Growth, yield and fruit quality of 'Van' and 'Stark Hardy Giant' sweet cherry cultivars as influenced by grafting on different rootstocks

Celia M. Cantín[a], Jorge Pinochet[b], Yolanda Gogorcena[a], María Ángeles Moreno[a,*]

[a]Departamento de Pomología, Estación Experimental de Aula Dei (CSIC). Apdo. 13034, 50080 Zaragoza, Spain

[b]Agromillora Catalana S.A., C/El Rebato s/n, 08739 Subirats, Barcelona, Spain

Abstract

The influence of Adara, CAB 6P, Gisela 5, MaxMa 14, Saint Lucie GF 64 (SL 64), Santa Lucía GF 405 (SL 405), and Tabel rootstocks onto vegetative growth, yield and fruit quality of ‘Van’ and ‘Stark Hardy Giant’ sweet cherry cultivars was studied during ten years after grafting. The experiment was performed in the Ebro Valley (Zaragoza, Spain), on a heavy and calcareous soil. Significant differences in some of these parameters such as vigour, yield, fruit size, soluble solids content (SSC), titratable acidity (TA), skin colour and fruit firmness were examined among rootstocks. In general, the highest vigour, annual and cumulative yield were induced by Adara rootstock, whereas Gisela 5 induced the lowest when grafted with both cultivars., The highest yield efficiency was induced by Gisela 5 due to its low trunk cross-sectional area (TCSA), together with Adara, CAB 6P and Tabel for ‘SHG’ cultivar. Regarding fruit quality, Adara, CAB 6P and MaxMa 14 showed, in general, the highest fruit weight and the more attractive skin colour for both sweet cherry cultivars. Furthermore, the high yield shown by Adara did not significantly affect its fruit size. Cherries of trees grafted on Adara also showed high firmness, which implies a better resistance to post-harvest damage. CAB 6P showed a tendency to induce higher TA. Despite the higher firmness of fruits on Gisela 5 and its tendency to induce higher SSC and Ripening Index, the smaller size fruits together with the less attractive skin colour resulted in a non interesting rootstock in terms of fruit quality for our growing conditions. Interesting correlations were found among quality parameters, such as the positive correlation showed by SSC with fruit weight and TA. The work demonstrates that the scion-rootstock combination influences some important sweet cherry attributes such as vigour, yield, fruit size, acidity, skin colour and firmness.

Key words: fruit weight, SSC, TCSA, acidity, colour.

1. Introduction

Different studies with *Prunus sp.* have demonstrated that rootstock influences the performance of the grafted scion cultivar. There have been numerous reports of a relationship between cherry rootstocks and water relations, leaf gas exchange, mineral uptake, plant size, blossoming, fruit bud survival, fruit quality and yield efficiency (Betrán et al., 1997; Davis et al., 2008; Facteau et al., 1996; Jiménez et al., 2004; Jiménez et al., 2007; Larsen et al., 1987; Millikan and Hibbard, 1984). Westwood et al. (1973) reported that the most common effects of rootstocks on fruit quality are differences of firmness, levels of organic acids and sugar content. However, a better understanding of the relationships between some cherry fruit quality attributes and rootstock influence is needed to achieve favourable scion/rootstock combinations for specific growing areas. Sweet cherries have expanded rapidly in Spain over the past decade to current annual production levels of around 90,000 tonnes (MARM, 2007), and Spain is now the third largest producer of sweet cherries in the world (FAOSTAT, 2007). In turn, the Ebro Valley is the first producer region in Spain, and consequently one of the most important productive areas of Europe with an average of around 28,000 tonnes per year over the last three years.

The previously cited vegetative and quality traits are very important for horticulture since they supply the base for the selection of the best rootstock-scion cultivar combination for specific climatic conditions and soil types. Furthermore, nowadays breeders are not only interested in productivity, but also in better fruit quality (Byrne, 2002; Cevallos-Casals et al., 2006). However, it is unlikely that a single rootstock will have all of these attributes (Westwood and Bjornstad, 1970).

The three most 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 (Crisosto et al., 2003), and these properties are highly influenced by rootstocks. According to Usenik et al. (2006), studies on cultivar-rootstock responses to specific growing conditions are needed to achieve the main goal of economically viable production of high quality sweet cherries. It is important to find a suitable rootstock for the extensive Mediterranean growing conditions, as well as for particular cultivar characteristics.

The present study was carried out over ten years with ‘Van’ and ‘Stark Hardy Giant’ sweet cherry cultivars, grafted on seven different rootstocks, and grown on typical heavy and calcareous soil conditions in the Ebro Valley (Spain). The aim of this study was to assess the influence of these rootstocks on vegetative growth, yield and fruit quality of ‘Van’ and ‘Stark Hardy Giant’ sweet cherry cultivars.

2. Materials and methods

2.1. Plant material

Seven cherry rootstocks were compared in one trial established in the winter of 1997-1998. They were grafted *in situ* with ‘Stark Hardy Giant’ (‘SHG’) and ‘Van’ mid- to late-maturing sweet cherry cultivars (*Prunus avium* L.) during the summer of 1998.

Rootstocks under evaluation included two sour cherry (*P. cerasus*) selections: CAB 6P and Tabel-Edabriz (Tabel); two selections of *P. mahaleb*: Saint Lucie GF 64 (SL 64) and Saint Lucie GF 405 (SL 405); a *P. cerasifera* rootstock: Adara; one semi-dwarfing selection considered to be of *P. avium* x *P. mahaleb* parentage: MaxMa 14; and a dwarfing *P. cerasus* x *P. canescens*: Gisela 5. Due to bud-take and mortality problems of 'Van' grafted on Tabel and SL 405 respectively, these rootstock-cultivar combinations were not included in the trial.

