Horticultural, leaf mineral and fruit quality traits of two ‘Greengage’ plum cultivars budded on plum based rootstocks in Mediterranean conditions

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Abstract

Field performance, leaf mineral content and fruit quality of two ‘Greengage’ plum cvs. ‘R.C. Bavay’ and ‘R.C. GF 1119’ budded on two plum based rootstocks (Ishtara and P.8-13) were studied in the network of an international European plum trial, promoted by the Fruit Research Station of the INRA of Bordeaux (France) and other European Research Centers. Trees were established in the winter of 1993-1994 in a heavy and calcareous soil with climate conditions typical of the Mediterranean area. Trees of ‘R.C. GF 1119’ were more vigorous than those from ‘R.C. Bavay’. The highest yield was observed on the P.8-13 rootstock for both cultivars. In contrast, the highest cumulative yield and yield efficiency were induced by ‘R.C. Bavay’, independently of the rootstock. All trees budded on Ishtara survived well, whereas tree mortality was reported in trees budded on P.8-13 for each cultivar. Leaf chlorophyll content varied depending of the rootstock-scion combination. Most of the mineral nutrient concentrations were not affected by the rootstock-scion combination, with the exception of Mn, which was significantly lower on Ishtara for both cultivars. Overall, Ishtara resulted the best adapted rootstock to soil waterlogging and calcareous soil conditions showing a good tree survival and best leaf Fe mineral content. Further studies with plum varieties budded onto P.8-13 rootstock should be carried out in order to recommend their use on soils with no waterlogging and/or associated diseases. Comparing the two cultivars, ‘R.C. Bavay’ showed better agronomic performance than ‘R.C. GF 1119’, in terms of cumulative yield and yield efficiency, and similar good fruit quality.

Keywords: *Prunus domestica*, survival rate, vigor, micronutrients, soluble solids content

Introduction

Plums, with a production of 11.52 million tons (Mt), are the second worldwide stone fruit produced after peaches and nectarines. Spain, with a total production of 0.19 Mt, is the third plum producer in the European Union and the seventh producer in the world (FAOSTAT, 2017). The hexaploid European plums (*Prunus domestica* L.) and the diploid Japanese plums (*Prunus salicina* Lindl.) are amongst the most widely cultivated fruit species in temperate climates (Ferlito et al., 2015). In Spain, Japanese plum occupied more than 65% of the total plum area cultivated, while the rest is occupied by European plum, mainly by the ‘Reine Claude’ group (MAPAMA, 2017), also called ‘Greengage’.

In the framework of *Prunus* sp. rootstocks, Myrobalan (*Prunus cerasifera* Ehrh.) and Marianna (*P. cerasifera* × *P. munsoniana*) groups include some of the most widely used rootstocks for plum production. They are more tolerant to heavy and calcareous soils, with root waterlogging and iron-chlorosis problems, than other *Prunus* species (Moreno et al., 1995). However, they induce, in general, an excessive vigor to the scion, exhibit high presence of root suckers, and present cases of grafting incompatibilities with certain cultivars of the ‘Reine Claude’ group (Moreno et al., 1995) and other plum cultivars (Butac et al., 2015). To overcome these problems, together with the increasing demand for high density plum plantings with more precocious rootstocks, other plum rootstocks and different *Prunus* sp. rootstocks have been selected and evaluated during the last years.

Worldwide information related to the rootstock influence on vigor, graft-compatibility, leaf mineral content and yield characteristics of plum tree is well known (Butac et al., 2015; Ferlito et al., 2015; Hartmann et al., 2007; Meland and Frøynes, 2006; Mészáros et al., 2015; Moreno et al., 1995; Pedersen, 2010; Sosna, 2002; Sottile et al., 2012). However, to the best of our knowledge, no long-term (more than 10 years) European plum orchard performance studies have been conducted under heavy and calcareous soils, typical of the Mediterranean area. Therefore, the main objective of this study was to evaluate the orchard and fruit quality performance of two of the most popular European plums originated from ‘Reine Claude Verde’ (‘Reine Claude Bavay’ and ‘Reine Claude GF 1119’) budded on two plum based rootstocks of different genetic background. They are of great interest in France and other European countries, as well as the Ebro Valley area in Spain, because of their good fruit quality and maturity time (early August for ‘R.C. GF 1119’ and mid-late August for ‘R.C. Bavay’). This study was established in the framework of an international trial of plum, promoted by the

Fruit Research Station of the INRA of Bordeaux (France) and other European Research Centers, due to the increasing interest in plum cultivation in Europe (Hartmann et al., 2007).

