

1 **Growth, yield and fruit quality of ‘Van’ and ‘Stark Hardy Giant’ sweet**
2 **cherry cultivars as influenced by grafting on different rootstocks**

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1 **Abstract**

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

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

26 **1. Introduction**

27 Different studies with *Prunus sp.* have demonstrated that rootstock influences the
28 performance of the grafted scion cultivar. There have been numerous reports of a
29 relationship between cherry rootstocks and water relations, leaf gas exchange, mineral
30 uptake, plant size, blossoming, fruit bud survival, fruit quality and yield efficiency
31 (Betrán et al., 1997; Davis et al., 2008; Facticeau et al., 1996; Jiménez et al., 2004;
32 Jiménez et al., 2007; Larsen et al., 1987; Millikan and Hibbard, 1984). Westwood et al.
33 (1973) reported that the most common effects of rootstocks on fruit quality are
34 differences of firmness, levels of organic acids and sugar content. However, a better
35 understanding of the relationships between some cherry fruit quality attributes and
36 rootstock influence is needed to achieve favourable scion/rootstock combinations for
37 specific growing areas. Sweet cherries have expanded rapidly in Spain over the past
38 decade to current annual production levels of around 90,000 tonnes (MARM, 2007),
39 and Spain is now the third largest producer of sweet cherries in the world (FAOSTAT,
40 2007). In turn, the Ebro Valley is the first producer region in Spain, and consequently
41 one of the most important productive areas of Europe with an average of around 28,000
42 tonnes per year over the last three years.

43 The previously cited vegetative and quality traits are very important for horticulture
44 since they supply the base for the selection of the best rootstock-scion cultivar
45 combination for specific climatic conditions and soil types. Furthermore, nowadays
46 breeders are not only interested in productivity, but also in better fruit quality (Byrne,
47 2002; Cevallos-Casals et al., 2006). However, it is unlikely that a single rootstock will
48 have all of these attributes (Westwood and Bjornstad, 1970).

49 The three most important components in the organoleptic quality of fruit are aroma,
50 sugar content and acidity, which are related to many chemical and physical properties of
51 fruits (Crisosto et al., 2003), and these properties are highly influenced by rootstocks.
52 According to Usenik et al. (2006), studies on cultivar-rootstock responses to specific
53 growing conditions are needed to achieve the main goal of economically viable
54 production of high quality sweet cherries. It is important to find a suitable rootstock for
55 the extensive Mediterranean growing conditions, as well as for particular cultivar
56 characteristics.

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

62

63 **2. Materials and methods**

64 *2.1. Plant material*

65 Seven cherry rootstocks were compared in one trial established in the winter of
66 1997-1998. They were grafted *in situ* with ‘Stark Hardy Giant’ (‘SHG’) and ‘Van’ mid-
67 to late-maturing sweet cherry cultivars (*Prunus avium* L.) during the summer of 1998.

68 Rootstocks under evaluation included two sour cherry (*P. cerasus*) selections: CAB
69 6P and Tabel-Edabriz (Tabel); two selections of *P. mahaleb*: Saint Lucie GF 64 (SL 64)
70 and Saint Lucie GF 405 (SL 405); a *P. cerasifera* rootstock: Adara; one semi-dwarfing
71 selection considered to be of *P. avium* x *P. mahaleb* parentage: MaxMa 14; and a
72 dwarfing *P. cerasus* x *P. canescens*: Gisela 5. Due to bud-take and mortality problems

73 of ‘Van’ grafted on Tabel and SL 405 respectively, these rootstock-cultivar
74 combinations were not included in the trial.

75 The trial was carried out at the Experimental Station of Aula Dei (Zaragoza, North-
76 Eastern Spain, latitude around 41.5°) on calcareous soils, with 27% total calcium
77 carbonate, 8% active lime, water pH 8.3, and a clay-loam texture. Trees were planted at
78 5 x 4 m, and were minimally pruned throughout the experiment, excepting the Spanish
79 Bush developed the first years. This training system controlled tree height by pruning in
80 the summer and fall. The orchard was managed following the usual local procedures.
81 The plot was level-basin irrigated every 12 days during the summer. The experiment
82 was established in a randomized complete block design with five single-tree replications
83 for each scion-stock combination. Guard rows were used to preclude edge effects.

