New Training Systems for High-density Planting of Sweet Cherry

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Abstract. We assessed the vegetative growth and fruit production behavior of different sweet cherry cultivars grown using multiple new ultra-high-density planting (HDP) and training systems. An experimental orchard established in 2007 in the Ferrara province of Italy was used for this trial. The sweet cherry cultivars under evaluation were ‘Giorgia’ and ‘Grace Star’ grafted on Gisela® 6; and ‘Black Star’, ‘Early Bigi’, ‘Early Star’, ‘Ferrovia’, ‘Grace Star’, ‘Kordia’, ‘Regina’, ‘Summit’, ‘Sweet Early’, and ‘Sylvia’ grafted on Gisela® 5 rootstock. Each cultivar–rootstock combination was trained to spindle, V-system, or Super Spindle Axis (SSA). Planting densities ranged from 1906 trees/ha for spindle with Gisela® 6 to 5714 trees/ha for V-system and SSA with Gisela® 5.

Vegetative growth, yield productivity, and fruit quality were evaluated. Among the three systems grafted on Gisela® 5, trees trained to the spindle system had the highest trunk cross-sectional area (26.2 cm²), followed by V-system (21.8 cm²) and SSA (20.2 cm²). Seven years after planting, ‘Ferrovia’ had the highest cumulative yield per hectare among cultivars on Gisela® 5, especially with V-system (50.5 t·ha⁻¹) and SSA (52.2 t·ha⁻¹) training systems. For cultivars on Gisela® 6, ‘Giorgia’ on had the highest cumulative yield per hectare after 7 years, but ‘Grace Star’ on had higher production (≈14.0 t·ha⁻¹ with V-system and SSA and 12.8 t·ha⁻¹ with spindle) than ‘Giorgia’ in 2013.

Sweet cherry (Prunus avium) production is increasing in many areas in both the Northern (United States, Italy, Spain, Hungary, and Turkey) and Southern (Chile, Australia) hemispheres. Sweet cherry production has advanced in the last decade as a result of new dwarfing rootstock selections, improvements in crop protectants to reduce rain-induced cracking, and better methods in postharvest handling and storage. New cultivars have also been released, characterized by novel traits such as precocity, self-fertility, improved mechanical harvest, and improved fruit appearance and quality (Bassi, 2010; Lugli, 2003).

Semi-dwarfing and dwarfing rootstocks improve the potential for developing HDP systems for sweet cherry (Balmer, 2001; Hrotkó, 2010; Weber, 2001). The dwarfing rootstock series Gisela®, developed at the Liebig University of Giessen in Germany, induce early bearing of sweet cherry. Gisela® 5 and Gisela® 6, in particular, show promise for use in high-density cherry orchards (Robinson et al., 2004; Sitarek et al., 2005). Several years of experimentation have led to a more specialized and intensive cherry orchard cultivation with densities of 5000 trees/ha (Balmer, 2001; Lugli and Musacchi, 2010).

The current trend toward higher densities in pome and stone fruit orchards, including sweet cherry, requires adopting more efficient training systems. Novel architectures that enhance light interception and distribution into the canopy have been developed, ensuring early cropping, high yield, improved cropping efficiency, and fruit quality (Laui and Claverie, 2005; Long et al., 2005; Whiting, 2006).

Worldwide research has focused on comparing rootstocks and training systems suitable for different sweet cherry orchard models. The choice of training systems should account for cultivar–rootstock, growing environment, and labor force availability. Rootstock vigor can determine if low–medium, medium–high, and high-density plantings are possible. For low–medium density, the principal training systems are vane, palmette, and Drapeau Marchand (Savini et al., 2007). For medium–high density, the spindle system, with various modifications (Zahn, Vogel, and Modified Brunner spindle) (Hrotkó, 2005; Hrotkó et al., 1997; Long, 2001), the Spanish Bush (Negueroles Perez, 2005), its Australian variant, the KGB (Kym Green Bush; Green, 2005), the innovative UFO system (Upright Fruiting Offshoots) developed at Washington State University (Ampatidis and Whiting, 2013), and the Solaxe, which was initially adopted for apple orchards (Laui, 2005), are possible. Inclined shapes, including the Tatura trellis (Y-shape) and V-system, are suitable for high-density plantings (Musacchi and Lugli, 2014).

