Agronomical and fruit quality traits of two peach cultivars on peach-almond hybrid rootstocks growing on Mediterranean conditions

C Font i Forcada, Y Gogorcena and MA Moreno*

Dpto. de Pomología. Estación Experimental de Aula Dei (CSIC). Apdo. 13034, 50080 Zaragoza, Spain

***Corresponding author. Tel: +34 976 71 61 36. Fax: +34 976 71 61 45; E-mail address: mmoreno@eead.csic.es

Abstract

The agronomical and fruit quality trait influence was evaluated for five almond x peach hybrid and one *P. davidiana* x peach hybrid rootstocks. The six rootstocks, Adafuel, Adarcias, Cadaman, Felinem, Garnem and GF 677, were budded with 'Tebana' peach and 'Queen Giant' nectarine cultivars during the summer of 1997, and trees were established in two adjacent plots during the winter of 1998-1999. The trial was located in the Ebro Valley (Zaragoza, Spain), on a heavy and calcareous soil typical of the Mediterranean area.

At the twelfth year after budding, growing conditions generated varying levels of tree mortality, the highest with Felinem and Garnem rootstocks. In contrast, all Adarcias and GF 677 trees survived and the mortality rate was low in Adafuel and Cadaman. The lowest vigour was induced by Adarcias for both cultivars, a 37% and 48% reduction in trunk cross-sectional area (TCSA) for 'Tebana' and 'Queen Giant' respectively compared to vigour on GF 677. For 'Queen Giant', cumulative yield was greater on Felinem, although no significant differences were found with Garnem. Other rootstocks

that showed high cumulative yields were Adafuel and GF 677. The highest yield efficiency was recorded on Cadaman rootstock with both varieties, although differences were not significant with Felinem for ‘Queen Giant’.
On average, the highest fruit weight was recorded on Adafuel and Cadaman for both cultivars. For ‘Queen Giant’, the greatest soluble solids content (SSC) was recorded on Adarcias and Cadaman, and the lowest on Garnem and GF 677. The highest titratable acidity was also induced by Cadaman rootstock but it did not differ significantly from Adarcias. Correlations between some agronomical and fruit quality traits were found. The less vigourous rootstocks seem to induce a better fruit quality to the studied cultivars based on fruit sugar content. Our results show the relationship between the characteristics on plant adaptability and development, such as yield, vigour or fruit weight, and the factors of fruit quality value.

Keywords: acidity, firmness, fruit weight, SSC, TCSA, yield

1. Introduction

Peach [*Prunus persica* (L.) Batsch] is one of the most important temperate fruits trees grown in the world, after crops such as apples or pears. Peach production comes mainly from China, Mediterranean area (Italy and Spain) and United States (Faostat, 2011).

Stone fruit rootstock development is the aim of several breeding programs around the world (Moreno and Webster, 2004). The hybrids of almond x peach are largely used as rootstocks for peach trees in the Mediterranean countries, because they are tolerant to lime induced Fe chlorosis and they are graft-compatible with peach cultivars (Bernhard and Grasselly, 1981; Moreno et al., 1994). They are vigourous and appropriate for use in poor dry soils (Cambra, 1990). New selections have also been developed with resistance to biotic stresses such as root-knot nematodes (*Meloidogyne* spp.) (Felipe, 2009; Pinochet, 2009) and tolerance to replant conditions (Jiménez et al., 2011). Different studies with *Prunus* spp. have demonstrated that rootstock influences the performance of the grafted scion cultivar. There have been numerous reports of a relationship between rootstocks and water relations, leaf gas exchange, mineral uptake, plant size, blossoming, fruit bud survival, yield efficiency and tree vigour (Albás et al., 2004; Zarrouk et al., 2005). Also, it has been demonstrated that rootstock influences the fruit quality of the scion cultivar. Thus, previous research has shown the rootstock effects on fruit quality parameters like soluble solids content and firmness (Albás et al., 2004; Caruso et al., 1996; Giorgi et al., 2005; Loreti and Massai, 2002; Remorini et al., 2008). Fruit quality was defined by Kramer and Twigg (1996) as the conjunction of physical and chemical characteristics which give good appearance and acceptability to the consumable product. The three more important components in the organoleptic quality of fruit are aroma, sugar content and acidity, which are related to many chemical and physical properties of fruits, and these properties are highly influenced by rootstocks. Different studies in peach (Byrne et al., 1991) have investigated the relationships between some fruit quality traits with agronomical parameters, such as between trunk cross-sectional area (TCSA) and fruit weight and between TCSA and soluble solids content (SSC).

The present work was carried out over twelve years of study, to evaluate the effect of different almond x peach hybrid rootstocks on tree growth and survival, yield and fruit quality characteristics of ‘Queen Giant’ and ‘Tebana’ cultivars on heavy and calcareous soil conditions, typical of the Mediterranean area.

2. Materials and methods

2.1. Plant material

Five almond x peach hybrid [*Prunus amygdalus* Batsch x *P. persica* (L.) Batsch] and one *P. davidiana* x peach hybrid [*Prunus davidiana* (Carrière) Franch x *P. persica* (L.) Batsch] rootstocks (Table 1) were evaluated in this study. They were budded with ‘Tebana’ peach and ‘Queen Giant’ nectarine cultivars during the summer of 1997. The cultivars were of possible interest in the Ebro Valley area, because of their maturity time and good fruit quality. The six rootstocks were compared in a trial established during the winter of 1998-1999 in two adjoining plots, one for each cultivar.

Rootstocks chosen for this study were Adafuel (Cambra, 1990) and Adarcias (Moreno and Cambra, 1994; Moreno et al., 1994), selections from the Experimental Station of Aula Dei (CSIC); Garnem and Felinem (Felipe, 2009), selections from the Centre of Research and Agro-food Technology of Aragón (CITA); Cadaman (Edin and Garcin, 1994), a French-Hungarian co-obtention; and GF 677 rootstock (Bernhard and Grasselly, 1981), the most widespread rootstock in the Mediterranean peach-growing area, was the standard.