84

85 2.2. *Vegetative growth, yield and fruit quality attributes*

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

92 Over the last four years of study, the cherries were hand-picked at commercial
93 maturity over a period of 5-10 days, depending on the year, to assess optimum maturity
94 for a given scion-rootstock combination. Fruits were considered ripe when they no
95 longer grew and exhibited the red ground colour representative for each cultivar. Fruit
96 samples were harvested by a single person to keep consistency of maturity grade. At

97 each harvest, 50 fruits at commercial ripening stage were sampled from each single-tree
98 replication and they were immediately used to determine fruit weight (g), soluble solids
99 content (SSC), titratable acidity (TA) and pH. In 2005, skin colour and fruit firmness
100 were also considered.

101 Fruit juice SSC from each sample was measured using an Atago PR-101 digital
102 refractometer and expressed in °Brix. Titratable acidity (TA) was determined in a
103 sample of juice from 50 fruits. The juice samples were diluted with distilled water
104 (1:10), and microtitrated with 0.1 N NaOH. Firmness was estimated by a durometer
105 (Shore A, Durofel), a non-destructive method, whose value (from 0 to 100 durofel
106 graduation) is a relative value of firmness (Kappel et al., 2000). The ripening index (RI)
107 was calculated based on the SSC/acidity ratio (Ferrer, 1998). Skin colour was measured
108 in 50 fruits with a tristimulus colourimeter (Minolta CR-200 Chroma Meter, Minolta,
109 Japan) having an 8-mm-diameter viewing area. Values of lightness (L^*), redness and
110 greenness (a^* and $-a^*$) and yellowness and blueness (b^* and $-b^*$) on the hue circle
111 (Voss, 1992) were measured to describe a three-dimensional colour space. The values
112 presented for each measurement date are the means of triplicate measures on equidistant
113 points of each fruit.

114

115 2.3. *Data analysis*

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

120

121 3. Results

122 3.1. Vegetative growth and yield

123 *Tree growth:* Tree size, as assessed by TCSA, was significantly affected by rootstock
124 starting from the fourth year after grafting (Fig. 1). The increasing rate of TCSA was
125 highly affected by the rootstocks (Table 1), being higher for Adara in both cultivars.
126 Gisela 5 by far showed the lowest annual increasing rate in both cultivars, with an
127 increase lower than 5 cm²/year for ‘SHG’ cultivar, and lower than 12 cm²/year for
128 ‘Van’ cultivar. In the tenth year after grafting (Table 1), trees grafted on Adara showed
129 the highest TCSA value for both cultivars, although differences were not significant
130 with MaxMa 14 and SL 64. The lowest TCSA was shown by Gisela 5 for both cultivars,
131 although no significant differences were found with CAB 6P and Tabel for ‘Van’ and
132 ‘SHG’, respectively.

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

141 *Cumulative yield and yield efficiency:* By year ten after grafting, the cumulative
142 yield was greater on Adara rootstock for both cultivars (Table 1), although no
143 significant differences were shown when compared with CAB 6P for ‘SHG’. However,
144 the highest yield efficiency was recorded on Gisela 5 for both cultivars, although no

145 significant differences were found for ‘SHG’ when compared with Adara, CAB 6P and
146 Tabel. In this study, CAB 6P induced greater yield efficiency than MaxMa 14 and SL
147 64 rootstocks (Table 1). MaxMa 14 and both *P. mahaleb* selections showed the lowest
148 yield efficiency for both cultivars.

149 3.2. *Fruit quality*

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

164 *Soluble solids content (SSC)*: No consistent differences were found among
165 rootstocks for SSC along the study for any of the cultivars (Tables 3 and 4). In general,
166 higher SSC values were obtained for both ‘Van’ and ‘SHG’ cultivars in 2007, when
167 yield was lower than other years. Higher SSC was shown by Gisela in 2007 for ‘Van’
168 (Table 3), whereas lower SSC was found for ‘SHG’ in 2006. On the other hand, SSC

169 showed significant positive correlations ($P \leq 0.01$) with fruit weight and TA for ‘Van’
170 ($r = 0.763$ and $r = 0.642$, respectively) and ‘SHG’ cultivars ($r = 0.522$ and $r = 0.557$,
171 respectively). The correlation between fruit weight and SSC was higher in ‘Van’
172 cultivar than in ‘SHG’ cultivar when studied separately for each rootstock-scion
173 combination.

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

185 Similarly to what occurred with SSC, TA was significantly correlated with fruit
186 weight for ‘Van’ cultivar cherries ($r = 0.533$, $P \leq 0.01$), showing that TA increased with
187 fruit mass. However, no correlation was found in the case of ‘SHG’. As mentioned, TA
188 showed a significant positive correlation with SSC for both ‘Van’ and ‘SHG’ cultivars,
189 and negative, as expected, with pH ($r = -0.491$ and $r = -0.450$, respectively) and RI ($r =$
190 -0.407 and $r = -0.717$, respectively).