There are major differences of vigor and fruiting habit among cherry cultivars. It is important to consider cultivar growth habit in orchard management activities, particularly in regard to pruning, to ensure that proper distribution between vegetative and reproductive output is realized (Bargioni, 1994). Depending on the cultivar, cherries are mainly produced on spurs of 2-year-old wood or older. The fruiting density on these spurs varies from one to 20 fruits per cluster. Flower buds, residing on 1-year-old wood, are typically solitary and produce one to three fruits. On wood 2 or more years old, the number of flower buds per spur typically increases from base to apex of the branch (Lang, 2005). In Italy, new tree pruning and training systems have been tested for HDP of sweet cherry including the spindle, the intensive V-system, and the SSA. (Lugli and Musacchi, 2010; Musacchi et al., 2012; Musacchi and Lugli, 2014). Planting densities range from 2000 trees/ha to almost 6000 trees/ha. In the past, other pruning and training systems tested never exceeded 1500 to 2000 trees/ha and were typically 3.5 m (11.5 ft) between rows and 0.5 m between trees.

The spindle is mainly used for apple (Robinson et al., 1991), pear (Musacchi et al., 2005), and peach (Caruso et al., 2001), but has recently been adopted for cherry production. The spindle is a central axis with a strong scaffold of four to five permanent structural basal branches. The fruiting branches are renewed frequently to improve fruit size. The fruiting spurs are positioned on basal branches or branches connected directly to the central axis. The planting distance for spindle-trained trees is typically 3.5 to 4.0 m between rows and 1.0 to 2.5 m within the row. Harvesting from these trees is carried out mainly from the ground and with platforms. The conical habit improves light interception, whereas the reduced size of the plant can improve the efficiency of chemical treatments as well as facilitate the use of protective nets to protect the orchard from birds, hail, and rain (Hrotkó et al., 1998).

The management-intensive V-system is an angled training system characterized by a double fruiting wall in each row. Trees are planted at a 20° angle from the vertical, alternating the direction each tree faces from the center of the row, allowing a high planting density ranging from 3000 to 5000 trees/ha (Sansavini et al., 2001). The V-system requires a support structure with three wires on each side (Sansavini et al., 2001). The planting distance initially adopted for this type of training system was 5.5 to 6.0 m between the rows and 1 m within the row, but recently this system has been used to increase planting density up to 5000 trees/ha by using planting distances of 3.5 × 0.5 m combined with intensive pruning.

The SSA system has been developed as a modification of the spindle to have better control over tree growth. The training system is a central axis with short limbs and the ability to fruit on 1-year-old wood; winter pruning promotes renewal (Musacchi and Lugli, 2014). Cultivars with relatively high numbers of flowers and good fertility in the
basal portion of 1-year-old wood are preferred when developing a SSA orchard.

Low vigor or self-fertile varieties may also be used in combination with Gisela® 6. All of these rootstocks, trained to SSA, require relatively higher levels of water and nutrients and have limitations resulting from their sensitivity to certain soil conditions and environmental factors (De Salvador et al., 2005).

The SSA and V-system do not require a particular kind of feathering or other training from the nursery such as “knip” trees that are used in other high-density planting systems like the spindle or the solaxe. The SSA system presents a very positive fruit/leaf ratio that helps to increase fruit size and quality. Production can range from 10 to 15 Mt·ha–1 and in some cases 20 Mt·ha–1 is possible. A weakness of the SSA system is that not all cultivars have fertile basal buds; therefore, suitable cultivars must be selected (Musacchi and Lugli, 2014).

In all the training systems described, the key feature is that the cropping occurs mainly on basal floral buds of 1-year-old shoots, which represents an innovative management approach. However, cherry cultivars vary in their potential to produce flower buds on 1-year-old wood as well as disposition toward tree architecture suitable to management-intensive HDP training systems. The objective of this research was to compare training systems suited for HDP in combination with different rootstock–cultivar combinations to test vegetative control and yield performance.

**Materials and Methods**

Two experimental trials were carried out in an orchard planted in Feb. 2007 to assess the behavior of different cultivars grafted on Gisela® 6 and Gisela® 5. The orchard was located in a pilot farm in Ferrara province (Northern Italy, lat. 44°43’39.55” N, long. 11°47’4.84” E). This area belongs to the Po river delta and the soil has from medium to fine texture with 3% to 6% of active lime in the tilled profile; in some periods of the year, water saturation can occur.

