# Tree and orchard variability of Silver King nectarine (*Prunus persica* (L.) Batsch) fruit quality components

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**Abstract**

Ligouri G., Farina V., Gullo G., Inglese P., 2013. **Tree and orchard variability of Silver King nectarine (*Prunus persica* (L.) Batsch) fruit quality components**. Hort. Sci. (Prague), *40*: 72–77.

The variability of crop quality accounts for most of seasonal variation of farmers' incomes, since fruit growth and quality components may greatly change according to various environmental and within-tree factors. Canopy architecture and orchard layout are mainly responsible for fruit size, quality and its variability. A positive relationship was measured in peach between intercepted radiation and PAR and Trolox equivalent antioxidant capacity (TEAC). This study was carried out to measure within tree and orchard variability of fruit of the early ripening cv. Silver King nectarine (*Prunus persica* (L.), Batsch) 8-years-old peach trees trained to a Y-shape and Delayed vase. Fruit were picked twice and all harvested fruit were analysed in terms of size, soluble solids content, titratable acidity, pH, firmness and TEAC. Fruit weight variability between single trees was larger than within the tree and between training systems. Fruit soluble solid content and firmness had a higher variability than fruit size and within tree variability was higher in Delayed vase trees than in Y-shaped ones. TEAC changed with fruit position within the canopy.

**Keywords**: training system; total antioxidant capacity; firmness; soluble solids

Increasing crop uniformity, particularly in terms of fruit size and firmness, is one of the major goals of fruit tree growers, since the variability of crop quality accounts for most of the seasonal variation of their incomes. The between-fruit variation of quality variables is high within the tree, depending on a number of factors that affect fruit relative sink strength and specific growth rate during their different developmental stages (DeJong, Grossmann 1995). In order to support fruit growth, bearing shoots usually need supplementary contribution of C from shoots without fruit, and variation of fruit dry mass between bearing shoots is higher than within individual ones (Walcroft et al. 2004). Fruit position along the canopy, proximity to other sinks and distance from tissue source (Caruso et al. 2001; Forlani et al. 2002; Gugliuzza et al. 2002), shoot type (Corelli Grappadelli et al. 1996), leaf-to-fruit ratio (Wu et al. 2005), greatly account for the variability of fruit quality. Exposure and leaf area affect most quality components (Génard, Bruchou 1992). Orchard layout, canopy architecture and pruning system are responsible for within-tree light environment (De Salvador, DeJong 1989), resources availability and partitioning (Corelli Grappadelli et al. 1999), and between-fruit variability of quality variables (Dann, Jerie 1988; Génard, Bruchou 1992; Marini, Sowers

1994; Caruso et al. 1998; Forlani et al. 2002; Luchsinger et al. 2002; Farina et al. 2005, 2006). Marini (1985) found the sweetest and softest peach fruit occurring in the higher part of peach trees trained to an open centre, and fruit soluble solid content decreased linearly from top/outside to bottom/inside canopy in vase- and Y-shaped cv. Elegant Lady peach trees (Farina et al. 2005). Fruit have a higher total equivalent antioxidant capacity (TEAC) than conventional synthetic antioxidants used as food additives (Eberhardt et al. 2000). Peach fruit TEAC shows a remarkable variability within the peach germplasm (Di Vaio et al. 2008), and canopy architecture and light distribution within the canopy play a role in TEAC content in fruit (Remorini et al. 2008). A positive correlation between light distribution within the canopy, fruit antioxidant capacity and polyphenol content was found in peach (Motisi et al. 2005).

Considering that between-fruit variation of most of quality variables may be as large as the between cultivar variation (Génard, Bruchou 1992), one major horticultural implications concerns the extent of the variation of the coefficient of variability of fruit components, within and between the trees, and in relation to training system and harvest date. In order to address this question, the current study was carried out to measure the range of within-tree and between trees variability for each of the fruit quality components of the early ripening nectarine cv. Silver King (*Prunus persica* (L.), Batsch).