The trial was carried out at the Experimental Station of Aula Dei (Zaragoza, North-Eastern Spain, latitude around 41.5°) on calcareous soils, with 27% total calcium carbonate, 8% active lime, water pH 8.3, and a clay-loam texture. Trees were planted at 5 x 4 m, and were minimally pruned throughout the experiment, excepting the Spanish Bush developed the first years. This training system controlled tree height by pruning in the summer and fall. The orchard was managed following the usual local procedures. The plot was level-basin irrigated every 12 days during the summer. The experiment was established in a randomized complete block design with five single-tree replications for each scion-stock combination. Guard rows were used to preclude edge effects.

2.2. Vegetative growth, yield and fruit quality attributes

Trunk girths were measured during the dormant season at 20 cm above the graft union, and the trunk cross-sectional area (TCSA) was calculated. Cumulative yield per tree and yield efficiency (cumulative yield in kg per final TCSA) of each scion-stock combination were computed from the harvest data. The annual increasing rate of TCSA was calculated based on the tree growth from the third to the tenth year after grafting, and the average was calculated.

Over the last four years of study, the cherries were hand-picked at commercial maturity over a period of 5-10 days, depending on the year, to assess optimum maturity for a given scion-rootstock combination. Fruits were considered ripe when they no longer grew and exhibited the red ground colour representative for each cultivar. Fruit samples were harvested by a single person to keep consistency of maturity grade. At each harvest, 50 fruits at commercial ripening stage were sampled from each single-tree replication and they were immediately used to determine fruit weight (g), soluble solids content (SSC), titratable acidity (TA) and pH. In 2005, skin colour and fruit firmness were also considered.

Fruit juice SSC from each sample was measured using an Atago PR-101 digital refractometer and expressed in ºBrix. Titratable acidity (TA) was determined in a sample of juice from 50 fruits. The juice samples were diluted with distilled water (1:10), and microtitrated with 0.1 N NaOH. Firmness was estimated by a durometer (Shore A, Durofel), a non-destructive method, whose value (from 0 to 100 durofel graduation) is a relative value of firmness (Kappel et al., 2000). The ripening index (RI) was calculated based on the SSC/acidity ratio (Ferrer, 1998). Skin colour was measured in 50 fruits with a tristimulus colourimeter (Minolta CR-200 Chroma Meter, Minolta, Japan) having an 8-mm-diameter viewing area. Values of lightness (L*), redness and greenness (a* and –a*) and yellowness and blueness (b* and –b*) on the hue circle (Voss, 1992) were measured to describe a three-dimensional colour space. The values presented for each measurement date are the means of triplicate measures on equidistant points of each fruit.

2.3. Data analysis

Data were evaluated by analysis of variance with SPSS 17.0 (SPSS, Inc, Chicago, USA). When the F test was significant, means were separated by Duncan's Multiple Range Test ($P \leq 0.05$). The relationship between quality parameters was examined using a bilateral Pearson correlation.

3. Results

3.1. Vegetative growth and yield

Tree growth: Tree size, as assessed by TCSA, was significantly affected by rootstock starting from the fourth year after grafting (Fig. 1). The increasing rate of TCSA was highly affected by the rootstocks (Table 1), being higher for Adara in both cultivars. Gisela 5 by far showed the lowest annual increasing rate in both cultivars, with an increase lower than 5 cm^2/year for 'SHG' cultivar, and lower than 12 cm^2/year for 'Van' cultivar. In the tenth year after grafting (Table 1), trees grafted on Adara showed the highest TCSA value for both cultivars, although differences were not significant with MaxMa 14 and SL 64. The lowest TCSA was shown by Gisela 5 for both cultivars, although no significant differences were found with CAB 6P and Tabel for 'Van' and 'SHG', respectively.

Yield: In the first bearing years (2001-2002), yields were very low, and there were no significant rootstock differences (data not shown). However, in 2005, differences among rootstocks became evident (Table 2). Throughout the last four years of the study, Adara induced, in general, the highest yield for both cultivars, while dwarfing Gisela 5 induced the lowest. Fruit yield was also affected by cultivar, being greater in 'Van' than in 'SHG'. A significant ($P \leq 0.01$) high correlation was observed for both cultivars between tree vigour (TCSA) and yield ($r = 0.780$ and $r = 0.811$ for 'Van' and 'SHG', respectively).

Cumulative yield and yield efficiency: By year ten after grafting, the cumulative yield was greater on Adara rootstock for both cultivars (Table 1), although no significant differences were shown when compared with CAB 6P for 'SHG'. However, the highest yield efficiency was recorded on Gisela 5 for both cultivars, although no significant differences were found for 'SHG' when compared with Adara, CAB 6P and Tabel. In this study, CAB 6P induced greater yield efficiency than MaxMa 14 and SL 64 rootstocks (Table 1). MaxMa 14 and both *P. mahaleb* selections showed the lowest yield efficiency for both cultivars.

3.2. Fruit quality

Fruit size was affected by rootstock in both cultivars (Tables 3 and 4). For 'Van' cultivar, CAB 6P showed a tendency to induce bigger, heavier fruit, being significantly higher than Gisela 5 in the four years of study. Significant differences were also found between CAB 6P and Adara in the second and fourth year of study when yields were higher for all the rootstock/scion combinations, especially for Adara (Table 2). In a similar way for 'SHG', the highest fruit weight was induced by Adara, CAB 6P, MaxMa 14 and both *P. mahaleb* rootstocks. In contrast, Gisela 5 and Tabel induced the lowest fruit weights. Gisela 5 showed the lowest yield and had the smallest fruit size for both cultivars. Fruit weight was variable over the years for both cultivars. In general, bigger fruits were harvested in 2007 when yield was lower. However, no significant correlation was found between yield and fruit weight over the four years of study, with the exception of 'Van' cultivar in 2008 (r = -0.476, $P \leq 0.05$). Regarding rootstocks, only Gisela 5 showed a significant negative correlation ($P \leq 0.01$) between yield and fruit weight for both 'Van' (r = -0.462) and 'SHG' (r = -0.612) cultivars.