Uniform, high-quality trees were selected for all training systems. Quality aspects considered in selection included preference for short internodes combined with strong buds well distributed from the middle through the apical part of the tree. Selected trees were 1.20 to 1.60 m tall with trunk.

| Rootstock | Training system | Tree spacing (m) | Planting density (trees/ha) |
|-----------|----------------|-----------------|-----------------------------|
| Gisela® 5 | V              | 3.5 × 0.5       | 5714                        |
|           | SSA            | 3.5 × 0.8       | 2857                        |
|           | Spindle        | 3.5 × 1.0       | 1905                        |
| Gisela® 6 | V              | 3.5 × 0.8       | 3571                        |
|           | SSA            | 3.5 × 0.8       | 3571                        |
|           | Spindle        | 3.5 × 1.5       | 1905                        |

SSA = Super Spindle Axis.

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**Fig. 1.** Trunk cross-sectional area (TCSA) measured 10 cm above the grafting point in 2011 for both rootstocks (Gisela® 5 and Gisela® 6): comparisons were made between training systems (SSA, spindle, and V) and cultivars (‘Black Star’®, ‘Early Bigi’®, ‘Early Star’®, ‘Ferrovia’®, ‘Grace Star’®, ‘Kordia’, ‘Regina’, ‘Summit’, ‘Sweet Early’®, and ‘Sylvia’® grafted on Gisela® 5 and Gisela® 6). Mean values followed by same letters do not differ significantly according to Student-Newman-Keuls test (P = 0.05). Significance: *P < 0.05, **P < 0.01, ***P < 0.001, NS = nonsignificant. SSA = Super Spindle Axis.
diameter measuring 10 to 15 mm at 10 cm from the grafting union. Trees were produced in a nursery in a 1-year cycle; a bench graft was used to graft the scion onto the rootstock.

The sweet cherry cultivars under evaluation were ‘Giorgia’ and ‘Grace Star’\textsuperscript{5} grafted on Gisela\textsuperscript{6} and ‘Black Star’\textsuperscript{5}, ‘Early Bigi’\textsuperscript{6}, ‘Early Star’\textsuperscript{5}, ‘Ferrovia’, ‘Grace Star’\textsuperscript{5}, ‘Kordia’, ‘Regina’, ‘Summit’, ‘Sweet Early’\textsuperscript{5}, and ‘Sylvia’ grafted on Gisela\textsuperscript{6}.

Each rootstock–cultivar combination was trained to three different training systems: spindle, V-system, and SSA.

In the orchards, the interrow spacing was 3.5 m, whereas the along-row spacing varied according to requirements of the rootstock-training system combination (Table 1). In the first trial, the planting distances allowed for a density comparison from 1905 trees/ha to 3571 trees/ha, respectively, for spindle, V-system, and SSA grafted on Gisela\textsuperscript{6}. In the second trial, the planting density ranged from 2857 trees/ha to 5714 trees/ha for the spindle, V-system, and SSA grafted on Gisela\textsuperscript{5} (Table 1). A randomized block design was used with the orchard divided into four blocks with plots of five to 10 trees for the Gisela\textsuperscript{5} depending on the along-row spacing of the rootstock-training system combination. The total number of trees under evaluation was 1720. Among those trees, 220 were grafted on Gisela\textsuperscript{6} and 1500 were grafted on Gisela\textsuperscript{5}.

The SSA and the spindle training systems were constructed as a simple trellis structure with posts every 8 m and three horizontal wires in each row. The V-system training structure was constructed to have two fruiting walls, each containing two wires, oppositely oriented 20° from the vertical. Tree pruning and training in the spindle system were developed by selecting four or five wide-angle lateral shoots in the bottom part of the tree to establish a permanent scaffold of branches. Trees in the V-system were planted to face alternating sides of the trellis along the row and tied to trellis wires. In all systems, trees were planted on 30-cm-high berms to prevent root system damage resulting from excessive soil moisture in the winter. A microirrigation system was used to provide water and nutrients, which were applied annually at the same rates for each rootstock–cultivar training system combination. The whole orchard was covered by antihail netting, but anticracking netting was not set up.

Because the new trees initially had few small side branches, a gridling technique was performed at three different levels (every 40 cm) on the central leader during the first year after planting to promote lateral branch development (10 to 15) with the application of a cytokinin-gibberellin growth regulator (e.g., Promalin\textsuperscript{5}, Valentbiosciences). In the first growing season, the management goal was to achieve 75% of the final leader height for the SSA and V-system and 60% of the final leader height for the spindle. All the systems presented at least 10 to 15 lateral branches with relatively uniform moderate vigor, which provide shoot basal fruiting capacity in the second year in the SSA and V-system. Trees in the spindle system tend to exhibit lateral branches with more vigor compare with the other training systems.