2.2. Field trial

The experiment was located in the Ebro Valley (North-Eastern of Spain) at the Experimental Station of Aula Dei (CSIC-Zaragoza, Spain), on a heavy and calcareous soil, with 27% total calcium carbonate, 8% active lime, water pH 8.3, and a clay-loam texture. Trees were trained to a low density open-vase system (6 × 5 m). 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. 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. Guard rows were used to preclude edge effects. The experiment was established in a randomized block design with five single-tree replications for each scion-stock combination.

2.3. Growth, yield determinations and harvest

Trunk girths were measured during the dormant season 20 cm above the graft union, and the trunk cross-sectional area (TCSA) was calculated. At harvest, all fruits from each tree were counted and weighed to determine total yield per tree (Kg/tree) and mean fruit weight. Cumulative yield per tree and yield efficiency (cumulative yield in kilograms per tree per final TCSA) of each scion-stock combination were computed from the harvest data.

2.4. Fruit sampling

Over the last 3 years of study, 20 fruits were hand-picked at commercial maturity, to assess optimum maturity for a given scion-rootstock combination. They were considered ripe when they no longer grew and exhibited the ground colour representative for each cultivar. Fruit samples were harvested by a single person to keep consistency of maturity grade. They were used to determine fruit quality parameters such as soluble solids content (SSC), titratable acidity, firmness and colour during three years (2008-2010).

2.5. Evaluation of fruit quality traits

The effects of five almond x peach and one *P. davidiana* x peach rootstocks on fruit quality parameters were studied for at least three years to estimate seasonal effect on agronomical and fruit quality parameters.

Fruit size (g) was calculated considering the total number of fruits and the total yield per tree. SSC of fruit juice was measured with a digital refractometer (Atago PR-101, Tokyo, Japan) and was expressed as ºBrix. Titratable acidity (TA) of samples was determined using an automatic titrator (Metrohm Ion analysis, 807 Dosing Unit, Switzerland). Ten grams of homogenized samples were diluted with 90 g of distilled water, and microtitrated with 0.1 N NaOH. The results were expressed as g malic acid/100 g FW. Ripening index was calculated based on the SSC/TA ratio. Flesh firmness 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 (Model FT-327). The two readings were averaged for each fruit and data were expressed in Newtons (N). Colour determinations were measured on the two opposite sides of the fruits. Values of L* (brightness or lightness), a* (-a* = greenness, +a* = redness), b* (-b* = blueness, +b* = yellowness), C* (chroma) and H (lightness's angle) were measured using a colourimeter (Chroma Meter, CR-400 Konica Minolta, Japan).

2.6. Data analysis

Data were analyzed statistically using SPSS 17.0 (SPSS, Inc, Chicago, USA). Data were evaluated by two-way variance (ANOVA) analysis. When the F test was significant, means were separated by Duncan's multiple range ($P \leq 0.05$). Regression analysis was carried out by Pearson's correlation.

3. Results

3.1. Tree mortality

Mortality rate was high for some of the rootstocks tested, particularly Felinem and Garnem (Fig. 1). These two rootstocks experienced the highest tree mortality with 100% of dead trees for the ‘Tebana’ cultivar. Therefore, these scion-rootstock combinations were not included in the rest of the study.

For ‘Tebana’ cultivar, Garnem rootstock had lost all replicates at the third year after budding (2001). Felinem experienced more progressive tree mortality with 16.5%, 67% and 16.5% of dead trees in 2000, 2001 and 2006, respectively (Fig. 1). Lower mortality was found for Adafuel and Cadaman with only a single dead tree (16.5%). In contrast, all trees budded on Adarcias and GF 677 survived well to the end of the experiment.

‘Queen Giant’ showed a 33% mortality rate on Felinem at the third year after budding. Nine years after budding, mortality on Garnem was 16.5%. No dead trees were found for Adafuel, Adarcias, Cadaman and GF 677.

3.2. Tree growth, yield, cumulative yield and yield efficiency

Results for ‘Tebana’ include only Adafuel, Adarcias, Cadaman and GF 677 rootstocks, due to the high mortality of trees on Felinem and Garnem (Fig 2). At the twelfth year after budding (2010), the lowest vigour was induced by Adarcias for both cultivars (Table 2). This rootstock showed 37% and 48% reductions in TCSA for ‘Tebana’ and ‘Queen Giant’ respectively, compared to TCSA on GF 677. Contrastingly, the highest TCSA was shown by Garnem and GF 677, although not significant differences were found with Felinem for ‘Queen Giant’ (Table 2). For this cultivar, vigour of Cadaman was intermediate, showing a 31% reduction in TCSA compared to GF 677 at the end of the experiment. A similar trend was found from year 2001 to 2010 (Fig. 2).

In general, throughout the last 6 years of the study, highest fruit yields were induced by Felinem and GF 677 for 'Queen Giant', and Cadaman and GF 677 for 'Tebana' (data not shown). For 'Queen Giant', cumulative yield was greater on Felinem, although not significantly different from Garnem. For 'Tebana', cumulative yield was higher on Cadaman, GF 677 and Adafuel (Table 2). The lowest cumulative yield was recorded on the less vigourous rootstock Adarcias. Yield efficiency was greatest on Cadaman for both cultivars, but not significantly different for 'Queen Giant' on Felinem. For this cultivar, the lowest yield efficiency was recorded on Adafuel and GF 677, although they did not differ significantly from Garnem.

3.3. Fruit quality traits

Table 3 shows factors affecting fruit quality parameters in both cultivars. ANOVA results showed no significant interaction between rootstock and year, except for the ripening index of 'Queen Giant' with a significance value of 0.05. The significant effect of year was found for all traits except for SSC in 'Tebana' cultivar.