Soluble solids content (SSC): No consistent differences were found among rootstocks for SSC along the study for any of the cultivars (Tables 3 and 4). In general, higher SSC values were obtained for both 'Van' and 'SHG' cultivars in 2007, when yield was lower than other years. Higher SSC was shown by Gisela in 2007 for 'Van' (Table 3), whereas lower SSC was found for 'SHG' in 2006. On the other hand, SSC showed significant positive correlations ($P \leq 0.01$) with fruit weight and TA for 'Van' (r = 0.763 and r = 0.642, respectively) and 'SHG' cultivars (r = 0.522 and r = 0.557, respectively). The correlation between fruit weight and SSC was higher in 'Van' cultivar than in 'SHG' cultivar when studied separately for each rootstock-scion combination.

Acidity: Regarding titratable acidity (TA), small but not consistent differences were found among rootstocks for both cultivars through the years of study. In average, the lowest values were recorded in 'Van' trees grafted on Gisela 5, without being significantly different from Adara (Table 3). In contrast, the *P. cerasus* CAB 6P showed a tendency to induce the highest TA among the rootstocks over the years, although no differences were observed in 2007. For 'SHG' cultivar (Table 4), trees grafted on Tabel and *P. mahaleb* selections showed, in general, the lowest TA values, although no consistent differences were observed throughout the years of evaluation. Any significant difference was found in TA for 'SHG' in the seventh year (2005) after grafting. No effect of rootstock on fruit pH was found for any of the cultivars and years of study (data not shown).

Similarly to what occurred with SSC, TA was significantly correlated with fruit weight for 'Van' cultivar cherries (r = 0.533, $P \leq 0.01$), showing that TA increased with fruit mass. However, no correlation was found in the case of 'SHG'. As mentioned, TA showed a significant positive correlation with SSC for both 'Van' and 'SHG' cultivars, and negative, as expected, with pH (r = -0.491 and r = -0.450, respectively) and RI (r = -0.407 and r = -0.717, respectively).

SSC/acid ratio (ripening index): Ripening index (RI) values for each scion/cultivar combination along the study were comparable, which assures a similar ripening stage of evaluated cherries over the years. Slight significant differences ($P \leq 0.05$) were found among rootstocks on the ripening index (RI) for both cultivars along the study. Fruits of ‘Van’ trees (Table 3) showed a tendency to have higher RI when grafted on Gisela 5, SL 64 and Adara rootstocks, both in 2006 and in the four years average, as well as on Gisela 5, MaxMa 14 and SL 64 in 2008, although no significant differences were found in the lower yielding years. Fruits from ‘SHG’ trees (Table 4) showed, in general, higher RI when grafted on Tabel, both *P. mahaleb* selections (SL 64 and SL 405) and MaxMa 14, although no differences were found in 2006. A slight positive correlation ($P \leq 0.01$), was found among RI and fruit weight for both cultivars ($r= 0.225$ and $r= 0.289$ for ‘Van’ and ‘SHG’, respectively).

Fruit firmness: With regard to fruit firmness, rootstock effect was observed in cherries from both cultivars. ‘Van’ and ‘SHG’ cherries had the highest firmness when grafted on Gisela 5 and Adara rootstocks (Table 5). The *P. mahaleb* selections including MaxMa 14 appear to induce lower firmness. The rest of the rootstocks induced intermediate firmness values. In general, high firmness values were measured in ‘Van’ fruits than in ‘SHG’. Firmness showed significant negative correlation with pH in ‘Van’ cultivar cherries ($r = -0.414$, $P \leq 0.01$). Similarly, firmness showed a significant positive correlation with TA in ‘SHG’ cherries ($r = 0.439$, $P \leq 0.01$).

Fruit colour: Significant differences were found between rootstocks in L* parameter for both cultivars. In the case of ‘Van’ cultivar, Adara showed significant higher L* parameter than Gisela 5 and SL 64. Similarly, in ‘SHG’ cultivar, L* parameter on Adara fruits was significantly higher than on CAB 6P, Gisela 5, and both *P. mahaleb* selections (SL 405 and SL 64) fruits. With regard to a* and b* parameters, the highest values for ‘Van’ cultivar were found when grafting on MaxMa 14, without being significantly different from Adara. For ‘SHG’ cultivar, the highest a* and b* values were recorded on Adara, and the lowest on SL 64, as for ‘Van’ cultivar. However, significant differences were only found when comparing Adara to Gisela 5 and SL 64.

4. Discussion

4.1. Vegetative growth and yield

The high vigour and yield shown by Adara has already been reported (Jiménez et al., 2007; Moreno et al., 1996), and could be explained by its best nutrient status in heavy and calcareous soils. The better adaptation of Adara to the growing conditions may explain larger fruit retention, and thus a better overall performance in yield. It has also been reported that these greater growth properties could induce a higher growth rate in the scion through increasing the supply of specific cytokinins (eg. zeatin riboside) to the shoot (Sorce et al., 2002b). The significant high correlation observed between tree vigour (TCSA) and yield for both cultivars was expected. The high vigour shown by Adara rootstock (Fig. 1) may be recommendable when planting on poor soils or under replant conditions (Moreno et al., 1996).