Controlling vigor is a key component of these HDP planting system and applying “short-pruning” to existing lateral shoots to simultaneously balance leaf area with the fruit load of the second year and renew/initiate new fruiting laterals is fundamental. SSA “short-pruning” was done in the first dormant season by removing the majority of the length of each 1-year-old (previous season) shoot, retaining only the basal flower buds plus at least two vegetative buds for new shoot formation. This was performed during bud swell, when it is easier to differentiate between flower buds and vegetative buds.

During the second year, all the training systems achieved the final height and showed good lateral shoot formation. All the systems under evaluation start to crop at the second year, although the spindle system did not achieve a full production until Year 4 to 5.

In the second and subsequent dormant seasons, “short-pruning” on all lateral shoots was done to all shoots to maintain renewal of all fruiting laterals and maintain balanced between vigor and crop, because overcoppicing can compromise fruit quality. Although fruiting buds were fewer in the early years of
the experiment, trees in the spindle system were treated similarly and all the lateral shoots present on the branches were shortened to four to five buds. Trimmed shoots were longer at the bottom relative to the upper part of the tree to allow the penetration of light into the canopy. The fruiting branches were also cut back to induce new growth.

The trunk diameter 10 cm above the grafting point and the weight of winter-pruned wood were measured as vegetative parameters (2007–11), whereas number of fruit and yield per tree were collected as productive parameters (2008–13). Fruit size distribution was estimated on 1 kg of fruit per plot.

In 2009 and 2010, for each combination of cultivar–rootstock training system, a sample of 20 fruit for each replication was measured to determine quality parameters. Peel color was measured with a Minolta colorimeter CR-200 (Konica Minolta, Ramsey, NJ). Epi-dermal elasticity was assessed with Durofel Dft 100 (Apollinaire Ltd., Forges Les Eaux, France). Flesh firmness was measured with an EFFEGI Model: FT 327 (Effegi Elettronica, Turin, Italy) electronic penetrometer with a 6 mm-tip; one measure was done per cherry and skin was peeled before testing. Acidity and pH were measured with a Crison Compact Titrator (Sciware Systems S.L., Bunyola, Balearic Islands, Spain), and soluble solids content (SSC) were measured using portable digital refractometer (PAL-1; Atago U.S.A Inc., Bellevue, WA) using juices obtained from each replication.

All data collected were analyzed using SAS® software (SAS Institute, Inc., Cary, NC) and means separation was performed using the Student-Newman-Keuls test; differences were considered significant with $P \leq 0.05$.

Results and Discussion

Vegetative parameters. Training systems, rootstocks, and pruning techniques adopted in this trial substantially impacted the vigor and the productivity of evaluated cultivars. After 5 years, there were major differences in the trunk cross-sectional area (TCSA) between the Gisela® 5 and Gisela® 6 rootstocks. Trees grafted on Gisela® 6 had TCSAs that were at least double of those grafted on Gisela® 5 (Fig. 1). Among the cultivars on Gisela® 5, ‘Grace Star®’ had the highest TCSA (37.7 cm$^2$) followed by ‘Black Star®’ (34.7 cm$^2$). The Gisela® 5 rootstock induced low vigor in combination with ‘Summit’ (16.8 cm$^2$), ‘Early Bigi®’ (15.7 cm$^2$), and ‘Sylvia’ (10.6 cm$^2$), possibly indicating the dwarfing effect was too severe. The Gisela® 6 trees did not have significant differences in TCSA among the three training systems. ‘Grace Star®’ was the only cultivar grafted on both rootstocks; trees on Gisela® 5 were smaller than those on Gisela® 6 (37.7 cm$^2$ and 74.2 cm$^2$, respectively). Trees trained using the V-system and SSA were less vigorous, particularly on the Gisela® 5 rootstock. However, the impact of planting density on the fruit tree growth is not fully understood and depends on rootstock and scion interaction.