For 'Queen Giant', the highest mean fruit weight was recorded on Adafuel, Cadaman and GF 677, and the lowest on Adarcias, although not significantly different from Felinem (Table 4). For soluble solids content (SSC), the greatest values were recorded on Adarcias and Cadaman (Table 4) and the lowest on Garnem and GF 677, while Adafuel and Felinem did not significantly differ from either of them. Small but consistent differences in titratable acidity (TA) were found among rootstocks throughout the years of study (Table 4). On average, the highest TA was induced by Cadaman, although it did not differ from Adarcias. The lowest TA was recorded on Garnem, GF 677, Felinem and Adafuel. The highest average ripening index (RI) values were recorded on Adafuel, Adarcias, Felinem and GF 677 and the lowest on Cadaman, although Garnem did not differ from any of them. No consistent differences were found among rootstocks for fruit firmness during the study, except for the first year of analysis (2008) when Cadaman produced the highest firmness of fruits, although it did not differ from Adafuel (Table 4).

Throughout the study, no consistent differences for fruit quality parameters were found among rootstocks for 'Tebana' cultivar, with the exception of fruit weight (Table 4) and chromatic parameters in 2010 (data not shown). On average, Adafuel and Cadaman rootstocks resulted in the largest fruit weight of 'Tebana' peaches, whereas Adarcias and GF 677 induced the lowest (Table 4).

Significant differences were found between rootstocks in L*, a*, b*, C* and H colour parameters for 'Queen Giant' cultivar (Table 5). In 2009, Adafuel and Adarcias induced the highest values for a* and C* parameters, and GF 677 induced the lowest value, although not significantly different from the other rootstocks. In 2010, Adarcias and Cadaman induced higher values for L* parameter, compared to the other rootstocks. For b* and H parameters, Adafuel induced the highest values although not significantly different from Adarcias and Cadaman. In the year 2010, Cadaman induced the highest C* value and GF 677 the lowest on 'Tebana' peach (data not shown). No significant differences were found between Adafuel and Adarcias.

3.4. Phenotypic correlations

A high significant and positive correlation (Table 6) was observed between TCSA and yield for 'Queen Giant' (r = 0.556, $P \leq 0.01$) and 'Tebana' (r = 0.688, $P \leq 0.01$). However, in 'Tebana' cultivar, a significant negative correlation was found between TCSA and fruit weight.

In ‘Queen Giant’, a significant positive correlation was found between TA and flesh firmness (FF), as well as between RI and SSC. On the contrary, a significant negative correlation was found between TCSA and SSC and between TA and fruit weight. In both cultivars, we found a significant positive correlation between yield and FF, SSC and fruit weight, and FF and SSC. Significant negative correlations were also found between SSC and yield, as well as between FF and RI (Table 6).

For both cultivars, significant correlations were observed between year and fruit weight, as well as between year and SSC. There was no correlation between year and TA.

Only hue angle (H) showed a significant negative correlation with TA (r = -0.315, $P \leq 0.01$) in both cultivars, meaning that decreasing the TA will increase the H parameter. No significant relationship was found between colour measurements and FF, SSC or fruit weight (Table 6).

4. Discussion

Twelve years after budding, growing conditions generated varying levels of tree mortality, the highest with Felinem and Garnem rootstocks. For these two rootstocks, 100% of trees died for ‘Tebana’ cultivar. The ‘Tebana’ plot situation was established closer to the irrigation canal than the plot with ‘Queen Giant’, and likely more prone to flooding. For Adafuel and Cadaman, the mortality rate was low. No dead trees were found on Adarcias and GF 677 at the end of the experiment. In these growing conditions, tree mortality could be attributed to the sensitivity of almond x peach hybrid rootstocks to root asphyxia (Felipe, 2009) or susceptibility to various root rot pathogens such as *Phytophtora* spp (Zarrouk et al., 2005).

The lower vigour of Adarcias has already been mentioned (Moreno et al., 1994). Consequently, Adarcias may be suitable for reducing excessive growth of peach cultivars or to increase planting density and to decrease management costs (Moreno and Cambra, 1994). The higher vigour induced by Felinem, Garnem and GF 677 on 'Queen Giant' and Adafuel, Cadaman and GF 677 on 'Tebana' is comparable to that induced by Adafuel with a similar productivity for 'Catherine' and 'Flavortop' cultivars, as described by Moreno et al. (1994). The greater vigour, on fertile and well-irrigated soils, may become excessive for good orchard practice unless some irrigation and other cultural practices are modified. Vigourous rootstock appears suitable for peach production under replanting conditions or in poor and calcareous soils that might otherwise not be favourable for growing peach (Cambra, 1990; Moreno et al., 1994).

Cadaman rootstock induced higher yield efficiency in both cultivars, because of its intermediate vigour and high yield. On the contrary, the tendency of Garnem and GF 677 to show low yield efficiency, is probably due to their high vigour and the resulting high TCSA, as previously reported (Zarrouk et al., 2005). The highest yield of Felinem and GF 677 with 'Queen Giant' and Cadaman and GF 677 with 'Tebana' was already mentioned by Zarrouk et al. (2005) for the first bearing years. In the study performed by Jiménez et al. (2008), GF 677 and Felinem seem to be better adapted than Cadaman and Garnem, among other rootstocks, to calcareous soils with high lime content. This is probably because of a more chlorosis-tolerant almond parent. Such adaptation probably results in higher vigour and yield for GF 677 and Felinem rootstocks. In Zarrouk et al. (2005) it is interesting to note that the most vigourous rootstocks, such as Felinem and Garnem (in our study), have best efficiency of some mineral nutrition (Ca). Furthermore, a positive correlation was found between yield efficiency and flower nutrient concentration for Mg, showing that Cadaman has the maximum value of yield efficiency (in our study) and a maximum concentration of Mg in Zarrouk et al. (2005).