On the other hand, the low TCSA shown by Gisela 5 for both cultivars was already observed by Jiménez et al. (2007) for the former years. In the Mediterranean area, the poor growth induced by Gisela 5 has been previously reported (De Salvador et al., 2001; Gonçalves et al., 2007). However, it has been reported as one of the most yield efficient and precocious rootstocks for sweet cherry in continental climate areas (Ruisa and Rubauskis, 2002; Whiting et al., 2005). The size-controlling properties of Gisela 5 is considered of high interest for reducing production cost, particularly pruning and harvest, due to smaller tree size (Whiting et al., 2005). Some authors have suggested that dwarfing rootstocks, such as Gisela 5, would limit scion growth because of their reduced production of growth promoting hormones (auxins and gibberellins) or by lowering the basipetal auxin transport in their tissues (Lockard and Schneider, 1981). In grafted trees, the control of plant size is mainly due to the rootstock, although the mechanism by which rootstock regulates scion vigour is still unclear (Basile et al., 2003; Sorce et al., 2002a).

The highest yield efficiency recorded on Gisela 5 for both cultivars could be associated with its lower vigour. The greater yield efficiency induced by CAB 6P and Adara when compared with MaxMa 14 and SL 64 rootstocks (Table 1) has been previously reported by other authors (Jiménez et al., 2004; 2007). MaxMa 14 and both *P. mahaleb* selections showed the lowest yield efficiency for the two cultivars, probably due to the unbalanced nutrient status when grafted with these cultivars (Jiménez et al., 2007). This result could also be due to the *P. mahaleb* selections susceptibility to root asphyxia in heavy soils with level-basin irrigated system where waterlogging occurs (Perry, 1987).

4.2. Fruit quality

In this study, Gisela 5 induced the smallest fruit size for both cultivars, as reported in other studies (Facteau et al., 1996; Gonçalves et al., 2006). Although, in general, bigger fruits were harvested in 2007 when yield was lower, no significant correlation was found between yield and fruit weight over the four years of study, with the exception of 'Van' in 2008. It is worthy to note that the high yield shown by Adara when compared with other rootstocks, did not significantly affect its fruit size in the case of 'SHG', and it was rated lower for 'Van' cultivar only in 2008.

Regarding soluble solids content (SSC), no consistent differences were found among rootstocks throughout the study, as it has been previously mentioned by other authors (Ferree, 1992; Meheriuk et al., 1994). On the contrary, an influence of rootstocks in SSC of ‘Sunburst’ cherry cultivar was reported by Jiménez et al. (2004). The higher SSC showed by Gisela in 2007 for ‘Van’ (Table 3) may be due to the very low yield induced by this rootstock in that year (Table 2). The significant positive correlation found between fruit weight and SSC suggests that selecting a cultivar/scion combination that induces big cherry size, will also produce a good SSC value.

Regarding titratable acidity (TA), the tendency by *P. cerasus* CAB 6P to induce a higher TA among the rootstocks was previously reported by Moreno et al. (2001), who observed that *P. cerasus* selections induced the greatest TA in ‘Sunburst’ cultivar. On the other hand, no effect of rootstock on fruit pH was found for any of the cultivars and years of study, in agreement with other authors (Gonçalves et al., 2006; Jiménez et al., 2004), who reported no consistent effect of rootstocks on fruit acidity.

Similarly to what occurred with SSC, TA was significantly correlated with fruit weight for ‘Van’ cherries, showing that TA increased with fruit mass. No correlation was found in the case of ‘SHG’. As expected, a negative correlation between pH and RI was found for both cherry cultivars studied.

The comparable ripening index (RI) values found for each scion/cultivar combination throughout the study assures a similar ripening stage of evaluated cherries over the years. The RI is commonly used as a quality index for different fruit species, such as peach, nectarine, plum and sweet cherry, and higher ratios are usually preferred (Crisosto et al., 2002; Ferrer et al., 2005; Kader, 1999). In addition, RI has been reported to have a closer relationship with fruit eating quality than TA or SSC (Crisosto et al., 2002; Harker et al., 2002). Slight significant differences on this trait were found among rootstocks in the study. The high RI values induced by Gisela 5 on 'Van' cultivar fruits were probably due to its low acidity. Differences found in RI are directly due to the SSC and TA values, since the RI is calculated as SSC/TA ratio. A slight positive correlation was found among RI and fruit weight for both cultivars, reflecting that SSC/TA ratio increases with fruit size.

With regard to fruit firmness, the highest value found in 'Van' and 'SHG' cherries when grafted on Gisela 5 and Adara rootstocks, implies a better resistance of fruit to post-harvest damage. In addition, fruit firmness of cherries is also appreciated by consumers, together with fresh green stems (Serrano et al., 2005). It has been reported that dwarfing rootstocks, such as Gisela 5, induce higher firmness in 'Van' and other sweet cherry cultivars (Gonçalves et al., 2006). The higher firmness induced by the vigorous Adara could be due to its good adaptation to the growing conditions. The higher firmness values measured in 'Van' fruits when compared with 'SHG' fruits, is in agreement with previous studies where 'Van' cherries have been reported to have high firmness (Gonçalves et al., 2006). Firmness showed significant negative correlation with pH in 'Van' cultivar cherries showing that pH increases as firmness decreases. Similarly, firmness showed a significant positive correlation with TA in 'SHG' cherries, reflecting the decrease of acidity with fruit softening.

Regarding fruit colour, in general, fruits of trees grafted on Adara showed the more luminous colour (higher L* parameter) and the opposite for both Gisela 5 and *P. mahaleb* selections (SL 64 and SL 405), which in general showed the lowest L* values. On the other hand, 'Van' trees grafted on MaxMa 14 showed redder and darker cherries (higher a* and b* parameters) than fruits from other rootstocks. Jiménez et al. (2004) and Gonçalves et al. (2006) also reported a darker colour of 'Sunburst' and 'Burlat' respectively, when grafted on MaxMa 14. Nevertheless, Adara seems to induce redder and darker cherries for 'SHG'. In general, full dark red cherries have higher consumer acceptance (Bruhn et al., 1991; Crisosto et al., 2002; Crisosto et al., 2003). Therefore, cherries from these rootstocks should have a greater acceptance. For both cherry cultivars, Gisela 5 and SL 64 effect resulted in less attractive fruit colour, probably due to their bad adaptation to heavy soils or where waterlogging occurs (Perry, 1987). The unbalanced nutrient status of these rootstocks when grafted with 'Van' and 'SHG' (Jiménez et al., 2007) could also explain the lack of colour. These findings are similar to those of Autio and Southwick (1993) and Gonçalves et al. (2006), who reported significant effect of rootstock on the three chromatic parameters of sweet cherry fruit.