2. Material and methods

2.1. Plant material and field trial

Two plum based rootstocks from INRA of Bordeaux (France), the interspecific diploid hybrid Ishtara [*(P. cerasifera* × *P. salicina*) × (*P. cerasifera* × *P. persica*)] and the pentaploid open pollinated seedling of Marianna P.8-13, were budded with two European plums ('Reine Claude Bavay' and 'Reine Claude GF 1119').

The trial, established in the winter of 1993-1994, was carried out at the Experimental Station of Aula Dei (Zaragoza, Spain) on a heavy and calcareous soil (see description in Table 1). Trees were planted at 6 m × 4 m and trained in a low density open-vase system to avoid vigor interferences between trees. Cultural management practices, such as fertilization and winter pruning, were conducted as in a commercial orchard. The orchard was fertilized with 350 kg/ha N-P-K fertilizer 8-15-15 between January and February every year. No Fe chelates were used in the orchard. The plot was level-basin irrigated with a dose of 1000 m³ ha⁻¹ every 12 days during the summer. 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. The experiment was established in a randomized block design with four blocks, with the basic plot consisting of two trees per scion-rootstock combination. Guard rows were used to preclude edge effects.

2.2. Growth measurement, yield and fruit sampling

Trunk girths were measured during the dormant season since 1994 until 2011 at 20 cm above the graft union, and the trunk cross-sectional area (TCSA, in cm²) was calculated. Dead trees were recorded each year at the time when growth measurements were taken. The yield from all rootstock-scion combinations was weighed. Cumulative yield per tree and yield efficiency (cumulative yield in kg per final TCSA) were computed from the harvest data.

Over the last three years (2009-2011), twenty-five 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 exhibited the ground color representative for each cultivar.

2.3. Chlorophyll content and leaf mineral analysis

The chlorophyll (Chl) content of leaves per unit leaf area was estimated in the field at 115 days after full bloom (DAFB) in 2011, using a SPAD 502 meter (Minolta Co., Osaka, Japan) as described in other *Prunus* rootstocks studies (Jiménez et al., 2007; Mestre et al., 2015, 2017).

Leaf mineral element concentrations were determined in 2010 and 2011, as described in cherry and peach rootstock studies (Jiménez et al., 2007; Mestre et al., 2015, 2017). Leaf sampling was carried out at 115 DAFB for both plum cultivars. Total N was determined by Kjeldahl analysis (Gerhardt Vapodest); P was analyzed spectrophotometrically by the phospho-vanadate colorimetric method (Hewlett-Packard 8452A); K, Ca, and Mg by atomic emission spectroscopy (ICP, Horiba–Jobin Yvon, Activa-M); and Fe, Mn, Cu and Zn by atomic absorption spectroscopy (PerkinElmer 1100).

The Σ DOP index (deviation from optimum percentage) was estimated for the diagnosis of the leaf mineral status of the trees. The DOP index was calculated from the leaf analysis by the algorithm:

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

where C is the nutrient concentration in the sample to be studied and C_{ref} is the nutrient concentration considered as optimum, both values from dry matter tissues basis. The C_{ref} has been taken from the optimum values proposed by Reuter et al. (1997). For any given nutrient, a negative DOP index indicates a deficiency, whereas a positive DOP index indicates an excess (Kumar et al., 2017). The Σ DOP is obtained by adding the values of DOP indices irrespective of sign.

2.4. Fruit quality analysis

Fruits were assessed at harvest for fruit weight (FW), skin color, flesh firmness (FF), soluble solids content (SSC), and titratable acidity (TA) as described in Cantín et al. (2010) for cherries. Skin color determinations were measured using a colorimeter (Chroma Meter, CR-400 Konica Minolta, Japan). FF was measured by a durometer (Shore A, Durofel). SSC of juice extracted was measured with a digital refractometer (Atago PR-101, Tokyo, Japan), and TA by titrating the juice samples with 0.1 N NaOH to pH 8.2.

2.5. Analysis of data

Data were analyzed by one-way analysis of variance (ANOVA) using IBM SPSS Statistics 24.0 (USA). Means separation were conducted using a t-test at $P \leq 0.05$.

Pearson correlation was performed to study correlations among agronomic and fruit quality traits, and leaf mineral elements. A principal component analysis (PCA) was performed to understand how agronomic, leaf and fruit quality traits contribute to variability between Ishtara and P.8-13 rootstocks budded with ‘R.C. Bavay’ and ‘R.C. GF 1119’ plum cultivars, using Unscrambler X 10.3 software (CamoAsa, 2001).