In a study on apple, Loreti et al (1978) found a reduction of growth when trees were planted at higher densities, probably as a result of early cropping. This reduction in growth was also observed in the current study and may explain the lower value of the TCSA associated with the SSA (which can bear fruit in the second year). Reduced growth can be attributed to the competition between adjacent trees at the root level as a result of the shorter distance in the row compared with the spindle training system. As also observed in this study, closer tree spacing may negatively affect trunk and root growth.
Parry (1978) observed that the vegetative growth restriction observed in his trials was primarily caused by the proximity of adjacent trees. Chalmers et al. (1981) postulated that, in case of lower planting density and regulated deficit irrigation, canopy competition can influence trees’ growth capacity.

The winter pruning data for 2007–11 are shown in Figures 2 and 3. Gisela® 6 induced higher vigor in the trees compared with Gisela® 5. The spindle on both rootstocks had a higher weight of pruned wood each year compared with the V-system and SSA (Fig. 2A).

The cumulative pruning weight of spindle system trees was 3.0 kg/tree for the Gisela® 5 and 6.9 kg/tree for the Gisela® 6 in a 5-year period. The SSA and the V-system showed a cumulative weight of pruned wood similar to spindle system with 1.9 and 2.0 kg/tree for the Gisela® 5 (not significantly different) and 5.3 and 5.2 kg/tree for Gisela® 6, respectively (Fig. 2A). Regarding the planting density, the V-system and SSA produced a greater quantity of pruning wood compared with spindle: 11.5 and 11.0 Mt·ha⁻¹ for Gisela® 5 (not significantly different) and 18.7 and 19.1 Mt·ha⁻¹ for Gisela® 6, respectively (Fig. 2B).

Comparing cultivars grafted on Gisela® 5 (Fig. 3), regardless of the specific training system, ‘Grace Star®’ and ‘Black Star®’ produced the largest quantity of pruning wood over 5 years, 16.3 and 16.2 Mt·ha⁻¹, respectively. In contrast, ‘Sylvia’ had the lowest weight of pruned wood, amounting to 4.0 Mt·ha⁻¹. Between the two combinations tested on Gisela® 6, ‘Grace Star®’ had the highest pruning weight (22.6 Mt·ha⁻¹) compared with ‘Giorgia’ (8.8 Mt·ha⁻¹) (Fig. 3).
Management aspects of the HDP orchard differ greatly from traditional orchards. The HDP orchard on dwarfing rootstock needs a very intense pruning to maintain the renewal capacity of the productive wood. Especially in the SSA, “short-pruning” is applied by removing the majority of the length of each 1-year-old (previous season) shoot, saving only the basal flower buds plus at least two vegetative buds for new shoot formation. This is a quite new concept in cherry pruning, where removing branches in undesirable positions and bending long branches are traditionally the sole pruning and training techniques.

**Productive parameters.** In Years 6 (2012) and 7 (2013), the trees trained to spindle had the highest yield per tree (1.32 and 1.01 kg/tree, respectively) among the three training systems on Gisela® 5 (Fig. 4A). However, the Gisela® 5 combined with the V- and SSA training systems induced cropping earlier than with the spindle (Fig. 4A and B). At the end of Year 7 (2013), the cumulative yield per tree was similar for the V- and SSA training systems (4.7 kg/tree) in combination with the V-system, SSA, and spindle on Gisela® 5, respectively. The Gisela® 5 cumulative yield per tree over the first 7 years was 46.3, 43.6, and 31.3 Mt·ha⁻¹ for the V-system, SSA, and spindle, respectively (Fig. 4B).

Among the scion cultivars grafted on Gisela® 5 (Fig. 5), ‘Ferrovia’ had the best yield performance in the highest density planting training systems (V-system and SSA) with a cumulative yield of over 50.0 Mt·ha⁻¹ on both systems by the end of Year 7. Early production of ‘Ferrovia’ was 4.70 Mt·ha⁻¹ in 2008 and 5.41 Mt·ha⁻¹ in 2009 with the V-system and 6.30 Mt·ha⁻¹ in 2008 and 6.87 Mt·ha⁻¹ in 2009 with SSA. ‘Black Star®’ also produced high early yields with 4.1 Mt·ha⁻¹ on the V-system, 3.5 Mt·ha⁻¹ on SSA, and 0.9 Mt·ha⁻¹ on spindle in 2008. In the last assessed year, 2013, ‘Grace Star®’ was the most productive cultivar producing 14.7 Mt·ha⁻¹ with SSA followed by spindle (8.5 Mt·ha⁻¹) and the V-system (7.7 Mt·ha⁻¹) (Fig. 5). Among the early-ripening cultivars, ‘Early Bigi’ had high yields in the first 4 years after planting, but this result was not confirmed in the following years. ‘Early Star®’ showed a late bearing attitude; however, the yield increased from 2011 to 2013 (Fig. 5). ‘Sweet Early’ produced the lowest cumulative yields regardless of the training system with a maximum of 6.5 Mt·ha⁻¹ when trained as a V-system (Fig. 5).