The statistical analysis showed the significant effect of year for all quality traits, except for SSC in ‘Tebana’ cultivar. The year-to-year variation in fruit quality parameters may be explained by the differences in annual temperatures and crop load over the 3 years of study. However, no interaction was found between rootstock and year, except for the ripening index of ‘Queen Giant’. This result suggests that ripening index is more influenced by the environmental conditions over the growing season than the other traits, in agreement with Brooks et al. (1993).

Although all rootstocks exhibited acceptable fruit weight, Adafuel and Cadaman produced the largest fruit weight on both cultivars. The tendency of Adafuel to produce higher fruit weight has been previously reported by Albás et al. (2004) and Moreno et al. (1994). Cadaman, with an intermediate level of vigour, tends to show higher fruit weight probably due to its higher productive efficiency. In ‘Tebana’ cultivar the negative correlation between TCSA and fruit weight is probably due to GF 677 (one of the most vigourous rootstocks) inducing lower fruit weight, in agreement with Tsipouridis and Thomidis (2005).

The tendency of Adarcias and Cadaman to induce higher soluble solids content could be related with their lower vigour, showing a stronger sink competition of fruit compared to vegetative development. The tendency of Adarcias to induce high SSC was already reported by Albás et al. (2004). For ‘Queen Giant’, Cadaman showed, in general the highest titratable acidity, although it did not differ from Adarcias. Despite higher acidity of fruits on these rootstocks, their SSC was not affected. High sugar contents and, to a lower extent, high acid contents seem to be favourable to fruit quality as evaluated by consumers (Crisosto and Crisosto, 2005).

The negative correlation between yield and SSC for 'Queen Giant' and 'Tebana' cultivars confirms the sink competition among fruits by the assimilate supply (Mounzer et al., 2008). Titratable acidity was negatively correlated with fruit weight for both cultivars, showing that titratable acidity decreases with fruit mass (Cantín et al., 2010). No significant differences for flesh firmness were found among rootstocks, with the exception of the first sampling year for 'Queen Giant'. Firmness was significantly positive correlated with TA, reflecting the decrease of acidity with fruit softening. Also, the positive correlations between SSC and firmness are in agreement with other studies in peach (Abidi et al., 2011; Cantín et al., 2010) and in sweet cherry (Jiménez et al., 2004), showing that firmer fruits have higher sugar content.

Fruits on Cadaman rootstock showed, in general, the most luminous colour (higher L* parameter), although it did not differ from Adarcias. Conversely, Adafuel and Adarcias seem to induce redder and darker fruit to 'Queen Giant' nectarines (higher a* and b* parameters). However, in the study of Albás et al. (2004) 'Catherina' trees on GF 677 induced a darker red skin than Adafuel and Adarcias (a* and b* parameters). Significant negative relationships were observed between the Hue angle (H parameter) and titratable acidity. In general, high Hue angle values could indicate low acidity, in agreement with Génard et al. (1994) and Ruíz and Egea (2008). Colour measurements in general are good predictors for fruit quality parameters except for the fruit firmness because fruits with the same hue angle may have different firmness (Lewallen and Marini, 2003).

The results of correlations among agronomical and fruit quality parameters show the important relationships between the characteristics of yield, vigour, fruit weight and fruit quality traits. However, for each rootstock type, the most appropriate combination of plant training and cultivation system can help to increase the yield efficiency and fruit size, while retaining their adaptability and fruit quality. These results underline the important relationships between plant adaptability and development and the major factors of fruit quality.

5. Conclusions

The results of this study show the influence of different peach-almond hybrid rootstocks on tree performance. In these growing conditions, Adarcias and GF 677 rootstocks superior adaptation is obviated by the absence of dead trees, twelve years after budding, especially when compared with Garnem and Felinem, likely the most susceptible rootstocks to root asphyxia conditions. Cadaman induced the highest yield efficiency for both cultivars. Cadaman and Adarcias rootstocks seem to induce higher fruit quality, probably because of their lower vigour and stronger sink competition of fruit versus vegetative growth.

Acknowledgments

We thank R. Giménez and J. Aparicio for technical assistance. We gratefully acknowledge S. Jiménez for statistical analysis and C. Fleck for critical review of the manuscript. This study was funded by the Spanish MICINN (Ministry of Science and Innovation) grants AGL2005-05533, AGL2008-00283 and AGL2011-24576, and RFP 2009-00016 cofunded by FEDER and the Regional Government of Aragon (A44). C. Font was supported by a JAE fellowship from CSIC (Consejo Superior de Investigaciones Científicas).

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.

Albás, E.S., Jiménez, S., Aparicio, J., Betrán, J.A., Moreno, M.A., 2004. Effect of several almond × peach hybrid rootstocks on fruit quality of peaches. Acta Hort. 658, 321-326.

Bernhard, R., Grasselly, C., 1981. Les pêchers x amandiers. L'Arboriculture Fruitière 328, 37-42.

Byrne, D.H., Nikolic, A.N., Burns, E.E., 1991. Variability in sugars, acids, firmness, and colour characteristics of 12 peach genotypes. J. Am. Soc. Hortic. Sci. 116, 1004-1006.

Brooks, S.J., Moore, J.N., Murphy, J.B., 1993. Quantitative and qualitative changes in sugar content of peach genotypes [*Prunus persica* (L.) Batsch]. J. Am. Soc. Hortic. Sci. 118, 97-100.

Cambra, R., 1990. Adafuel, an almond x peach hybrid rootstock. HortScience 25, 584-584.

Cantín, C.M., Gogorcena, Y., Moreno, M.A., 2010. Phenotypic diversity and relationships of fruit quality traits in peach and nectarine [*Prunus persica* (L.) Batsch] breeding progenies. Euphytica 171, 211-226.

Caruso, T., Giovanni, D., Liverani, A., 1996. Rootstock influences the fruit mineral, sugar and organic acid content of a very early ripening peach cultivar. J. Hortic. Sci. 71, 931-937.

Crisosto, C.H., Crisosto G.M., 2005. Relationship between ripe soluble solids concentration (RSSC) and consumer acceptance of high and low acid melting flesh peach and nectarine (*Prunus persica* (L.) Batsch) cultivars. Postharv. Biol. Technol. 38, 239-246.