3. Results

3.1. Tree mortality

After the seventeenth year of evaluation, tree mortality was only observed in plum trees of both cultivars on Marianna P.8-13 (Fig. 1). In contrast, all trees budded on Ishtara survived well, exhibiting homogenous growth. Tree losses were distributed throughout the trial duration.

3.2. Vegetative growth and yield

Tree vigor and fruit production were markedly influenced by cultivar, rootstock and the interaction of both. Over a seventeen-year period (from 1994 to 2011), tree vigor as assessed by trunk cross sectional area (TCSA) was significantly affected by cultivar, but not by rootstock (Table 2). ‘R.C. GF 1119’ was more invigorating than ‘R.C. Bavay’ on both rootstocks, starting from the 5th year after grafting (data not shown) until the end of the experiment. Comparing all scion-rootstock combinations, both rootstocks budded with ‘R.C. GF 1119’ had statistically similar vigor. However, at the seventeenth year (2011), the reduction in TCSA on Ishtara and P.8-13 trees budded with ‘R.C. Bavay’ was 35% and 37% compared to those trees with ‘R.C. GF 1119’.

The ‘R.C. Bavay’ trees came into production one year before (in the fifth leaf) than ‘R.C. GF 1119’, independently of the rootstock. Nevertheless, as an average, yield per tree was not affected by cultivar (Table 2). In the first bearing years, yields were very low, and there were no rootstock differences (data not shown). At the seventeenth year after grafting (2011), P.8-13 rootstock induced higher yield per tree than Ishtara, especially when budded with ‘R.C. Bavay’.

Regarding the cumulative yield and yield efficiency, ‘R.C. Bavay’ trees had higher production and were more efficient on both rootstocks (Table 2).

3.3. SPAD values and leaf mineral analysis

Cultivar, rootstock and the interaction of both were slightly significant regarding SPAD values and micro and macronutrients concentration (Table 3). In fact, SPAD readings were only significantly affected by cultivar-rootstock interaction. It is noted that ‘R.C.

GF 1119' had the highest SPAD value when it was budded on P.8-13 rootstock, although it did not differ from 'R.C. Bavay' trees on Ishtara.

Table 3 represents the mean value of leaf macro and micronutrients evaluated in this study over two years (2010 and 2011). Owing to the non-significant cultivar $\times$ year and rootstock $\times$ year interactions on most of the nutrients, the data from the two years were analyzed together. Among the leaf macronutrients, N and P were significantly affected by cultivar, whereas all of them were not significantly affected by rootstock and cultivar-rootstock interaction (Table 3). 'R.C. GF 1119' trees had higher N and P concentrations than 'R.C. Bavay' trees. Regarding the micronutrients, only leaf Mn was significantly affected by cultivar, rootstock and their interactions, being the cultivar 'R.C. GF 1119' and the rootstock P.8-13 the ones with the highest values.

Regarding the DOP index, only rootstock affected significantly. In spite of the negative values in absolute terms, trees on P.8-13 were more nutritional balanced than those on Ishtara rootstock.

3.4. Fruit quality

Fruit weight (FW), skin color (L^* , a^* , b^* , C^* and H parameters), flesh firmness (FF), soluble solids content (SSC), pH, and titratable acidity (TA) values of the two plums budded on the two rootstocks are shown in Table 4. Cultivar seemed to affect all these traits, with the exception of SSC, b^* , C^* and H. Fruits of 'R.C. GF 1119' were smaller, greener, firmer and more acid than those from 'R.C. Bavay'. On the other hand, FF and H were the only traits affected by rootstock. Trees on Ishtara induced firmer fruits with lesser color appearance (Hue, H). In particular, Ishtara trees budded with 'R.C. GF 1119' presented the highest FF mean value, and, together with Ishtara budded with 'R.C. Bavay', had low H values.

3.5. Correlation among traits

Table 5 shows the correlations found between the agronomic, leaf mineral and fruit quality traits. Most of the significant correlations found had moderate to high coefficients when all cultivars and rootstocks combinations were considered together. Among them, it is noteworthy the high correlations found among some of the leaf nutrients, such as those correlations between N and Mn, Cu and K, between Mg and Ca, K and DOP, between K and Ca, Fe and DOP, and between Ca and DOP.

Fruit quality traits (FF, SSC, pH, TA and color parameters) had also significant correlations among them, even so with fruit production traits (vigor, yield and yield efficiency) and leaf mineral nutrients. The most relevant correlations were those

between SSC and color parameters, such as C* and b*, and yield. This last trait together with yield efficiency and TA were also highly correlated with color parameters (C* and b*). Other significant correlations were found between yield and fruit weight, and N and yield efficiency.