Adopting SSA and the V-system in combination with Gisela® 5, it was possible to harvest a consistent crop 2 and 3 years after planting, especially with ‘Ferrovia’ and ‘Black Star®’. Some other cultivars like ‘Grace Star®’ and ‘Sylvia’ showed late bearing, but in Years 6 and 7, the yield increased dramatically. These data illustrate that fruit yield potential and vegetative growth differ among possible HDP training systems according to scion cultivar. Moreover, some cultivars like ‘Sweet Early’, ‘Kordia’, ‘Black Star’, ‘Early Bigi’, and ‘Summit’ do not exhibit sufficient sustained production when trained in a high-density planting. It was also possible that some rootstock/scion combinations, especially ‘Sweet Early’ and ‘Early Bigi’ grafted on Gisela® 5, exhibit aging on bearing wood that can reduce the crop productivity through reduced flower bud formation. ‘Kordia’ and ‘Summit’, on the contrary, had a high bloom level but poor fruit set and high fruit drop until harvest. It was also observed that after the fifth year some cultivars showed a decrease in the yield, mainly as a result of adverse climate conditions during bloom time and harvest, especially in 2013.

In this trial, ‘Ferrovia’ was the most suitable cultivar for HDP orchards, probably as a result of its bearing habit with cropping occurring mainly on 1-year-old wood after a short-pruning in winter. Earlier bearing was observed on trees grafted on Gisela® 5 and trained to SSA; this characteristic is very important in HDP orchards to hasten economic returns. It was also evident that a combination of ‘Grace Star’ grafted on Gisela® 5...
and Gisela® 6 resulted in very comparable yield levels among the different training systems.

In 2013, with the exception of ‘Grace Star’ grafted on Gisela® 6 and Gisela® 5, a reduction in yield was observed in all the cultivars under evaluation.

**Qualitative parameters.** Regarding fruit size distribution (Fig. 6), ‘Ferrovia’ produced a high percentage of fruit greater than 28 mm. Over 90% of the fruit was greater than 28 mm in diameter with the V-system and SSA in 2012. ‘Kordia’ produced ≈60% of fruit greater than 28 mm in diameter for each training systems in 2012, but in 2013, 70% of the fruit was less than 28 mm. ‘Sylvia’ and ‘Black Star’ produced the highest percentage of fruit less than 28 mm in both years. In 2012, fruit distribution was similar between the two rootstocks for ‘Grace Star’, whereas in 2013, trees grafted on Gisela® 6 were more productive with a larger fruit size than those grafted on Gisela® 5. ‘Regina’ produced a high percentage (greater than 75%) of fruit greater than 28 mm with each training system in both years; however, it had a very low yield per hectare, especially in 2013, as

![Fig. 6. Fruit size distribution in 2012 (above) and 2013 (below) were considered according to two size classes (below 28 mm and over 28 mm) for both rootstocks (Gisela® 5 and Gisela® 6). Size comparisons were made according to training systems within each cultivar.](image-url)
a result of a high fruit drop, which occurred after fruit set.

The results of fruit qualitative analyses for 2009 and 2010 are shown in Tables 2 and 3. In 2010, for both rootstocks, trees trained to the spindle produced the largest and sweetest fruit, whereas the fruit from the V-system were the less firm (0.47 kg cm⁻²; Table 2).

Ferrovia, ‘Kordia’, and ‘Summit’ had the highest fruit weight (≈11 g) in 2009 (Table 3). The highest SSC fruit was ‘Kordia’ (20.3%), ‘Regina’ (19.2%), and ‘Summit’ (19.0%) followed by ‘Ferrovia’ (17.3%).

‘Grace Star™’ was the most acidic cultivar regardless of rootstock (12.2 g L⁻¹ for Gisela® 5 and 9.21 g L⁻¹ for Gisela® 6). In 2010, ‘Black Star™’ produced the smallest (9.0 g) and most firm fruit (0.68 kg cm⁻²).

‘Early Bigi™’, which was the earliest ripening cultivar, produced the softest fruit.