5. Conclusion

The results of this investigation showed that, in heavy and calcareous soil growing conditions, trees grafted on dwarfing or very-dwarfing rootstocks such as Gisela 5 and Tabel-Edabriz tended to dwarf excessively. On the contrary, a better agronomic performance was found on intermediate or vigorous rootstocks which showed higher growth and yield, such as Adara and CAB 6P. The good adaptation of Adara to the growing conditions probably favoured higher yield, vigour, yield efficiency and good fruit quality. The high fruit quality (fruit weight and skin colour) of MaxMa 14 may also be interesting. However, the low yield and highly inconsistent cherry quality shown by both cultivars grafted on Gisela 5 make it a cherry rootstock that is not recommended for Mediterranean growing conditions. These results underscore the important relationships between plant adaptability and development and the major factors of fruit quality. We conclude that, despite quality attributes being more dependent on the cultivar than on the rootstock, the scion-rootstock combination is an important parameter to consider in orchard planting strategies since its influence in some attributes such as fruit size, acidity, skin colour and firmness of sweet cherry has been demonstrated in this study.

Acknowledgement

The authors acknowledge financial support from Comisión Interministerial de Ciencia y Tecnología (AGL 2002-04219 and 2005-05533) projects. Celia M. Cantín was supported by a FPU fellowship from MICINN (Ministerio de Ciencia e Innovación). We also acknowledge J. Aparicio, T. Buhner, R. Giménez, and M.P. Soteras for technical assistance in the experimental field and laboratory assays.

Tables

Table 1.

Effect of rootstock on TCSA (trunk cross-sectional area), cumulative yield and yield efficiency of 'Van' and 'Stark Hardy Giant' (SHG) sweet cherry cultivars in the tenth (2008) year after grafting.

Cultivar	Rootstock	TCSA increasing rate (cm^2/year)[a]	TCSA (cm^2)	Cumulative yield (kg tree^{-1})	Yield efficiency (kg cm^{-2})
Van	Adara	63.7 * a	499.9 a	298.6 a	0.60 b
	CAB 6P	29.4 bc	229.3 bc	160.6 b	0.69 b
	Gisela 5	11.9 c	44.4 c	37.1 c	0.86 a
	MaxMa 14	40.9 abc	310.6 ab	135.6 b	0.45 c
	SL 64	50.7 ab	390.0 ab	132.0 b	0.39 c
SHG	Adara	38.7 a	288.6 a	164.5 a	0.57 ab
	CAB 6P	28.2 b	218.2 b	130.9 ab	0.61 a
	Gisela 5	3.7 d	34.7 d	23.4 e	0.67 a
	MaxMa 14	37.2 ab	274.8 ab	116.7 bc	0.42 c
	SL 405	19.5 c	145.5 c	64.4 de	0.44 bc
	SL 64	30.2 ab	230.5 ab	88.2 cd	0.38 c
	Tabel	12.3 cd	94.0 cd	59.1 de	0.63 a

[a]TCSA increasing rate calculated based on the growth from the third to the tenth year after grafting.

*For each cultivar, means having the same letter in each column are not significantly different at $P \leq 0.05$ by Duncan's Multiple Range test.

Table 2.

Effect of rootstock on yield (kg) of 'Van' and 'Stark Hardy Giant' (SHG) sweet cherry cultivars, from the seventh (2005) to the tenth (2008) year after grafting.

Cultivar	Rootstock	2005	2006	2007	2008	Average
Van	Adara	46.0 * a	88.1 a	42.0 a	100.8 a	69.2 a
	CAB 6P	17.1 b	53.0 b	27.9 ab	56.8 b	38.9 b
	Gisela 5	7.1 b	10.7 c	3.5 c	7.7 c	7.2 c
	MaxMa 14	16.3 b	43.6 b	24.2 b	46.6 b	32.7 b
	SL 64	19.5 b	47.0 b	23.1 b	38.0 b	31.9 b
SHG	Adara	30.5 a	55.3 a	26.0 a	47.8 a	40.4 a
	CAB 6P	12.6 b	40.9 ab	27.3 a	40.7 a	30.6 b
	Gisela 5	2.6 c	7.8 d	0.2 c	7.7 c	4.6 d
	MaxMa 14	11.5 b	34.9 b	28.3 a	41.3 a	28.7 b
	SL 405	7.8 bc	23.1 bcd	10.2 bc	23.2 bc	16.1 c
	SL 64	9.3 bc	28.5 bc	15.5 b	33.9 ab	21.8 bc
	Tabel	9.3 bc	15.5 cd	11.1 b	22.1 bc	14.5 c

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

Table 3.

Effect of rootstock on fruit quality of 'Van' sweet cherry cultivar, from the seventh (2005) to the tenth (2008) year after grafting.