3.6. Principal component analysis

The first two components of the PCA performed on the different traits explained 55% of the variation in the dataset, with 31% being captured by the first and 24% by the second principal component (PC) (Fig. 2). The first PC showed moderate correlations with Fe, Ca, CY, SSC, N and Y. The second PC was highly correlated with TCSA and FW, as well as with FF. Therefore, these results showed that scion-rootstock combinations on the negative side of PC1 corresponding to ‘R.C. GF 1119’ budded on Ishtara induced, in general, higher Fe, FF, SSC, TA, and TCSA, and lower CY, Y, FW, Ca and N, whereas ‘R.C. Bavay’ budded on P.8-13 induced the contrary.

4. Discussion

Under heavy and calcareous soil conditions, the most limiting abiotic stresses in this area (Legua et al., 2011), the pentaploid open pollinated seedling of Marianna P.8-13 had higher tree mortality as compared to Isthara for both ‘Greengage’ plum cultivars. It is interesting to highlight that Marianna plum rootstocks are generally considered more tolerant to waterlogging than other *Prunus* species, whereas Isthara has been reported more sensitive to waterlogging in winter than Marianna GF 8-1 (Renaud et al., 1988) and more adapted to well-drained soils (Karp and Mariani, 2013). In the present trial, soil characteristics could indicate waterlogging conditions, but the tree decline and death was probably caused by the soil borne fungus *Phytophthora* spp., which is very common on waterlogged sites, rather than root asphyxia or even graft incompatibility between rootstock and scion. In fact, *Phytophthora* was isolated from necrotic roots and trunk bark samples from dead trees (Miguel Cambra, personal communication).

The two ‘Greengage’ plum cultivars and the two plum based rootstocks induced significant growing differences in tree vigor and yield characteristics. P.8-13 and Isthara rootstocks budded with ‘R.C. GF 1119’ were more vigorous and less productive (less cumulative yield and yield efficiency) than budded with ‘R.C. Bavay’. Despite this, a very low correlation was found between vegetative growth (TCSA) and yield. Ishtara rootstock was selected to induce less vigor and higher yield efficiency to the scion. In general, it reduces the vigor 15-20% compared to Myrobalan and Marianna rootstocks (Renaud et al., 1988). However, this trend was not observed in this study especially

with the less productive cultivar ‘R.C. GF 1119’. The mechanism by which rootstocks regulate scion vigor is still unclear. For peach rootstocks (Sorce et al., 2007) and apple rootstocks (Lordan et al., 2017), vigor induction has been associated with hormonal relationships (auxins, cytokinins) between scion and rootstock, and hydraulic conductance of roots and stems (Basile et al., 2003). These statements could help to explain the vigor differences found between cultivars for the same rootstock.

The Marianna seedling P.8-13 budded with ‘R.C. GF 1119’ tended to have more cumulative yield and yield efficiency as compared to Ishtara in absence of significant differences in vigor between them. In contrast, Meland and Frøynes (2006) reported that, in another trial belonging to the same international plum rootstock network, P.8-13 produced the largest trees with ‘Opal’ and ‘R.C. GF 1119’ cultivars at the seventh year compared to Plumina, Ishtara, Jaspi and St. Julien rootstocks under northern climatic conditions. Similarly, Pedersen (2010) reported that Ishtara budded with the plum cv. ‘Ive’ had a growth below the average compared to the other rootstocks evaluated, the trunk only increased 64 mm in a six-year study in Denmark. In our study, Ishtara during the first six years increased more than 120 mm for ‘R.C. GF 1119’ and more than 80 mm for ‘R.C. Bavay’. This could suggest that the agronomic performance of Ishtara is strongly influenced by different soil and climatic conditions.

Plums are generally slow to come into bearing (Meland and Frøynes, 2006). Consequently, precocity is an important trait of rootstocks used in high density planting systems. In this trial, ‘R.C. Bavay’ cultivar seemed to be more precocious in fruit bearing and more productive in comparison to ‘R.C. GF 1119’, independently of the rootstock. The lowest yield of ‘R.C. GF 1119’ during the first bearing years was also mentioned by Meland and Frøynes (2006) and Renaud et al. (1988). In addition, the lowest yield produced by this cultivar over the seventeenth years of study could explain its higher vegetative growth due to a lower sink competition of fruits.

The indirect measurement of leaf chlorophyll concentration by SPAD readings has been used as an indicator of iron chlorosis in fruit trees (El-Jendoubi et al., 2012; Jiménez et al., 2008). A moderate to low negative significantly correlation was found between SPAD and Fe in this study. Nevertheless, our results were within the range as previously reported in other *Prunus* studies (Jiménez et al., 2008; Mestre et al., 2015, 2017).

