant to chlorosis might explain the absence of such disorder in the present study.

According to the average Σ DOP index, invigorating rootstocks 'Garnem' and 'PADAC 150' showed the tendency to have a wider imbalance in nutritional values based on the highest average values. Leaf mineral analyses showed that the nutrient status of

354 'Rootpac® 70' was closer to the optimum, according to the Σ DOP index and
355 reference values for peach trees reported by (Leece, Cradock and Carter (1971)).
356 However, the obtained DOP value did not really reflect the behavior of the rootstocks.
357 'Rootpac® 70', 'ADAGAF 04-03' and 'PADAC 04-01' had better adaptation under
358 warm Tunisian conditions but high Σ DOP index. However, rootstocks like 'Krymsk®
359 1', despite their low DOP value, it showed chlorosis symptoms as well as leaf drop
360 and seem stunted due to bad adaptation to Mediterranean conditions.

361 Multivariate analysis through the PCA model showed a general overview of the
362 different measured parameters in order to identify the best adapted rootstocks to the
363 soil and warm conditions. Two major groups were identified, with the first group
364 composed of 'Garnem', 'PADAC 04-01', 'ADAGAF 04-03' and 'Rootpac® 70' and the
365 rest of the rootstocks formed the second one. Within the first group, well adapted to
366 Tunisian conditions, 'Garnem' formed a separate subgroup due to the high TCSA and
367 cumulative yield. Similarly, the dwarfing rootstock 'Krymsk® 1' formed a separate
368 subgroup with low vigor, high buds falling and tree mortality.

369 In conclusion, the aim of our work was to look for rootstocks with contrasting vigor,
370 good adaptation and balanced nutritional values under warm Mediterranean
371 conditions. Our results showed that rootstocks with intermediate and high vigor are
372 better adapted to these warm conditions and show a better agronomic performance.

373 The vigorous rootstock 'Garmen' performed well in heavy-calcareous soil and warm
374 conditions. However, it induced the most unbalanced nutritional value (Σ DOP index).

375 The flat peach cultivar expressed a medium vigor and variable nutritional status
376 based on Σ DOP index on 'Krymsk® 86', 'AGAF 0301-04', 'ADAGAF 04-03', 'PAC
377 847', 'PM 105 AD' and 'PADAC 150' rootstocks. 'Rootpac® 70' presented the
378 tendency to show the most balanced nutrient status in contrast to 'PADAC 150' and

‘Garnem’. Our results showed also that the use of the most dwarfing rootstock ‘Krymsk® 1’ in heavy and calcareous soils induced significant vigor reduction, an inadequate uptake of mineral nutrients, a lower chlorophyll index and chlorosis symptoms, while it presented low DOP value. Consequently, it seems that is not well adapted to warm conditions and consequently not recommended for commercial intensive orchards. In contrast, Rootpac® 70 seems to be one of the most suitable rootstocks for the warm Tunisian conditions.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Tables captions

Table 1. Soil analysis description.

Table 2. Effect of rootstock on trunk cross-sectional area (TCSA) (cm²) of 'Subirana' flat peach cultivar in the fifth (2012), sixth (2013) and seventh (2014) year after budding.

Table 3. Effect of rootstock on leaf chlorophyll content measured as SPAD values of 'Subirana' flat peach cultivar from the fifth year (2012) to the seventh year (2014) after budding.

Table 4. Rootstock effects on leaf mineral element contents of 'Subirana' flat peach cultivar at 120 days after full bloom and seventh (2014) year after budding.

Figures captions

Figure 1. Principal component analysis (PCA) representing the diversity of the ten *Prunus* rootstocks, plotted with the contribution of each parameter on the two PCA axes and all the physiological parameters measured over the experimental period.

Abbreviation: TCSA, trunk cross sectional area; DOP, deviation from optimum percentage.

Table 1: Effect of rootstock on trunk cross-sectional area (TCSA) (cm²) of ‘Subirana’ flat peach cultivar from 2012 to 2014.

Rootstock	2012	2013	2014
Garmen	121.1 ^a	184.3 ^a	213.9 ^a
PADAC 150	95.5 ^b	103.7 ^e	106.8 ^{de}
ADAGAF 04-03	115.1 ^a	123.6 ^c	135.5 ^c
PADAC 04-01	82.9 ^{cd}	94.2 ^f	105.0 ^e
Rootpac® 70	98.7 ^b	135.0 ^b	167.3 ^b
PM 105 AD	63.0 ^{de}	72.1 ^h	76.4 ^{gh}
AGAF 0301-04	79.5 ^d	111.0 ^d	114.1 ^d
Krymsk® 1	18.5 ^f	20.3 ⁱ	23.7 ⁱ
Krymsk® 86	76.8 ^d	86.0 ^g	90.1 ^{fg}
PAC 847	70.1 ^{de}	88.6 ^g	96.7 ^{ef}

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 2: Effect of rootstock on leaf chlorophyll content measured as SPAD values of ‘Subirana’ flat peach cultivar from the fifth year (2012) to the seventh year (2014) after budding.