Character	Rootstock	2005	2006	2007	2008	Average
Fruit weight (g)	Adara	5.0 * ab	5.0 b	8.4 ab	5.8 c	6.1 bc
	CAB 6P	6.2 a	6.6 a	8.7 a	7.6 a	7.2 a
	Gisela 5	4.1 c	3.8 c	7.8 b	6.3 bc	5.5 c
	MaxMa 14	5.3 ab	6.1 ab	8.0 ab	7.0 ab	6.6 ab
	SL 64	5.6 ab	5.6 ab	8.1 ab	7.4 a	6.7 ab
SSC (ºBrix)	Adara	13.0 ab	14.8 a	17.8 b	14.1 b	14.9 a
	CAB 6P	14.3 a	15.8 a	17.2 b	15.7 a	15.7 a
	Gisela 5	10.5 b	15.1 a	19.1 a	17.0 a	15.4 a
	MaxMa 14	12.1 ab	15.3 a	16.9 b	16.2 a	15.1 a
	SL 64	14.7 a	15.2 a	17.3 b	17.0 a	16.0 a
Titratable acidity	Adara	0.58 ab	0.71 ab	0.72 a	0.61 b	0.66 bc
	CAB 6P	0.71 a	0.82 a	0.74 a	0.70 b	0.74 a
	Gisela 5	0.50 b	0.62 b	0.76 a	0.62 b	0.62 c
	MaxMa 14	0.62 ab	0.78 a	0.73 a	0.64 a	0.69 ab
	SL 64	0.67 a	0.73 ab	0.71 a	0.67 ab	0.69 ab
Ripening index	Adara	22.4 a	20.8 ab	25.0 a	23.2 bc	22.8 ab
	CAB 6P	20.2 a	19.6 b	23.4 a	22.5 c	21.4 b
	Gisela 5	20.7 a	25.5 a	25.4 a	27.7 a	24.8 a
	MaxMa 14	19.4 a	19.7 b	23.3 a	25.3 ab	21.9 b
	SL 64	21.7 a	21.1 ab	24.6 a	25.5 ab	23.2 ab

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

SSC: soluble solid content; TA: titratable acidity (g malic acid 100 g^{-1} FW); RI: ripening index (SSC/TA).

Table 4.

Effect of rootstock on fruit quality of 'Stark Hardy Giant' sweet cherry cultivar, from the seventh (2005) to the tenth (2008) year after grafting.

Character	Rootstock	2005	2006	2007	2008	Average
Fruit weight (g)	Adara	5.5 * bc	5.8 a	8.8 a	8.1 a	7.1 a
	CAB 6P	5.8 abc	6.4 a	7.6 bc	7.9 a	6.9 a
	Gisela 5	5.0 cd	3.7 b	7.1 c	5.5 b	5.3 b
	MaxMa 14	5.6 bc	6.5 a	7.2 c	7.1 a	6.6 a
	SL 405	6.1 ab	6.2 a	8.2 ab	7.3 a	6.9 a
	SL 64	6.5 a	6.8 a	8.0 abc	7.0 a	7.1 a
	Tabel	4.6 d	4.6 b	7.0 c	5.3 b	5.4 b
SSC (ºBrix)	Adara	15.0 a	15.1 a	17.6 a	15.7 a	15.9 a
	CAB 6P	14.3 a	15.5 a	16.2 a	15.7 a	15.4 a
	Gisela 5	18.0 a	12.9 b	17.6 a	14.3 a	15.7 a
	MaxMa 14	14.5 a	15.2 a	16.3 a	15.6 a	15.4 a
	SL 405	14.1 a	16.1 a	16.7 a	15.2 a	15.5 a
	SL 64	13.7 a	16.1 a	16.6 a	15.7 a	15.7 a
	Tabel	13.7 a	15.5 a	16.4 a	13.9 a	14.8 a
Titratable acidity	Adara	0.65 a	0.66 ab	0.68 a	0.57 a	0.64 a
	CAB 6P	0.69 a	0.69 a	0.62 ab	0.55 ab	0.64 a
	Gisela 5	0.72 a	0.58 b	0.68 a	0.51 abc	0.62 ab
	MaxMa 14	0.62 a	0.66 ab	0.57 b	0.53 abc	0.60 ab
	SL 405	0.55 a	0.62 ab	0.61 ab	0.51 abc	0.57 ab
	SL 64	0.59 a	0.65 ab	0.55 b	0.49 bc	0.57 ab
	Tabel	0.51 a	0.62 ab	0.58 b	0.47 c	0.55 b
Ripening index	Adara	23.4 ab	23.1 a	25.9 b	27.7 b	25.1 ab
	CAB 6P	20.7 b	22.4 a	26.3 b	28.4 b	24.5 b
	Gisela 5	25.1 ab	22.2 a	26.0 b	28.3 b	25.4 ab
	MaxMa 14	24.1 ab	23.0 a	29.0 ab	29.3 ab	26.2 ab
	SL 405	25.4 ab	25.9 a	27.8 ab	30.2 ab	27.3 ab
	SL 64	23.3 ab	25.9 a	30.3 a	32.3 a	27.9 a
	Tabel	27.7 a	25.4 a	28.1 ab	30.0 ab	27.8 a

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

SSC: soluble solid content; TA: titratable acidity (g malic acid 100 g^{-1} FW); RI: ripening index (SSC/TA).

Table 5.

Effect of rootstock on firmness and chromatic parameters (L*= lightness; a*= redness and greenness; and b*= yellowness and blueness) of 'Van' and 'Stark Hardy Giant' (SHG) sweet cherry cultivars in the seventh (2005) year after grafting.