Differences in leaf concentration of major nutrients between trees on different rootstocks are likewise attributable to the inherent capacity of the rootstock to absorb

271 nutrients (Meland, 2010; Mestre et al., 2015, 2017). In the present work, most of the
272 nutrients were not affected by cultivar, rootstock and the interaction of both, with the
273 exception of N, P and Mn. In general, the leaf mineral concentrations appeared to be
274 within the optimum range according to reference values (Reuter et al., 1997), with the
275 exceptions of N, P, Fe and Mn. Leaf N values were slightly lower than the optimum,
276 explained mainly by the type of soil (calcareous with a high pH), in good agreement
277 with other studies in similar soil conditions (El-Jendoubi et al., 2012; Mestre et al.,
278 2015, 2017). Guo-yi et al. (2015) reported that N influenced fruit size and composition,
279 and higher N levels could decrease the amount of soluble solids and increase the
280 titratable acid level in apples, which agrees with the correlations found in the present
281 study between leaf N concentration and SSC and TA. The interaction between N and K
282 is well known in crop growth, due to potassium affects nitrate absorption and reduction
283 from the soil solution. Leaf P concentrations were considered to be in excess according
284 to Reuter et al. (1997). Ranade-Malvi (2011) reported that an excess amount of P
285 reduces uptake of cationic micronutrients like iron and manganese. In this study, that
286 statement was especially observed, with the exceptions of the 'R.C. GF 1119' when
287 budded on Isthara in the case of iron and when budded on P.8-13 in the case of
288 manganese.

289 Leaf Fe had lower values than the optimum except for Ishtara budded with 'R.C. GF
290 1119'. The tendency of Isthara rootstock to induce higher Fe concentration shows the
291 interest of this rootstock in heavy-calcareous soils where iron chlorosis is commonly
292 observed. Iron deficiency is the most prevalent nutritional disorder in fruit tree crops
293 growing in calcareous soils causing decreases in growth, and losses in both fruit yield
294 and quality (El-Jendoubi et al., 2012). In the case of Mn, P.8-13 budded with 'R.C. GF
295 1119' showed a mean value closer to the optimum range (40-160 mg kg⁻¹) in plums.
296 The Mn deficiency has been also reported for peach and cherry grown in calcareous
297 soils (Jiménez et al., 2004; Mestre et al., 2015) probably due to the insolubilization of
298 this element in this type of soil. In addition, increased Ca in soil or an excess of
299 phosphoric acid fertilization might decrease or block Mn uptake (Johnson and Uri,
300 1989).

301 Fruit weight is a function of crop load, tree vigor, and growing conditions (primarily
302 temperature and moisture) before harvest. Yield is also known to influence the fruit
303 weight (Rato et al., 2008) due to carbohydrate competition among fruits. This could
304 explain the negative correlations found in this study between yield and SSC and fruit

weight. In this study, rootstock did not affect fruit weight, in agreement with Meland and Frøynes (2006), who reported no differences in fruit size when ‘Opal’ and ‘R.C. GF 1119’ were budded on different rootstocks (Ishtara, Jaspi, P.8-13, Plumina, St. Julien A). In contrast, other studies underlined that Ishtara rootstock increased significantly the average fruit weight in comparison to other rootstocks (Kosina, 2007; Pedersen, 2010; Renaud et al., 1988; Sottile et al., 2012).

The rest of the fruit quality parameters (FF, SSC, pH, TA and skin color traits) were, in general, not affected by rootstock, in agreement with other plum studies (Milošević and Milošević, 2012; Rato et al., 2008). Flesh firmness is a key quality parameter, since it is directly related to fruit ripeness, and is often a good indicator of shelf-life potential (Valero et al., 2007). The high and positive correlation between FF and TA reflects the decrease of acidity with fruit softening. In this study, fruits of ‘R.C. GF 1119’ tended to have higher FF compared to those of ‘R.C. Bavay’, which could explain the negative values of a^* , meaning greener fruits, although the correlation between FF and a^* was low. The content of soluble solids and the acidity are also important components of plum quality (Meland and Frøynes, 2006; Vangal et al., 2007). The negative correlation between yield and SSC confirms the sink competition among fruits by the assimilate supply, as reported in other *Prunus* studies (Mounzer et al., 2008; Font i Forcada et al., 2012). Titratable acidity was negatively correlated with fruit weight for both cultivars, showing that titratable acidity decreases with fruit mass (Cantín et al., 2010; Font i Forcada et al., 2012). The ‘Greengage’ cultivars are known as having very sweet fruits with high content of soluble solids content, in agreement with our results. Under the typical climatic conditions from the Mediterranean warm areas, these ‘Greengage’ cultivars had similar SSC and TA mean values to those values reported by other ‘Greengage’ plum studies (Meland and Frøynes, 2006; Vangal et al., 2007) under colder conditions.