## MATERIALS AND METHODS

The experiment was carried out in 2006 and 2007, in a commercial peach orchard located in Sicily (Sciacca, 37°28'32''N; 13°11'35''E). The plots were made up of 8-year-old trees of the early ripening white flesh nectarine cv. Silver King (*Prunus persica* (L.) Batsch) grafted on GF 677 (*Prunus amygdalus* × *Prunus persica*) rootstock and trained either to a Y-shape, spaced 5.5 × 2.0 m apart (910 trees/ha), or to a Delayed vase (DV), spaced 5.0 × 4.0 m apart (500 trees/ha); trees yielded 24 ± 2.1 ( 21.8 t/ha) and 36 ± 4.1 kg of fruit/tree (18 t/ha), respectively. LAI (tree leaf area vs. ground area covered by the tree) was 2.2 in DV and 2.9 in Y-shape; crop efficiency (kg fruit/cm$^2$ trunk sectional area) was 1.05 and 0.98 respectively for DV and Y-shape. PAR (photosynthetic active radiation) interception was 64% in DV and 80% in Y-shape orchard, with an average photosynthetic photon flux density (PPFD), measured, at the top, middle and bottom canopy sites of 536 μmol/m$^2$/s in DV trees and 790 μmol/m$^2$/s in Y-shape trees.

The experimental design included 9 single-tree block replicates for each planting system and harvest date. Trees were randomly chosen in uniform blocks in the middle of the orchard, so that their apparent cropping performance and overall development fully reflected orchard conditions. Ordinary horticultural care was applied in both production systems, in terms of floor and pest management, pruning, irrigation and fertilization. Fruit were thinned to one every 20 cm, four weeks after full bloom.

In order to understand how whole crop variability changes with fruit ripening stage, fruit were harvested at the beginning of commercial harvest maturity (30 May 2006; 24 May 2007) and one week later (7 June 2006; 1 June 2007) when fruit firmness was 6.6 ± 0.8 kg/cm$^2$ and 4.9 ± 1.1 kg/cm$^2$, respectively (average of the two training systems, in the two seasons). At each harvest date the whole crop of each single tree was collected and, then, fruit were sorted by their canopy position in terms of exposure (North, East, South and West), and height (above/below 2.0 m in the Y-shape and 1.5 m in the DV). Size (weight, g), total soluble solid content (TSS) and firmness (kg/cm$^2$) measured with an 8 mm tip PCE-PTR 20 penetrometer (PCR-Italia, Lucca, Italy) were measured for each single fruit. In summary, at each sampling date, 2,350 and 3,025 single fruit were analysed for Y-shaped and DV trees, in both years. The total antioxidant capacity (TAC) was determined using the modified Trolox equivalent antioxidant capacity (TEAC, mmol Trolox Eq/g fresh weight) assay (Slinkard, Singleton 1977; Pellegrini et al. 1999; Scalzo et al 2005). TAC was evaluated, only at the latest harvest date, according to the ABTS modified assay (Pellegrini et al. 1999). For each of 3 replicates, 5 fruit were placed in polyethylene bags and frozen at –20°C until the analyses were performed on fruit pulp. For each fruit a quantity of 20 g of pulp was taken, with and without epicarp. TAC analyses were made for each training system and taking into account fruit position within the canopy, and in fruit with or without epicarp.

Within- and between-tree variability of fruit weight, total soluble solid content, firmness and TAC, was analysed by a two-way analysis of variance (Systat Statistical Package, SSCS© Inc., Chicago, USA); Tukey's test was applied to indicate

Table 1. Fruit weight, total soluble solid content (TSS) and firmness of cv. Silver King peach (*Prunus persica* Batsch) fruit, in relation to training system and harvest date, during two seasons (2006, 2007)

| Training system | | Fruit weight (g) | Fruit TSS (%) | Fruit firmness (kg/cm$^2$) |
|---|---|---|---|---|
| **2006** | | | | |
| Delayed vase | May 30 | 104.1$^b$ | 11.4$^{ns}$ | 6.6$^a$ |
| | June 07 | 119.0$^a$ | 11.6 | 5.4$^b$ |
| Y-shape | May 30 | 100.2$^b$ | 11.2$^{ns}$ | 6.7$^a$ |
| | June 07 | 109.1$^a$ | 11.4 | 4.4$^b$ |
| **2007** | | | | |
| Delayed vase | May 24 | 102.3$^b$ | 11.7$^{ns}$ | 6.9$^a$ |
| | June 01 | 117.2$^a$ | 11.9 | 5.6$^b$ |
| Y-shape | May 24 | 101.6$^b$ | 11.3$^{ns}$ | 6.9$^a$ |
| | June 01 | 110.4$^a$ | 11.8 | 4.2$^b$ |

$^{a,b}$significant differences within the column; $^{ns}$not significant at $P \leq 0.05$ (Tukey's test)

significant differences between means. Harvest date, training system and fruit position within the canopy were used as possible sources of variability.