Table 2. Results for fruit qualitative parameters including weight, skin elasticity, firmness, SSC, acidity, and pH are summarized according to high-density planting training systems in 2009 and 2010 for both rootstocks (Gisela® 5 and Gisela® 6).

| Rootstock | Training system | Avg fruit wt (g) | Skin elasticity (Durofel) | Firmness (kg cm⁻²) | SSC (%) | Acidity (g L⁻¹ malic acid) | pH |
|-----------|-----------------|-----------------|--------------------------|-------------------|--------|--------------------------|----|
| 2009      |                 |                 |                          |                   |        |                          |    |
| Gisela® 5 | V               | 9.7             | 57.1 a                   | 0.49              | 16.8   | 7.73                     | 4.01|
|           | SSA             | 9.6             | 57.7 a                   | 0.59              | 16.6   | 7.74                     | 3.93|
|           | Spindle         | 9.9             | 54.4 b                   | 0.45              | 16.9   | 7.58                     | 3.98|
|           | Significance    | NS              | ***                      | NS                | NS     | NS                       | NS |
| Gisela® 6 | V               | 9.4 a           | 59.6                     | 0.48              | 15.3   | 9.79                     | 3.82|
|           | SSA             | 9.1 b           | 61.0                     | 0.43              | 14.9   | 8.82                     | 3.83|
|           | Spindle         | 8.9 c           | 61.1                     | 0.41              | 14.8   | 8.93                     | 3.88|
|           | Significance    | NS              | NS                      | NS                | NS     | NS                       | NS |
| 2010      |                 |                 |                          |                   |        |                          |    |
| Gisela® 5 | V               | 10.9 b          | 51.8 b                   | 0.47 c            | 15.7 b | 5.79                     | 3.81|
|           | SSA             | 10.9 b          | 54.2 a                   | 0.51 b            | 15.3 c | 6.33                     | 3.79|
|           | Spindle         | 11.2 a          | 53.9 a                   | 0.52 a            | 16.0 a | 6.43                     | 3.81|
|           | Significance    | ***             | *                        | ***               | ***    | NS                       | NS |
| Gisela® 6 | V               | 9.6 b           | 59.2                     | 0.47 b            | 16.3 b | 7.78                     | 3.73|
|           | SSA             | 9.4 b           | 58.8                     | 0.52 a            | 16.2 b | 8.10                     | 3.70|
|           | Spindle         | 10.1 a          | 58.0                     | 0.51 a            | 16.9 a | 8.20                     | 3.77|
|           | Significance    | ***             | ***                      | NS                | NS     | NS                       | NS |

Table 3. Differences in fruit qualitative parameters including weight, skin elasticity, firmness, SSC, acidity, and pH are summarized according to cultivar for 2009 and 2010 for both rootstocks (Gisela® 5 and Gisela® 6).