Multivariate analysis through the PCA model showed a general overview of the two ‘Reine Claude’ plum cultivars budded on the two plum based rootstocks in order to identify the best adapted to the soil conditions. There was a clear separation between cultivars. Ishtara and P.8-13 rootstocks budded with ‘R.C. Bavay’ were separated from Ishtara and P.8-13 rootstocks budded with ‘R.C. GF 1119’. This separation correlated mainly with the effects on fruit production (higher CY and Y), fruit size and fruit quality (fruits less firm and green).

5. Conclusions

Regarding to the cultivars studied, the ‘R.C. Bavay’ has shown a better adaptability response in terms of fruit size, precocity, cumulative yield and yield efficiency, and fruit quality. Nevertheless, although ‘R.C. GF 1119’ was less efficient in terms of production, it had also fruits with excellent quality. Therefore, in terms of fruit quality, both ‘Greengage’ cultivars adapted well under climate (warm and dry summers) and soil conditions typical of the Ebro Valley in the Mediterranean area.

The results observed in this trial showed that with 100% trees surviving and optimum leaf Fe content after seventeenth years, Ishtara rootstock may be a better rootstock candidate for orchards established under heavy and calcareous soils, prone to waterlogging and iron chlorosis. Although the use of P.8-13 rootstock in these soil conditions tends to result in higher tree mortality, trees budded on P.8-13 had higher yield and yield efficiency. Therefore, further plum studies with P.8-13 rootstock should be carried out in order to recommend it on soils with no waterlogging and/or associated diseases.

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465 Table 1. Soil analysis description.

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Depth (cm)	Texture	E.C. (1:5) (dS/m)	pH	Organic Matter ^a (%)	P ^b (ppm)	K ^c (ppm)	NO ₃ ^d (ppm)	Mg (meq/100 g) ^c	CaCO ₃ ^e (%)	Active Limestone ^f (%)
0-30	Silty-clay-loam	0.17	8.5	2.4	23.7	242	13.6	2.1	30.9	8.8
30-60	Silt-loam	0.18	8.7	1.5	12.9	162	12.8	2.1	29.7	8.8
60-90	Clay	0.20	8.4	1.0	7.3	138	-	2.2	28.1	7.8

467 ^aOrganic matter was measured using the Walkley-Black (1934) method.

468 ^bThe assimilable phosphorus was measured using the Olsen and Watanabe (1957) method.

469 ^cPostassium and magnesium were extracted by ammonium acetate 1N at pH = 7 and analyzed by atomic absorption spectrophotometry.

470 ^dThe nitrogen was measured using Kjeldahl analysis (Gerhardt Vapodest).

471 ^eThe carbonates were measured using Bernard calcimeter method (Gaucher, 1971).

472 ^fThe active limestone was determined by Nijelson method.

Fig. 1. Tree mortality rate (%) after seventeenth years.

494 Table 2. Vigor and yield traits of the 'R.C. Bavay' and 'R.C. GF 1119' cvs. budded on
 495 Ishtara and P.8-13 rootstocks at the seventeenth year after budding (2011).

Trait	TCSA (cm ²)	Yield (Kg)	Cumulative yield (Kg)	Yield efficiency (kg cm ⁻²)
<u>Cultivar</u>				
'R.C. Bavay'	264 b	153 a	582 a	0.59 a
'R.C. GF 1119'	416 a	132 a	400 b	0.33 b
<i>Prob > F</i>	<0.0001	0.0946	<0.0001	<0.0001
<u>Rootstock</u>				
Ishtara	345 a	119 b	453 b	0.39 b
P.8-13	336 a	165 a	521 a	0.52 a
<i>Prob > F</i>	0.7734	0.0008	0.0040	0.0022
<u>Cultivar*Rootstock</u>				
R.C. Bavay / Ishtara	259 b	137 a	552 a	0.54 a
R.C. Bavay / P.8-13	270 b	168 a	612 a	0.64 a
R.C. GF 1119 / Ishtara	431 a	101 b	355 c	0.23 c
R.C. GF 1119 / P.8-13	402 a	163 a	445 b	0.42 b
<i>Prob > F</i>	0.0510	0.0482	0.0032	0.0081

496 Student t-test ($P \leq 0.05$) analysis was performed. Data followed by the same letter within a
 497 column are not significantly different.