## RESULTS AND DISCUSSION

Fruit weight significantly increased and firmness decreased with harvest date, in each season (Table 1). Significant differences ($P \leq 0.05$) between training systems in terms of fruit fresh weight and firmness occurred only at the latest harvest date (Table 1). TSS did not significantly change with harvest date, season and training system (Table 2). In both seasons, fruit on the sun-exposed top canopy sites of the two training systems had a significantly ($P < 0.05$) larger fruit weight (110 g vs. 101 g) and higher TSS (11.6% vs. 10.4%) content than those in the lower part, while fruit firmness did not change significantly along the canopy. TEAC was highest in Delayed vase trees (Fig. 1) and changed with fruit position within the canopy, being higher in fruit grown in the southern than in north, east or west canopy sites (5.5 ± 0.2 μmol TroloxE/g vs. 4.3 ± 0.4 μmol TroloxE/g) of DV trees and in fruit of the eastern rather than in the western scaffold (4.5 ± 0.3 μmol TroloxE/g vs. 3.4 ± 0.2 μmol TroloxE/g) of Y-shaped trees. Fruit without epicarp had a 25% lower TEAC than with it. The analysis of variance showed that the coefficient of variation of fruit weight, TSS and firmness did not change with the season (Table 3). The coefficient of variation of fruit fresh weight did not change with any of the sources of variability taken into account, but the harvest date. On the other hand, the coefficient of variation of fruit TSS and firmness changed with harvest date, training system and fruit position within the canopy, while TAC changed significantly with training system and fruit position within the canopy (Table 3). No interaction was found between training system, harvest date or season. The coefficient of variation of fruit TSS and firmness was significantly higher in Delayed vase than in Y-shape, both between trees and within the tree. TSS showed a lower variation than fruit weight and firmness (Table 4). The coefficient of variation of fruit fresh weight, TSS and firmness greatly increased with fruit ripening, and doubled, within a week, in the case of fruit firmness (Table 5). Fruit TSS and firmness had a higher variability (30% vs. 20%) in the top layer of the canopy (average PPFD

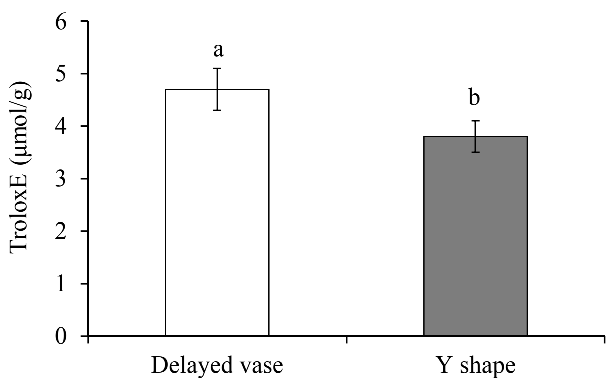


Fig. 1. Trolox Equivalent Antioxidant Capacity (TEAC) content of cv. Silver King peach (*Prunus persica* (L.) Batsch) fruit, on trees trained to Delayed Vase and Y-shape. Data are averages of fruit taken on 7 June 2006 and 1 June 2007, Bars indicate Standard errors, and different letters indicate significant differences at $P \leq 0.05$ (Tukey's test), ($n$ = 120)

Table 2. Analysis of variance (*P*-value) of the coefficient of variation of fruit weight, total soluble solids content (TSS), firmness and total antioxidant capacity (TAC), in relation to season (2006, 2007), harvest date, training system and fruit position within the canopy of cv. Silver King peach (*Prunus persica* Batsch) trees trained to Delayed vase and Y-shape

| Source of variation | Fruit weight | Fruit TSS | Fruit firmness | TAC |
|---|---|---|---|---|
| Season | 0.250 | 0.650 | 0.190 | 0.589 |
| Fruit harvest date | 0.048 | 0.000 | 0.000 | – |
| Training system | 0.570 | 0.033 | 0.030 | 0.034 |
| Fruit position within canopy | 0.921 | 0.034 | 0.032 | 0.021 |
| Harvest date × training system | ns | ns | ns | – |
| Season × training system | ns | ns | ns | ns |

significant at $P < 0.01$; ns – non significant (Tukey's test)

for the two training system was 1050 µmol/m$^2$/s) than in the bottom one (average PPFD for the two training system was 325 µmol/m$^2$/s).