191 *SSC/acid ratio (ripening index)*: Ripening index (RI) values for each scion/cultivar
192 combination along the study were comparable, which assures a similar ripening stage of
193 evaluated cherries over the years. Slight significant differences ($P \leq 0.05$) were found

194 among rootstocks on the ripening index (RI) for both cultivars along the study. Fruits of
195 ‘Van’ trees (Table 3) showed a tendency to have higher RI when grafted on Gisela 5,
196 SL 64 and Adara rootstocks, both in 2006 and in the four years average, as well as on
197 Gisela 5, MaxMa 14 and SL 64 in 2008, although no significant differences were found
198 in the lower yielding years. Fruits from ‘SHG’ trees (Table 4) showed, in general,
199 higher RI when grafted on Tabel, both *P. mahaleb* selections (SL 64 and SL 405) and
200 MaxMa 14, although no differences were found in 2006. A slight positive correlation (P
201 ≤ 0.01), was found among RI and fruit weight for both cultivars ($r = 0.225$ and $r = 0.289$
202 for ‘Van’ and ‘SHG’, respectively).

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

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

218 were recorded on Adara, and the lowest on SL 64, as for 'Van' cultivar. However,
219 significant differences were only found when comparing Adara to Gisela 5 and SL 64.

220

221 **4. Discussion**

222 *4.1. Vegetative growth and yield*

223 The high vigour and yield shown by Adara has already been reported (Jiménez et al.,
224 2007; Moreno et al., 1996), and could be explained by its best nutrient status in heavy
225 and calcareous soils. The better adaptation of Adara to the growing conditions may
226 explain larger fruit retention, and thus a better overall performance in yield. It has also
227 been reported that these greater growth properties could induce a higher growth rate in
228 the scion through increasing the supply of specific cytokinins (eg. zeatin riboside) to the
229 shoot (Sorce et al., 2002b). The significant high correlation observed between tree
230 vigour (TCSA) and yield for both cultivars was expected. The high vigour shown by
231 Adara rootstock (Fig. 1) may be recommendable when planting on poor soils or under
232 replant conditions (Moreno et al., 1996).

233 On the other hand, the low TCSA shown by Gisela 5 for both cultivars was already
234 observed by Jiménez et al. (2007) for the former years. In the Mediterranean area, the
235 poor growth induced by Gisela 5 has been previously reported (De Salvador et al.,
236 2001; Gonçalves et al., 2007). However, it has been reported as one of the most yield
237 efficient and precocious rootstocks for sweet cherry in continental climate areas (Ruisa
238 and Rubauskis, 2002; Whiting et al., 2005). The size-controlling properties of Gisela 5
239 is considered of high interest for reducing production cost, particularly pruning and
240 harvest, due to smaller tree size (Whiting et al., 2005). Some authors have suggested
241 that dwarfing rootstocks, such as Gisela 5, would limit scion growth because of their

242 reduced production of growth promoting hormones (auxins and gibberellins) or by
243 lowering the basipetal auxin transport in their tissues (Lockard and Schneider, 1981). In
244 grafted trees, the control of plant size is mainly due to the rootstock, although the
245 mechanism by which rootstock regulates scion vigour is still unclear (Basile et al.,
246 2003; Sorce et al., 2002a).

247 The highest yield efficiency recorded on Gisela 5 for both cultivars could be
248 associated with its lower vigour. The greater yield efficiency induced by CAB 6P and
249 Adara when compared with MaxMa 14 and SL 64 rootstocks (Table 1) has been
250 previously reported by other authors (Jiménez et al., 2004; 2007). MaxMa 14 and both
251 *P. mahaleb* selections showed the lowest yield efficiency for the two cultivars, probably
252 due to the unbalanced nutrient status when grafted with these cultivars (Jiménez et al.,
253 2007). This result could also be due to the *P. mahaleb* selections susceptibility to root
254 asphyxia in heavy soils with level-basin irrigated system where waterlogging occurs
255 (Perry, 1987).

256

257 4.2. *Fruit quality*

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

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

273 Regarding titratable acidity (TA), the tendency by *P. cerasus* CAB 6P to induce a
274 higher TA among the rootstocks was previously reported by Moreno et al. (2001), who
275 observed that *P. cerasus* selections induced the greatest TA in ‘Sunburst’ cultivar. On
276 the other hand, no effect of rootstock on fruit pH was found for any of the cultivars and
277 years of study, in agreement with other authors (Gonçalves et al., 2006; Jiménez et al.,
278 2004), who reported no consistent effect of rootstocks on fruit acidity.