498 Table 3. SPAD values and leaf mineral concentration of the ‘R.C. Bavay’ and ‘R.C. GF 1119’ cvs. budded on Ishtara and P.8-13 rootstocks.

Trait	SPAD	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Zn (mg kg ⁻¹)	ΣDOP
<u>Cultivar</u>											
‘R.C. Bavay’	32.4 a	1.59 b	0.33 b	2.59 a	2.24 a	0.35 a	89.7 a	5.27 a	31.6 b	23.6 a	-207.0 a
‘R.C. GF 1119’	32.6 a	1.70 a	0.37 a	2.45 a	2.13 a	0.31 a	97.6 a	5.34 a	36.1 a	27.2 a	-184.8 a
<i>Prob > F</i>	0.7822	0.0315	0.0273	0.7375	0.7606	0.5823	0.8523	0.9396	0.0373	0.5291	0.5273
<u>Rootstock</u>											
Ishtara	32.1 a	1.61 a	0.34 a	2.14 a	1.91 a	0.28 a	101.2 a	5.48 a	30.2 b	23.7 a	-239.0 b
P.8-13	32.9 a	1.69 a	0.36 a	2.91 a	2.46 a	0.38 a	83.5 a	5.13 a	37.7 a	27.1 a	-152.8 a
<i>Prob > F</i>	0.2210	0.1338	0.2144	0.0934	0.1359	0.1302	0.5273	0.6700	0.0021	0.5557	0.0210
<u>Cultivar*Rootstock</u>											
R.C. Bavay / Ishtara	33.3 ab	1.58 a	0.32 a	2.40 a	2.13 a	0.33 a	91.9 a	6.14 a	28.8 b	25.8 a	-222.7 a
R.C. Bavay / P.8-13	31.6 bc	1.61 a	0.35 a	2.78 a	2.43 a	0.37 a	86.8 a	4.41 a	34.4 ab	21.4 a	-191.4 a
R.C. GF 1119 / Ishtara	30.9 c	1.64 a	0.36 a	1.87 a	1.68 a	0.24 a	110.6 a	4.83 a	31.7 b	21.6 a	-255.3 a
R.C. GF 1119 / P.8-13	34.2 a	1.77 a	0.37 a	3.02 a	2.57 a	0.39 a	80.2 a	5.85 a	41.0 a	32.9 a	-114.3 a
<i>Prob > F</i>	0.0005	0.2934	0.6167	0.3807	0.3544	0.3644	0.1991	0.1056	0.0385	0.1830	0.1260

499 Student t-test ($P \leq 0.05$) analysis was performed. Data followed by the same letter within a column are not significantly different.

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506 Table 4. Fruit quality of the ‘R.C. Bavay’ and ‘R.C. GF 1119’ cvs. budded on Ishtara and P.8-13 rootstocks.

Trait	FW (g.)	FF (N)	SSC (°Brix)	pH	TA (%)	L*	a*	b*	C*	H
<u>Cultivar</u>										
‘R.C. Bavay’	43.3 a	81.0 b	21.9 a	3.74 a	0.84 b	56 a	1.7 a	28.1 a	28.7 a	100.8 a
‘R.C. GF 1119’	37.4 b	92.4 a	21.8 a	3.44 b	1.33 a	55 b	-6.1 b	28.8 a	29.6 a	102.2 a
<i>Prob > F</i>	0.0052	<0.0001	0.9146	<0.0001	<0.0001	0.0163	<0.0001	0.6780	0.5760	0.1479
<u>Rootstock</u>										
Ishtara	40.5 a	89.4 a	22.3 a	3.60 a	1.07 a	56 a	-1.0 a	28.3 a	29.1 a	99.7 b
P.8-13	40.3 a	84.1 b	21.5 a	3.58 a	1.10 a	56 a	-3.4 a	28.6 a	29.3 a	103.5 a
<i>Prob > F</i>	0.9031	0.0029	0.3127	0.3015	0.7345	0.7925	0.0685	0.8604	0.9274	0.0002
<u>Cultivar*Rootstock</u>										
R.C. Bavay / Ishtara	40.4 a	80.3 c	22.1 a	3.75 a	0.84 a	56 a	2.7 a	27.5 a	28.5 a	99.9 b
R.C. Bavay / P.8-13	43.3 a	81.7 bc	21.8 a	3.74 a	0.84 a	57 a	0.8 a	28.8 a	29.0 a	101.8 b
R.C. GF 1119 / Ishtara	37.7 a	98.4 a	22.5 a	3.46 a	1.30 a	55 a	-4.7 a	29.2 a	29.8 a	99.4 b
R.C. GF 1119 / P.8-13	37.2 a	86.5 b	21.3 a	3.42 a	1.36 a	55 a	-7.5 a	28.4 a	29.5 a	105.0 a
<i>Prob > F</i>	0.9200	0.0003	0.5556	0.5685	0.6586	0.3380	0.7275	0.4660	0.7849	0.0468