Cultivar	Rootstock	Firmness (dg[a])	L*	a*	b*
Van	Adara	40.5 * ab	36.9 a	34.7 ab	11.9 ab
	CAB 6P	38.0 bc	34.8 ab	31.7 bc	9.8 bc
	Gisela 5	42.8 a	34.7 b	30.9 bc	9.2 bc
	MaxMa 14	35.8 c	36.1 ab	36.0 a	11.9 a
	SL 64	37.7 bc	34.2 b	29.4 c	8.1 c
SHG	Adara	34.8 ab	36.4 a	33.7 a	11.2 a
	CAB 6P	31.6 bc	33.1 bc	30.2 abc	8.9 abc
	Gisela 5	37.2 a	34.8 bc	28.6 bc	7.8 bc
	MaxMa 14	32.2 bc	34.4 abc	31.5 ab	9.5 abc
	SL 405	30.0 c	34.2 bc	29.8 abc	8.7 abc
	SL 64	30.3 c	33.8 c	26.8 c	6.8 c
	Tabel	32.5 bc	35.0 ab	32.0 ab	9.6 ab

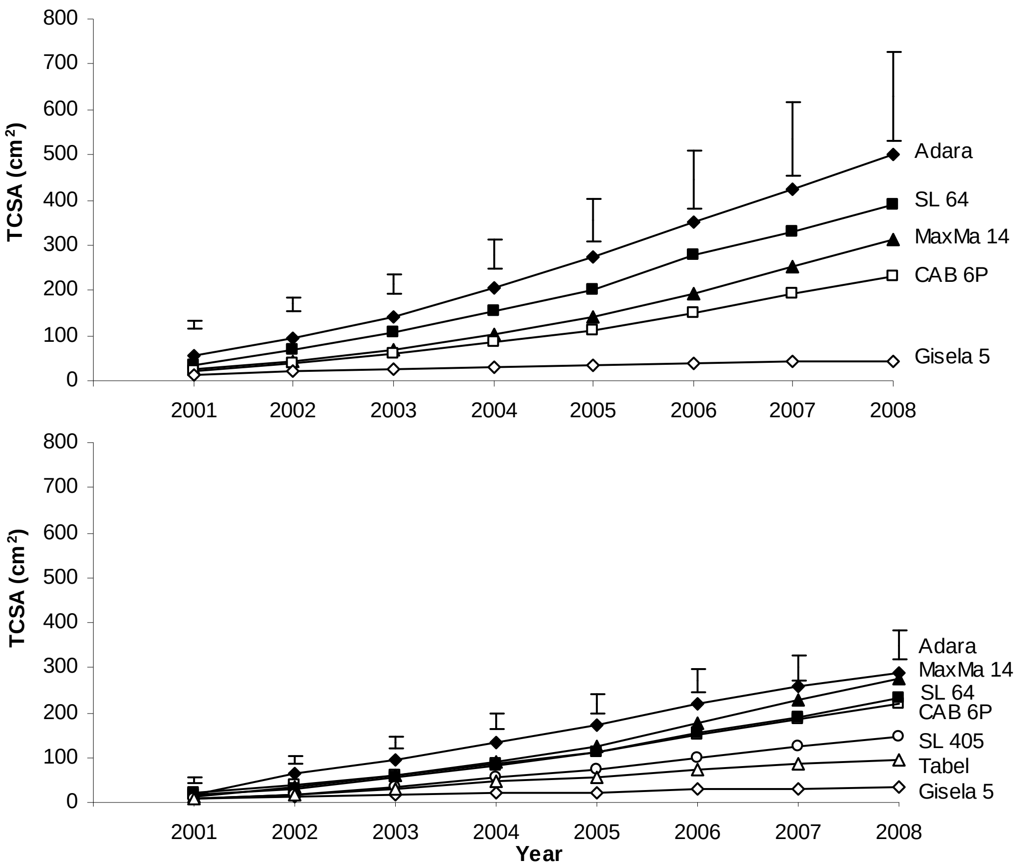
*For each cultivar, means having the same letter in each column are not significantly different at $P \leq 0.05$ by Duncan's Multiple Range test.

[a]dg: durofel graduation.

Figures

Fig. 1.

Effect of rootstock on trunk cross-sectional area (TCSA) of ‘Van’ (a) and ‘Stark Hardy Giant’(b) sweet cherry cultivars from the third (2001) to the tenth (2008) year after grafting. Vertical lines indicate LSD ($P \leq 0.05$).



References

Autio, W.R., F.W. Southwick. 1993. Evaluation of a spur and a standard strain of Mcintosh on 3 rootstocks and one dwarfing interstem over 10 years. Fruit Varieties Journal 47:95-102.

Basile, B., J. Marsal, T.M. DeJong. 2003. Daily shoot extension growth of peach trees growing on rootstocks that reduce scion growth is related to daily dynamics of stem water potential. Tree Physiology 23:695-704.

Betrán, J.A., J. Val, L.M. Millán, E. Monge, L. Montañés, M.A. Moreno. 1997. Influence of rootstock on the mineral concentrations of flowers and leaves from sweet cherry. Acta Horticulturae:163-167.

Bruhn, C.M., N. Feldman, C. Garlitz, J. Harwood, E. Ivans, M. Marshall, A. Riley, D. Thurber, E. Williamson. 1991. Consumer perceptions of quality. Apricots, cantaloupes, peaches, pears, strawberries and tomatoes. Journal of Food Quality 14:187-195.

Byrne, D.H. 2002. Peach breeding trends. Acta Horticulturae 592:49-59.

Cevallos-Casals, B.A., D.H. Byrne, W.R. Okie, L. Cisneros-Zevallos. 2006. Selecting new peach and plum genotypes rich in phenolic compounds and enhanced functional properties. Food Chemistry 96:273-280.

Crisosto, C.H., G.M. Crisosto, M.A. Ritenour. 2002. Testing the reliability of skin color as an indicator of quality for early season `Brooks' (*Prunus avium* L.) cherry. Postharvest Biology and Technology 24:147-154.

Crisosto, C.H., G.M. Crisosto, P. Metheney. 2003. Consumer acceptance of 'Brooks' and 'Bing' cherries is mainly dependent on fruit SSC and visual skin color. Postharvest Biology and Technology 28:159-167.

Davis, A.R., P. Perkins-Veazie, R. Hassell, A. Levi, S.R. King, X.P. Zhang. 2008. Grafting effects on vegetable quality. HortScience 43:1670-1672.

De Salvador, F.R., G. Di Tommaso, C. Piccioni, P. Bonofiglio. 2001. Performance of new and standard cherry rootstocks in different soils and climatic conditions. Acta Horticulturae 667:191-199.