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

283 The comparable ripening index (RI) values found for each scion/cultivar
284 combination throughout the study assures a similar ripening stage of evaluated cherries
285 over the years. The RI is commonly used as a quality index for different fruit species,
286 such as peach, nectarine, plum and sweet cherry, and higher ratios are usually preferred
287 (Crisosto et al., 2002; Ferrer et al., 2005; Kader, 1999). In addition, RI has been
288 reported to have a closer relationship with fruit eating quality than TA or SSC (Crisosto
289 et al., 2002; Harker et al., 2002). Slight significant differences on this trait were found

290 among rootstocks in the study. The high RI values induced by Gisela 5 on ‘Van’
291 cultivar fruits were probably due to its low acidity. Differences found in RI are directly
292 due to the SSC and TA values, since the RI is calculated as SSC/TA ratio. A slight
293 positive correlation was found among RI and fruit weight for both cultivars, reflecting
294 that SSC/TA ratio increases with fruit size.

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

308 Regarding fruit colour, in general, fruits of trees grafted on Adara showed the more
309 luminous colour (higher L* parameter) and the opposite for both Gisela 5 and *P.*
310 *mahaleb* selections (SL 64 and SL 405), which in general showed the lowest L* values.
311 On the other hand, ‘Van’ trees grafted on MaxMa 14 showed redder and darker cherries
312 (higher a* and b* parameters) than fruits from other rootstocks. Jiménez et al. (2004)
313 and Gonçalves et al. (2006) also reported a darker colour of ‘Sunburst’ and ‘Burlat’
314 respectively, when grafted on MaxMa 14. Nevertheless, Adara seems to induce redder

315 and darker cherries for 'SHG'. In general, full dark red cherries have higher consumer
316 acceptance (Bruhn et al., 1991; Crisosto et al., 2002; Crisosto et al., 2003). Therefore,
317 cherries from these rootstocks should have a greater acceptance. For both cherry
318 cultivars, Gisela 5 and SL 64 effect resulted in less attractive fruit colour, probably due
319 to their bad adaptation to heavy soils or where waterlogging occurs (Perry, 1987). The
320 unbalanced nutrient status of these rootstocks when grafted with 'Van' and 'SHG'
321 (Jiménez et al., 2007) could also explain the lack of colour. These findings are similar to
322 those of Autio and Southwick (1993) and Gonçalves et al. (2006), who reported
323 significant effect of rootstock on the three chromatic parameters of sweet cherry fruit.

324

325 **5. Conclusion**

326 The results of this investigation showed that, in heavy and calcareous soil growing
327 conditions, trees grafted on dwarfing or very-dwarfing rootstocks such as Gisela 5 and
328 Tabel-Edabriz tended to dwarf excessively. On the contrary, a better agronomic
329 performance was found on intermediate or vigorous rootstocks which showed higher
330 growth and yield, such as Adara and CAB 6P. The good adaptation of Adara to the
331 growing conditions probably favoured higher yield, vigour, yield efficiency and good
332 fruit quality. The high fruit quality (fruit weight and skin colour) of MaxMa 14 may
333 also be interesting. However, the low yield and highly inconsistent cherry quality shown
334 by both cultivars grafted on Gisela 5 make it a cherry rootstock that is not recommended
335 for Mediterranean growing conditions. These results underscore the important
336 relationships between plant adaptability and development and the major factors of fruit
337 quality. We conclude that, despite quality attributes being more dependent on the
338 cultivar than on the rootstock, the scion-rootstock combination is an important

339 parameter to consider in orchard planting strategies since its influence in some attributes
340 such as fruit size, acidity, skin colour and firmness of sweet cherry has been
341 demonstrated in this study.

342

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349

350 **Tables**

351 Table 1.

352 Effect of rootstock on TCSA (trunk cross-sectional area), cumulative yield and yield
 353 efficiency of ‘Van’ and ‘Stark Hardy Giant’ (SHG) sweet cherry cultivars in the tenth
 354 (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

355

356 ^aTCSA increasing rate calculated based on the growth from the third to the tenth year
 357 after grafting.

358 *For each cultivar, means having the same letter in each column are not significantly

359 different at $P \leq 0.05$ by Duncan’s Multiple Range test.