Edin, M., Garcin, A., 1994. Un nouveau porte greffe du pêcher Cadaman-Avimag. L'Arboriculture Fruitière 475, 20-23.

FAOSTAT (2011) http://faostat.fao.org/

Felipe, A.J., 2009. Felinem, Garnem, and Monegro almond x peach hybrid rootstocks. HortScience 44, 196-197.

Génard, M., Souty, M., Holmes, S., Reich, M., Breuils, L., 1994. Correlations among quality parameters of peach fruit. J. Sci. Food. Agric. 66, 241-245.

Giorgi, M., Capocasa, F., Scalzo, J., Murri, G., Battino, M., Mezzetti, B., 2005. The rootstock effects on plant adaptability, production, fruit quality, and nutrition in the peach (cv 'Suncrest'). Sci. Hortic. 107, 36-42.

Jiménez, S., Garín, A., Albás, E.S., Betrán, J.A., Gogorcena, Y., Moreno, M.A., 2004. Effect of several rootstocks on fruit quality of 'Sunburst' sweet cherry. Acta Hort. 658, 353-358.

Jiménez, S., Pinochet, J., Abadía, A., Moreno, M.A., Gogorcena, Y., 2008. Tolerance response to iron chlorosis of *Prunus* selections as rootstocks. HortScience 43, 304-309.

Jiménez, S., Pinochet, J., Romero, J., Gogorcena, Y., Moreno, M.A., Espada, J.L., 2011. Performance of peach and plum based rootstocks of different vigour on a late peach cultivar in replant and calcareous conditions. Sci. Hortic. 129, 58-63.

Kramer, A., Twigg, B.A., 1996. Fundamentals of quality control for the food industry, Avi Westport, CT, pp 512.

Lewallen, K.S., Marini, R.P., 2003. Relationship between flesh firmness and ground colour in peach as influenced by light and canopy position. J. Am. Hortic. Sci. 128, 163-170.

Loreti, F., Massai, R., 2002. The high density peach planting system: Present status and perspectives. Acta Hort. 592, 377-390.

Moreno, M.A., Cambra, R., 1994. Adarcias - an almond x peach hybrid rootstock. HortScience 29, 925-925.

Moreno, M.A., Webster, A.D., 2004. Proceedings of the 1st international symposium on rootstocks for deciduous fruit tree species, vols 1 and 2. Acta Hort. 658, 519-528.

Moreno, M.A., Tabuenca, M.C., Cambra, R., 1994. Performance of Adafuel and Adarcias as peach rootstocks. HortScience 29, 1271-1273.

Mounzer, O.R., Conejero, W., Nicolás, E., Abrisqueta, I., García-Orellana, Y.V., Tapia, L.M., Vera J., Abrisqueta, J.M., Ruíz-Sánchez, M.D., 2008. Growth pattern and phenological stages of early-maturing peach trees under a Mediterranean climate. HortScience 43, 1813-1818.

Pinochet, J., 2009. ‘Greenpac’, a new peach hybrid rootstock adapted to Mediterranean conditions. HortScience 44, 1456-1457.

Remorini, D., Tavarini, S., Degl'Innocenti, E., Loreti, F., Massai, R., Guidi, L., 2008. Effect of rootstocks and harvesting time on the nutritional quality of peel and flesh of peach fruits. Food Chem. 110, 361-367.

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

Tsipouridis, C., Thomidis, T., 2005. Effect of 14 peach rootstocks on the yield, fruit quality, mortality, girth expansion and resistance to frost damages of May Crest peach variety and their susceptibility on *Phytophthora citrophthora*. Sci. Hortic. 103, 421-428.

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.

Figure captions

Fig. 1. Tree mortality rate (%) from the second (2000) to the twelfth (2010) year after budding

Fig. 2. Effect of rootstock on TCSA (cm^2) of 'Queen Giant' (a) and 'Tebana' (b) cultivars during 10 years of study. Vertical lines indicate LSD ($P \leq 0.05$)

Tables

Table 1

List of studied rootstocks, description and origin

Rootstock	Species	Genetic background	Origin[a]	References
Adafuel	*P. amygdalus* x *P. persica*	'Marcona' seedlings (open-pollinated)	CSIC, Spain	Cambra (1990)
Adarcias	*P. amygdalus* x *P. persica*	Open-pollinated	CSIC, Spain	Moreno and Cambra (1994)
Cadaman	*P. davidiana* x *P. persica*	Controlled cross	INRA (France-Hungary)	Edin and Garcin (1994)
Felinem	*P. amygdalus* x *P. persica*	'Garfi' almond x 'Nemared' peach	CITA, Spain	Felipe (2009)
Garnem	*P. amygdalus* x *P. persica*	'Garfi' almond x 'Nemared' peach	CITA, Spain	Felipe (2009)
GF 677	*P. amygdalus* x *P. persica*	Open-pollinated	INRA, France	Bernhard and Grasselly (1981)

[a] CSIC = Consejo Superior de Investigaciones Científicas; INRA = Institut National de la Recherche Agronomique; CITA = Centro de Investigación y Tecnología Agroalimentaria de Aragón.

Table 2

Effect of rootstock on TCSA (trunk cross-sectional area), cumulative yield and yield efficiency of ‘Queen Giant’ and ‘Tebana’, at the twelfth year after budding (2010)

Cultivar	Rootstock	TCSA (cm^2)	Cumulative yield (kg $tree^{-1}$)	Yield efficiency (kg cm^{-2})
‘Queen Giant’	Adafuel	225.0 bc	224.0 b	0.99 a
	Adarcias	155.1 a	164.4 a	1.06 bc
	Cadaman	206.3 b	279.3 b	1.35 d
	Felinem	254.7 cd	306.9 c	1.20 cd
	Garnem	272.4 d	278.5 bc	1.02 ab
	GF 677	297.5 d	244.2 b	0.82 a
‘Tebana’	Adafuel	238.0 b	255.6 b	1.07 a
	Adarcias	146.1 a	154.4 a	1.06 a
	Cadaman	209.0 b	306.1 b	1.47 b
	GF 677	231.0 b	289.5 b	1.25 a

For each cultivar, 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.