Rootstock	2012	2013	2014	Average 2012-14
Garmen	40.5 ^{bc}	43.1 ^{ab}	43.1 ^{cde}	42.2 ^a
PADAC 150	39.9 ^c	43.5 ^a	46.7 ^a	43.4 ^a
ADAGAF 04-03	40.9 ^{ab}	43.6 ^a	46.6 ^a	43.7 ^a
PADAC 04-01	40.6 ^{bc}	40.6 ^c	46.3 ^a	42.5 ^a
Rootpac® 70	41.2 ^a	43.1 ^{ab}	45.3 ^{abc}	43.2 ^a
PM 105 AD	41.1 ^a	42.4 ^{abc}	41.0 ^e	41.5 ^a
AGAF 0301-04	40.8 ^{ab}	43.3 ^{ab}	42.6 ^{de}	42.2 ^a
Krymsk® 1	38.5 ^d	35.0 ^d	32.4 ^f	35.3 ^b
Krymsk® 86	40.5 ^{bc}	42.3 ^{abc}	46.1 ^{ab}	43.0 ^a
PAC 847	40.8 ^{ab}	43.5 ^a	43.6 ^{bcd}	42.6 ^a

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. Rootstocks effects on leaf mineral contents of the 'Subirana' flat peach cultivar at 120 DAFB.

	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	B	ΣDOP
Garmen	2.53 ^a	0.13 ^a	2.10 ^a	2.05 ^a	0.55 ^{ab}	0.03 ^a	121.0 ^a	37.6 ^{abc}	26.8 ^a	11.2 ^a	31.7 ^a	-260 ^a
PADAC 150	2.57 ^a	0.13 ^a	1.73 ^a	1.92 ^a	0.41 ^b	0.03 ^a	143.9 ^a	48.8 ^a	29.1 ^a	20.2 ^a	27.2 ^a	-228 ^a
ADAGAF 04-03	2.63 ^a	0.15 ^a	1.63 ^a	2.34 ^a	0.49 ^{ab}	0.02 ^a	142.4 ^a	50.1 ^a	35.3 ^a	21.4 ^a	33.5 ^a	-146 ^a
PADAC 04-01	2.75 ^a	0.14 ^a	2.12 ^a	1.90 ^a	0.52 ^{ab}	0.02 ^a	157.0 ^a	39.8 ^{abc}	28.9 ^a	23.8 ^a	31.9 ^a	-149 ^a
Rootpac® 70	2.59 ^a	0.14 ^a	1.89 ^a	2.24 ^a	0.67 ^a	0.02 ^a	158.7 ^a	44.1 ^{ab}	31.0 ^a	25.6 ^a	31.8 ^a	-97 ^a
PM 105 AD	2.69 ^a	0.13 ^a	1.79 ^a	2.12 ^a	0.59 ^{ab}	0.02 ^a	180.4 ^a	32.7 ^{bcd}	29.5 ^a	23.4 ^a	29.5 ^a	-141 ^a
AGAF 0301-04	2.66 ^a	0.14 ^a	2.01 ^a	1.78 ^a	0.43 ^b	0.03 ^a	139.6 ^a	25.8 ^{cd}	32.6 ^a	21.6 ^a	40.6 ^a	-178 ^a
Krymsk® 1	2.21 ^a	0.13 ^a	1.89 ^a	2.06 ^a	0.60 ^{ab}	0.02 ^a	106.9 ^a	19.5 ^d	36.6 ^a	26.3 ^a	41.6 ^a	-139 ^a
Krymsk® 86	2.62 ^a	0.13 ^a	1.87 ^a	2.30 ^a	0.60 ^{ab}	0.03 ^a	146.5 ^a	40.8 ^{ab}	27.2 ^a	22.5 ^a	37.3 ^a	-137 ^a
PAC 847	2.50 ^a	0.14 ^a	1.92 ^a	2.04 ^a	0.54 ^{ab}	0.02 ^a	142.8 ^a	39.4 ^{abc}	39.3 ^a	27.6 ^a	30.4 ^a	-114 ^a
Optimum value (Leece et al., 1971)	3-3.5	0.14-0.25	2-3	1.8 -2.7	0.3-0.8	0.02	100-250	40-160	20-50	15-16	20-60	-

Results for N, P, K, Ca, Mg and Na are expressed as percentage of dry matter; Results for Fe, Mn, Zn, Cu and B are expressed as mg kg⁻¹ of dry matter.

Means followed by the same letter in each column are not significantly different at P≤0.05 according to Duncan's Multiple Range Test.