360 Table 2.

361 Effect of rootstock on yield (kg) of ‘Van’ and ‘Stark Hardy Giant’ (SHG) sweet cherry
362 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

363

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

366

367 Table 3.

368 Effect of rootstock on fruit quality of ‘Van’ sweet cherry cultivar, from the seventh
369 (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 (°Brix)	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

370

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

373 SSC: soluble solid content; TA: titratable acidity (g malic acid 100 g⁻¹ FW); RI:
374 ripening index (SSC/TA).

375

376 Table 4.

377 Effect of rootstock on fruit quality of ‘Stark Hardy Giant’ sweet cherry cultivar, from
 378 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 (°Brix)	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

379

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

382 SSC: soluble solid content; TA: titratable acidity (g malic acid 100 g⁻¹ FW); RI:
 383 ripening index (SSC/TA).

384

385 Table 5.

386 Effect of rootstock on firmness and chromatic parameters (L*= lightness; a*= redness
387 and greenness; and b*= yellowness and blueness) of ‘Van’ and ‘Stark Hardy Giant’
388 (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

389

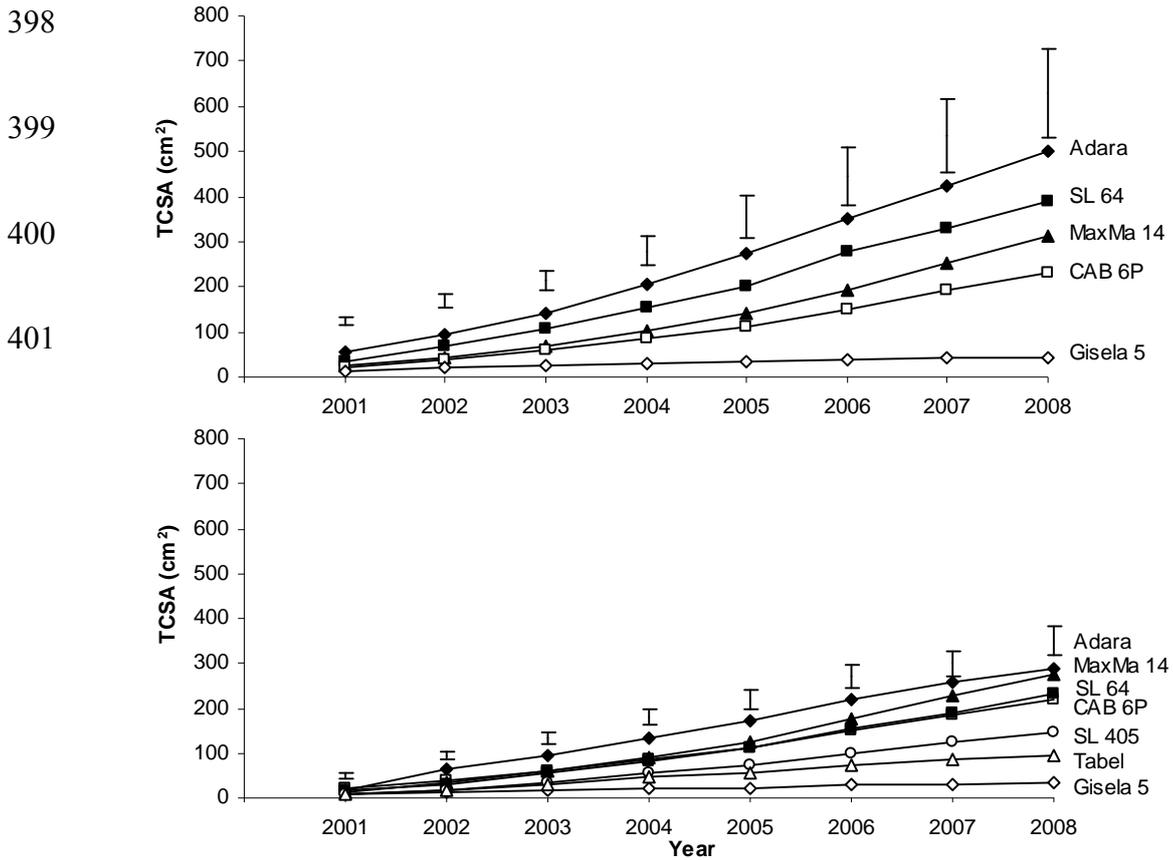
390 *For each cultivar, means having the same letter in each column are not significantly
391 different at $P \leq 0.05$ by Duncan’s Multiple Range test.

392 ^adg: durofel graduation.

393 **Figures**

394 Fig. 1.

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



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