Table 3

ANOVA analysis of the effect of rootstock and year on fruit quality traits in 'Queen Giant' and 'Tebana' cultivars for the average of the 3 years of study

Cultivar	Source of variation[1]	FW	SSC	TA	RI	FF	L*	a*	b*	C*	H
'Queen Giant'	Rootstock (R)	***	*	***	**	*	ns	ns	ns	ns	ns
	Year (Y)	*	***	*	***	***	***	***	***	***	***
	RxY	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
'Tebana'	Rootstock (R)	ns	**	ns	ns	ns	ns	ns	ns	*	ns
	Year (Y)	**	ns	***	***	***	***	***	***	***	***
	RxY	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]Data were evaluated by two-way variance (ANOVA); ****P*≤0.001; ***P*≤0.01; **P*≤0.05; ns, not significant. FW, fruit weight; SSC, soluble solids content; TA, titratable acidity; RI, ripening index; FF, flesh firmness; L*, a*, b*, C* and H, chromatic parameters.

Table 4

Effect of rootstock on fruit weight, soluble solids content, titratable acidity, ripening index and flesh firmness of ‘Queen Giant’ and ‘Tebana’ cultivars at the tenth (2008), eleventh (2009) and twelfth (2010) year after budding

Cultivar	Character	Rootstock	2008	2009	2010	Average
‘Queen Giant’	Fruit weight (g)	Adafuel	246 c	223 b	233 ab	234 c
		Adarcias	189 a	185 a	221 ab	198 a
		Cadaman	226 bc	228 b	234 ab	229 c
		Felinem	201 ab	219 b	215 a	212 ab
		Garnem	215 bc	210 ab	231 ab	219 b
		GF 677	229 bc	223 b	248 b	233 c
	SSC (ºBrix)	Adafuel	11.7 ab	10.3 ab	10.1 ab	10.7 ab
		Adarcias	12.6 b	11.0 b	10.8 b	11.5 b
		Cadaman	12.2 b	10.7 ab	10.3 ab	11.1 b
		Felinem	11.7 ab	10.9 ab	10.2 ab	10.9 ab
		Garnem	11.5 ab	9.9 a	9.8 a	10.4 a
		GF 677	10.7 a	10.5 ab	10.5 ab	10.6 a
	Titratable acidity	Adafuel	0.85 ab	0.75 ab	0.82 a	0.81 a
		Adarcias	0.81 a	0.82 bc	0.90 ab	0.88 ab
		Cadaman	0.94 b	0.87 c	0.99 b	0.93 b
		Felinem	0.77 a	0.73 a	0.88 ab	0.79 a
		Garnem	0.77 a	0.75 a	0.83 a	0.78 a
		GF 677	0.74 a	0.77 ab	0.87 a	0.79 a
	Ripening index	Adafuel	13.0 a	15.0 b	14.7 b	14.2 b
		Adarcias	15.0 a	13.5 ab	11.9 a	13.4 b
		Cadaman	12.9 a	12.3 a	10.9 a	12.0 a
		Felinem	14.8 a	14.9 b	12.7 ab	14.1 b
		Garnem	14.8 a	13.3 ab	11.5 a	13.2 ab
		GF 677	14.4 a	13.6 ab	13.3 ab	13.8 b
	Flesh firmness (N)	Adafuel	24.1 ab	32.2 a	35.5 a	30.6 a
		Adarcias	20.2 a	34.6 a	38.2 a	30.8 a
		Cadaman	26.7 b	36.1 a	40.8 a	34.5 a
		Felinem	17.7 a	35.7 a	38.6 a	30.7 a
		Garnem	17.2 a	30.5 a	33.9 a	27.2 a
		GF 677	13.7 a	31.9 a	36.3 a	27.3 a
‘Tebana’	Fruit weight (g)	Adafuel	174 a	208 a	214 b	199 b
		Adarcias	164 a	184 a	195 ab	181 a
		Cadaman	176 a	184 a	215 b	192 b
		GF 677	177 a	184 a	184 a	182 a
	SSC (ºBrix)	Adafuel	11.5 a	11.6 a	11.2 a	11.4 a
		Adarcias	12.3 a	12.2 a	11.8 a	12.1 a
		Cadaman	12.0 a	12.2 a	12.1 a	12.1 a
		GF 677	11.6 a	11.4 a	11.0 a	11.3 a
	Titratable acidity	Adafuel	0.33 a	0.40 a	0.55 a	0.43 a
		Adarcias	0.36 a	0.42 a	0.54 a	0.44 a
		Cadaman	0.35 a	0.39 a	0.56 a	0.43 a
		GF 677	0.38 a	0.38 a	0.49 a	0.42 a
	Ripening index	Adafuel	34.0 a	28.9 a	24.5 a	29.2 a
		Adarcias	34.3 a	29.4 a	22.0 a	28.6 a
		Cadaman	34.5 a	31.4 a	24.5 a	30.1 a
		GF 677	31.0 a	29.8 a	23.0 a	27.9 a
	Flesh firmness (N)	Adafuel	21.6 a	30.6 a	34.3 a	28.8 a
		Adarcias	19.5 a	30.1 a	34.6 a	28.1 a
		Cadaman	18.3 a	28.8 a	33.3 a	26.8 a
		GF 677	25.7 a	29.1 a	33.3 a	29.4 a

For each year and character, 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. SSC, soluble solids content; titratable acidity (g malic acid per 100 g FW); ripening index, SSC/TA.