| Rootstock | Training system | Avg fruit wt (g) | Skin elasticity (Durofel) | Firmness (kg cm⁻²) | SSC (%) | Acidity (g L⁻¹ malic acid) | pH |
|-----------|-----------------|-----------------|--------------------------|-------------------|--------|--------------------------|----|
| 2009      |                 |                 |                          |                   |        |                          |    |
| Gisela® 5 | Black Star™³⁴ | 8.5 d'          | 59.3 c                   | 0.68              | 15.2 c | 6.38 fg                  | 4.34 a|
|           | Early Bigi™³⁴  | 9.4 c           | 42.2 g                   | 0.56              | 14.8 c | 6.20 g                   | 3.57 c|
|           | Early Star™³⁴  | 7.4 e           | 61.8 b                   | 0.82              | 15.2 c | 6.89 ef                  | 4.42 a|
|           | Ferrovia        | 10.9 a          | 58.6 cd                  | 0.44              | 17.3 b | 7.97 c                   | 3.97 b|
|           | Grace Star™³⁴  | 10.1 b          | 56.7 de                  | 0.42              | 15.7 c | 11.47 a                  | 3.77 b|
|           | Kordia          | 10.8 a          | 57.7 cd                  | 0.37              | 20.3 a | 8.87 b                   | 3.91 b|
|           | Regina          | 9.5 c           | 54.1 f                   | 0.38              | 19.2 a | 7.13 de                  | 4.47 a|
|           | Summit          | 10.7 a          | 59.2 c                   | 0.49              | 19.0 a | 8.70 b                   | 3.96 b|
|           | Sweet Early™³⁴  | 9.0 c           | 55.3 ef                  | 0.41              | 15.2 c | 4.71 h                   | 3.98 b|
|           | Sylvia          | 9.3 c           | 64.0 a                   | 0.81              | 15.0 c | 7.64 cd                  | 3.93 b|
|           | Significance    | ***             | ***                      | NS                | ***    | NS                       | *** |
| Gisela® 6 | Giorgia         | 7.5 c           | 66.3 a                   | 0.47 b            | 13.9   | 9.06 b                   | 3.98 a|
|           | Grace Star™³⁴  | 10.4 a          | 58.3 b                   | 0.32 c            | 15.7   | 12.22 a                  | 3.69 c|
|           | Significance    | ***             | ***                      | NS                | NS     | NS                       | NS |
| 2010      |                 |                 |                          |                   |        |                          |    |
| Gisela® 5 | Black Star™³⁴  | 9.0 g           | 54.1 d                   | 0.68 a            | 13.2 g | 5.10 fgh                 | 4.02 b|
|           | Early Bigi™³⁴  | 11.4 c          | 33.0 g                   | 0.21 h            | 14.1 f | 5.74 def                 | 3.87 d|
|           | Early Star™³⁴  | 10.2 e          | 58.5 b                   | 0.50 e            | 13.8 f | 8.62 b                   | 3.69 fg|
|           | Ferrovia        | 11.7 c          | 53.8 d                   | 0.50 e            | 16.1 c | 5.37 efg                 | 3.71 e|
|           | Grace Star™³⁴  | 10.9 d          | 55.3 d                   | 0.62 b            | 15.7 d | 9.41 a                   | 3.47 h|
|           | Kordia          | 10.7 d          | 63.7 a                   | 0.58 c            | 16.1 c | 6.30 cd                  | 3.76 e|
|           | Regina          | 12.6 b          | 54.6 d                   | 0.58 c            | 17.4 b | 5.47 efg                 | 3.80 e|
|           | Summit          | 14.0 a          | 56.7 c                   | 0.55 d            | 18.3 a | 6.68 c                   | 3.65 g|
|           | Sweet Early™³⁴  | 9.8 f           | 51.1 c                   | 0.33 f            | 17.1 b | 4.83 gh                  | 4.16 a|
|           | Sylvia          | 10.0 ef         | 57.5 bc                  | 0.53 d            | 15.0 c | 4.49 h                   | 3.94 c|
|           | Significance    | ***             | ***                      | ***               | ***    | NS                       | *** |
| Gisela® 6 | Giorgia         | 8.8 b           | 63.3 a                   | 0.47 b            | 16.9 a | 6.84 b                   | 3.87 a|
|           | Grace Star™³⁴  | 10.5 a          | 54.1 b                   | 0.53 a            | 16.1 b | 9.21 a                   | 3.59 b|
|           | Significance    | ***             | ***                      | ***               | ***    | NS                       | *** |

Mean values followed by the same letters do not differ significantly according to Student-Newman-Keuls test (P = 0.05).

Significance: *P > 0.05, **P < 0.01, ***P < 0.001, NS = nonsignificant.
SSC = soluble solids content; SSA = Super Spindle Axis.
Gisela grade for sweet cherries. Fruit produced by than 28 mm, representing the first-quality produced a high percentage of fruits greater than 28 mm, representing the first-quality grade for sweet cherries. Fruit produced by Gisela® 5 are characterized by higher SSC and larger fruit size. Our results demonstrated that it is possible to develop an HDP sweet cherry orchard producing a significant yield by the second and third year after planting. The SSA and V-systems, in combination with the correct cultivar, guaranteed a high level of production and positively affected fruit quality. Generally speaking, the low production per tree (3 to 5 kg) is compensated by a high number of trees and the achieved quality is very high with over 90% of fruit having a diameter over 28 mm.

Pruning will be a key factor to minimize wood aging and yield reduction. The HDP training systems, particularly the SSA in combination with a short-pruning, offers the possibility for orchard mechanization. For mechanical pruning, the small width of the trees could allow lopping machines to shorten all the 1-year-old shoots at four to five buds of length. Similar trials have already been performed on apple (Masseron, 2002). A protection system against frost and rain is strongly recommended to maintain an efficient tree and avoid fluctuation in crop level. Further investigation must be carried out to better define the lifespan of the orchard and how long it will be possible to maintain the tree efficiency under high-density planting conditions.

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