507 Student t-test ($P \leq 0.05$) analysis was performed. Data followed by the same letter within a column are not significantly different. *Abbreviations:* a*,
508 greenness/redness; b*, blueness/yellowness; C*, chroma; FF, flesh firmness; FW, fruit weight; h, lightness’ angle; L*, lightness; SSC, soluble solids content;
509 TA, titratable acidity

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514 Table 5. Pearson's correlation coefficients among horticultural, leaf mineral and fruit quality traits.

	P	K	Ca	Mg	Fe	Cu	Mn	Zn	DOP	SSC	FF	TA	SPAD	L*	a*	b*	C*	H	FW	Y	YE	TCSA
N	-0.58**	0.63**	ns	0.46**	-0.34**	0.68**	0.73**	0.87**	0.30*	-0.70**	ns	0.62**	ns	0.32*	0.27*	0.66**	0.68**	ns	-0.36**	ns	-0.70**	-0.64**
P		-0.38**	ns	-0.49**	ns	-0.43**	ns	-0.43**	ns	0.71**	ns	-0.48**	ns	ns	-0.47**	-0.65**	-0.66**	ns	0.53**	-0.30**	0.57**	0.31**
K			0.59**	0.74**	-0.68**	0.44**	0.54**	0.66**	0.77**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.23*	-0.38**	-0.49**
Ca				0.81**	-0.46**	ns	ns	ns	0.73**	-0.36**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mg					-0.51**	0.29**	ns	0.32**	0.66**	-0.59**	ns	0.33*	ns	0.28*	0.30*	0.50**	0.51**	ns	-0.33**	0.26*	-0.37**	-0.26*
Fe						ns	-0.30**	-0.37**	-0.27*	ns	ns	ns	-0.45*	ns	ns	ns	ns	-0.36**	ns	ns	ns	0.29**
Cu							0.50**	0.62**	ns	-0.30*	ns	0.37**	ns	ns	ns	ns	ns	ns	-0.26*	ns	-0.53**	-0.47**
Mn								0.77**	ns	ns	ns	ns	ns	ns	-0.29*	ns	ns	ns	ns	-0.41**	-0.39**	-0.56**
Zn									0.39**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.45**	-0.53**	-0.76**
DOP										ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SSC											ns	-0.40**	ns	-0.45**	-0.37**	-0.81**	-0.83**	ns	0.54**	-0.75**	0.23*	ns
FF												0.67**	-0.39*	ns	-0.33*	ns	ns	ns	ns	ns	-0.49**	0.41**
TA													ns	ns	ns	0.52**	0.53**	ns	-0.54**	0.55**	-0.68**	0.57**
SPAD														ns	-0.39*	ns	ns	0.48**	ns	ns	ns	ns
L*															0.68**	0.54**	0.52**	ns	-0.26*	0.38**	-0.28*	ns
a*																0.50**	0.50**	-0.31*	ns	0.47**	ns	-0.45**
b*																	0.98**	ns	-0.82**	0.78**	-0.73**	ns
C*																		ns	-0.84**	0.80**	-0.74**	ns
H																			ns	ns	ns	ns
FW																				-0.42**	0.35**	-0.34**
Y																					0.21**	0.33**
YE																						ns

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516 * and ** represent statistical significance at $p \leq 0.05$ and $p \leq 0.01$ respectively; ns, not significant. *Abbreviations:* a*, greenness/redness; b*,
517 blueness/yellowness; C*, chroma; FF, flesh firmness; FW, fruit weight; h, lightness' angle; L*, lightness; RI, ripening index; SSC, soluble solids content; TA,
518 titratable acidity; TCSA, trunk cross sectional area; Y, yield; YE, yield efficiency.

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524 Fig. 2. Principal component analysis for agronomic, leaf and fruit quality traits evaluated on 'R.C. Bavay' and 'R.C. GF 1119' cvs. budded on
525 Ishtara and P.8-13 rootstocks.

526 *Abbreviations:* Cu, copper; CY, cumulative yield; Σ DOP, deviation from optimum percentage index; Fe, iron; FF, flesh firmness; FW, fruit
527 weight; K, potassium; Mg, magnesium; Mn, manganese; N, nitrogen; Na, sodium; P, phosphorus; SSC, soluble solids content; TA, titratable
528 acidity; TCSA, trunk cross sectional area; Zn, zinc.