Facteau, T.J., N.E. Chestnut, K.E. Rowe. 1996. Tree, fruit size and yield of 'Bing' sweet cherry as influenced by rootstock, replant area, and training system. Scientia Horticulturae 67:13-26.

FAOSTAT. 2007. FAOSTAT [Online] http://www.faostat.fao.org.

Ferree, D.C. 1992. Performance of Golden Delicious on 2 rootstocks and 4 dwarfing interstems over 10 years. Fruit Varieties Journal 46:93-97.

Ferrer, A. 1998. Estudios preliminares sobre la maduración y conservación en atmósferas controladas del melocotón de Jesca., Universidad de Zaragoza.

Ferrer, A., S. Remón, A.I. Negueruela, R. Oria. 2005. Changes during the ripening of the very late season Spanish peach cultivar Calanda. Feasibility of using CIELAB coordinates as maturity indices. Scientia Horticulturae 105:435-446.

Gonçalves, B., J. Moutinho-Pereira, A. Santos, A.P. Silva, E. Bacelar, C. Correia, E. Rosa. 2006. Scion-rootstock interaction affects the physiology and fruit quality of sweet cherry. Tree Physiology 26:93-104.

Gonçalves, B., C.M. Correia, A.P. Silva, E.A. Bacelar, A. Santos, H. Ferreira, J.M. Moutinho-Pereira. 2007. Variation in xylem structure and function in roots and stems of scion-rootstock combinations of sweet cherry tree (*Prunus avium* L.). Trees-Structure and Function 21:121-130.

Harker, F.R., K.B. Marsh, H. Young, S.H. Murray, F.A. Gunson, S.B. Walker. 2002. Sensory interpretation of instrumental measurements 2: sweet and acid taste of apple fruit. Postharvest Biology and Technology 24:241-250.

Jiménez, S., A. Garín, Y. Gogorcena, J.A. Betrán, M.A. Moreno. 2004. Flower and foliar analysis for prognosis of sweet cherry nutrition: Influence of different rootstocks. Journal of Plant Nutrition 27:701-712.

Jiménez, S., J. Pinochet, Y. Gogorcena, J.A. Betrán, M.A. Moreno. 2007. Influence of different vigour cherry rootstocks on leaves and shoots mineral composition. Scientia Horticulturae 112:73-79.

Kader, A.A. 1999. Fruit maturity, ripening, and quality relationships. Acta Horticulturae 485:203-208.

Kappel, F., W.D. Lane, R.A. MacDonald, H. Schmid. 2000. 'Skeena' sweet cherry. HortScience 35:306-307.

Larsen, F.E., S.S. Higgins, R. Fritts Jr. 1987. Scion/interstock/rootstock effect on sweet cherry yield, tree size and yield efficiency. Scientia Horticulturae 33:237-247.

Lockard, R.G., G.W. Schneider. 1981. Stock and scion growth relationships and the dwarfing mechanism in apple. Horticultural Reviews 3:315-375.

MARM. 2007. Ministerio de Medio Ambiente y Medio Rural y Marino [Online] http://www.marm.es.

Meheriuk, M., H.A. Quamme, R.T. Brownlee. 1994. Influence of rootstock on fruit and tree characteristics of Macspur Mcintosh. Fruit Varieties Journal 48:93-97.

Millikan, D.F., A.D. Hibbard. 1984. Increased productivity of Montmorency tart cherry on Wa-900 Mahaleb roots. Fruit Varieties Journal 38:143-145.

Moreno, M.A., L. Montañés, M.C. Tabuenca, R. Cambra. 1996. The performance of Adara as a cherry rootstock. Scientia Horticulturae 65:85-91.

Moreno, M.A., R. Adrada, J. Aparicio, J.A. Betrán. 2001. Performance of 'Sunburst' sweet cherry grafted on different rootstocks. Journal of Horticultural Science & Biotechnology 76:167-173.

Perry, R.L. 1987. Cherry rootstocks, p. 217-264, *In* J. Wiley and Sons, eds. Rootstocks for fruit crops, New York.

Ruisa, S., E. Rubauskis. 2002. Preliminary results of testing new sweet cherry rootstocks. Acta Horticulturae 658:541-546.

Serrano, M., F. Guillén, D. Martínez-Romero, S. Castillo, D. Valero. 2005. Chemical constituents and antioxidant activity of sweet cherry at different ripening stages. Journal of Agricultural and Food Chemistry 53:2741-2745.

Sorce, C., R. Massai, P. Picciarelli, R. Lorenzi. 2002a. Hormonal relationships in xylem sap of grafted and ungrafted *Prunus* rootstocks. Scientia Horticulturae 93:333-342.

Sorce, C., R. Massai, P. Ricciarelli, R. Lorenzi. 2002b. Hormonal relationships in xylem sap of grafted and ungrafted *Prunus* rootstocks. Scientia Horticulturae 93:333-342.

Usenik, V., N. Fajt, F. Stampar. 2006. Effects of rootstocks and training system on growth, precocity and productivity of sweet cherry. Journal of Horticultural Science & Biotechnology 81:153-157.

Voss, D.H. 1992. Relating colorimeter measurement of plant color to the Royal Horticultural Society color chart. HortScience 27:1256-1260.

Westwood, M.N., H.O. Bjornstad. 1970. Cherry rootstocks for Oregon. Proceedings of the Oregon Horticultural Society 61:76-79.

Westwood, M.N., M.H. Chaplin, A.N. Roberts. 1973. Effects of Rootstock on growth, bloom, yield, maturity, and fruit quality of prune (*Prunus domestica* L). Journal of the American Society for Horticultural Science 98:352-357.

Whiting, M.D., G. Lang, D. Ophardt. 2005. Rootstock and training system affect sweet cherry growth, yield, and fruit quality. HortScience 40:582-586.