Table 5

Rootstock effect on chromatic parameters (L*= lightness; a*= redness and greenness; and b*= yellowness and blueness; C*= chroma; H= lightness's angle) of 'Queen Giant' budded on different rootstocks, at the eleventh and the twelfth year after budding

Character	Rootstock	2009	2010	Average
L*	Adafuel	40.8 a	49.9 a	45.4 a
	Adarcias	41.5 a	50.4 b	46.0 ab
	Cadaman	42.0 a	51.1 b	46.5 b
	Felinem	41.8 a	45.9 a	43.9 a
	Garnem	41.9 a	45.4 a	43.7 a
	GF 677	41.5 a	45.2 a	43.3 a
a*	Adafuel	41.9 b	35.6 a	38.7 a
	Adarcias	42.2 b	37.7 a	39.9 a
	Cadaman	40.9 ab	35.4 a	38.2 a
	Felinem	41.4 ab	39.2 a	40.3 a
	Garnem	41.6 ab	39.4 a	40.4 a
	GF 677	39.8 a	39.7 a	39.7 a
b*	Adafuel	18.5 a	21.4 b	19.9 b
	Adarcias	18.1 a	21.0 ab	19.6 ab
	Cadaman	18.9 a	19.2 ab	19.0 ab
	Felinem	18.5 a	19.2 a	18.9 a
	Garnem	18.1 a	19.3 a	18.7 a
	GF 677	17.9 a	19.1 a	18.5 a
C*	Adafuel	45.9 b	42.1 a	44.0 a
	Adarcias	46.0 b	43.5 a	44.8 a
	Cadaman	42.2 ab	41.6 a	42.0 a
	Felinem	40.5 ab	43.9 a	44.7 a
	Garnem	45.1 ab	44.1 a	44.6 a
	GF 677	43.7 a	44.2 a	43.9 a
H	Adafuel	23.8 a	32.5 b	28.1 a
	Adarcias	23.2 a	30.1 ab	26.7 a
	Cadaman	24.8 a	31.8 ab	28.3 a
	Felinem	24.1 a	26.5 a	25.3 a
	Garnem	23.1 a	26.3 a	25.0 a
	GF 677	24.1 a	25.8 a	25.1 a

For each year and parameter, 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.

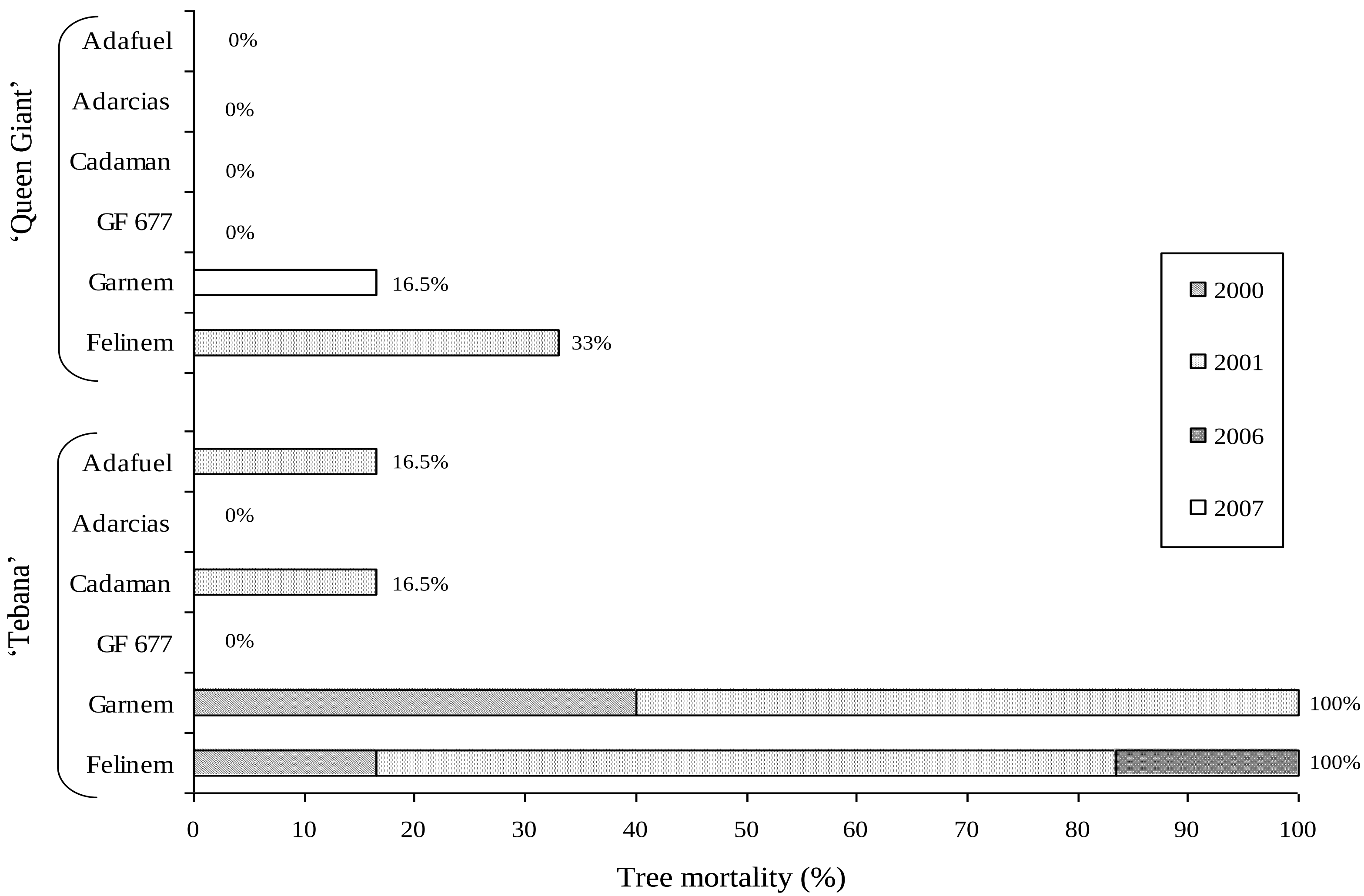
Table 6

Pearson's correlations coefficients between traits observed over three years (2008-2009-2010) in almond x peach hybrid rootstocks budded with 'Queen Giant' and 'Tebana' cultivars for the average of the 3 years of study

Cultivar	Trait	TCSA	Fruit weight	SSC	TA	FF	RI
'Queen Giant'	Yield	0.556**	ns	-0.505**	ns	0.482**	ns
	Year	ns	0.520**	0.427**	ns	ns	ns
	H (colour)	ns	ns	ns	-0.315**	ns	ns
	Fruit weight	ns	-	0.362**	-0.319*	ns	ns
	SSC	-0.491**	-	-	ns	0.311*	0.582**
	TA	ns	-	-	-	0.408*	ns
	FF	ns	-	-	-	-	-0.431*
'Tebana'	Yield	0.688**	ns	-0.379**	ns	0.300**	ns
	Year	ns	0.630**	0.392**	ns	ns	ns
	H (colour)	ns	ns	ns	-0.315**	ns	ns
	Fruit weight	-0.479**	-	0.392*	-0.437*	ns	ns
	SSC	ns	-	ns	ns	ns	ns
	TA	ns	-	-	-	0.695*	ns
	FF	ns	-	-	-	-	-0.717**

ns, not significant; *P≤0.05; **P≤0.01. Abbreviations: TCSA, trunk cross-sectional area; SSC, soluble solids content; TA, titratable acidity; FF, flesh firmness; RI, ripening index.

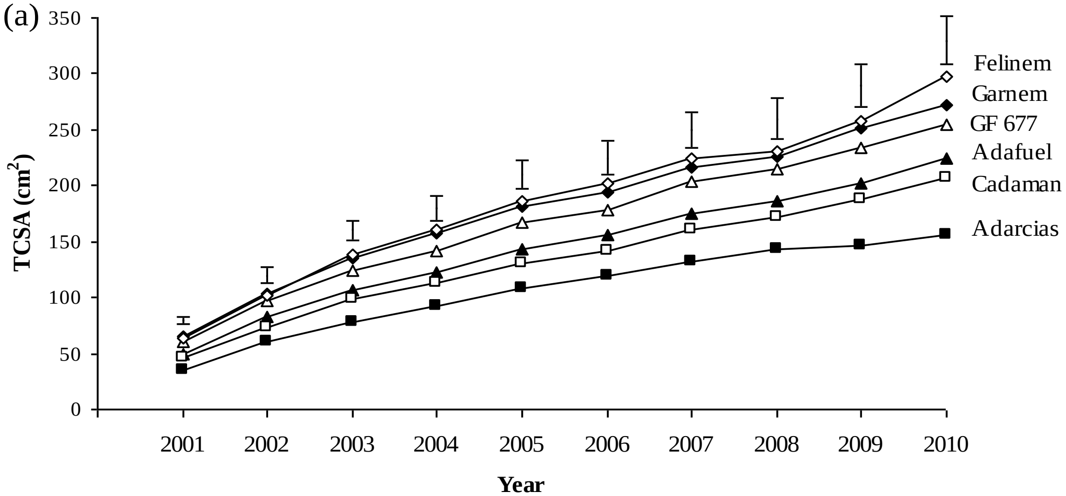
Figure



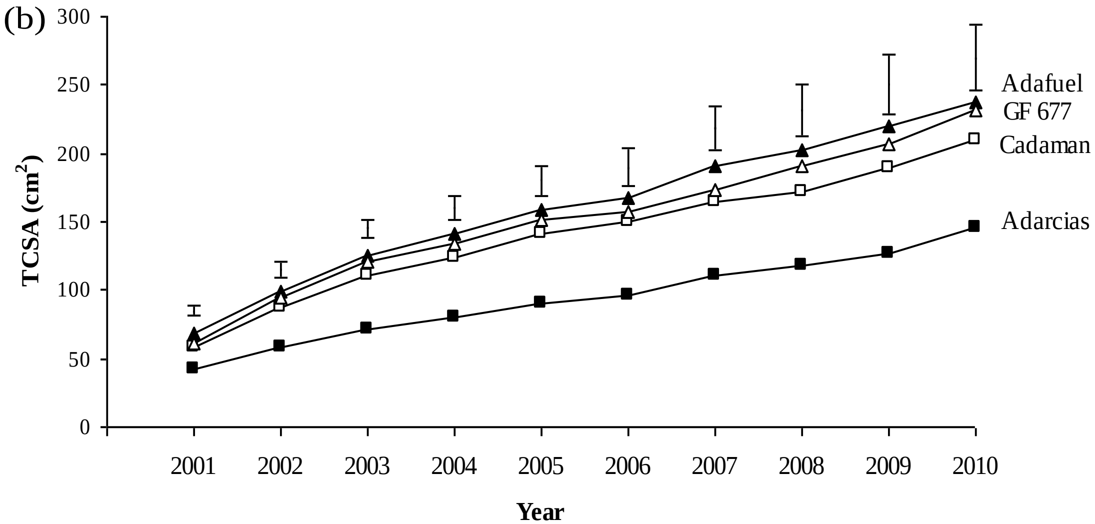
'Queen Giant'
Adafuel
0%
Adarcias
0%
Cadaman
0%
GF 677
0%
Garnem
16.5%
Felinem
33%
'Tebana'
Adafuel
16.5%
Adarcias
0%
Cadaman
16.5%
GF 677
0%
Garnem
100%
Felinem
100%
2000
2001
2006
2007
0
10
20
30
40
50
60
70
80
90
100
Tree mortality (%)

Figure

(a)


350
300
250
200
150
100
50
0
TCSA (cm²)
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year
Felinem
Garnem
GF 677
Adafuel
Cadaman
Adarcias

(b)


300
250
200
150
100
50
0
TCSA (cm²)
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year
Adafuel
GF 677
Cadaman
Adarcias