The coefficient of variation of fruit weight and firmness was higher between all single trees for each training system than within each tree: TSS showed the same variability both within and between trees (Table 5).

The rationale of this experiment was to investigate the seasonal extent of fruit variability, in relation to a number of factors, namely training system and harvest time, with the ultimate goal of improving tree and orchard management. Investigating the source of variability of fruit quality in terms of size, TSS, firmness and antioxidant capacity, made clear that the variability of each of the fruit quality components shows a different range of variability, particularly in relation to training system and harvest time. Peach fruit meet consumer quality standards when, at commercial harvest time, firmness is not higher than 4.5 kg/cm$^2$ and soluble solids content is not lower than 12%. These standard were about to be reached only at the second take, in both years. Indeed, early ripening peach fruit more than often fail to reach these values and are usually poor in aroma and flavour (Ramina et al. 2008). Fruit weight may change with training system significantly but the analysis of variance of the coefficient of variation showed that the variability of fruit weight, most likely as a result of appropriate thinning, did not change neither with training system nor with fruit position within the canopy, but only in relation to harvest time, being larger between single trees than within a single tree. Indeed, fruit weight increased significantly during the last week of growth, when significant differences between Y-shaped and delayed-vase trees occurred.

The two training systems, Delayed vase and Y-shape, have a different canopy architecture and tree radiation profile (De Salvador, DeJong 1989); nevertheless, the variability of fruit size was similar and close to 30%. Strategies to reduce crop variability in term of fruit weight, involves accurate fruit thinning (Caruso et al. 2001) and canopy pruning, particularly summer pruning, to reduce the variability of light environments within the canopy (Motisi et al. 2006). It is worthy of note that data from both harvests were used for the analysis of variance, and the higher variability encountered in the canopy top layer likely reflects a faster time course of fruit

Table 3. Coefficient of variation (cv %) of fruit weight, total soluble solid content (TSS) and firmness of cv. Silver King peach (*Prunus persica* Batsch) fruit, between and within trees, trained either to Delayed vase or Y-shape. Data are averages of two seasons (2006, 2007)

| Training system | Fruit weight | | Fruit TSS | | Fruit firmness | |
|---|---|---|---|---|---|---|
| | between trees | within tree | between trees | within tree | between trees | within tree |
| Delayed vase | 29.3$^{ns}$ | 23.0$^{ns}$ | 18.3$^{a}$ | 17.9$^{a}$ | 36.2$^{a}$ | 32.4$^{a}$ |
| Y-shape | 28.6 | 21.0 | 13.0$^{b}$ | 12.8$^{b}$ | 26.7$^{b}$ | 22.8$^{b}$ |

$^{a,b}$significant differences within the column at $P \leq 0.05$; $^{ns}$not significant (Tukey's test)

Table 4. Coefficient of variation (CV %) of fruit weight, total soluble solid content (TSS) and firmness of cv. Silver King peach (*Prunus persica* Batsch) fruit, in relation to harvest date. Data are averages of two seasons (2006, 2007) and two training systems (Delayed vase and Y-shape)

| Harvest date | Fruit weight | Fruit TSS | Fruit firmness |
|---|---|---|---|
| 30/5/2006–24/5/2007 | 19.2[b] | 11.3[b] | 16.8[b] |
| 7/6/2006–1/6/2007 | 28.2[a] | 17.8[a] | 35.3[a] |

[a,b]significant differences within the column at $P \leq 0.05$ (Tukey's test)

Table 5. Coefficient of variation (CV %) of fruit weight, total soluble solid content (TSS) and firmness of cv. Silver King peach (*Prunus persica* Batsch) fruit, within and between-trees trained to a Delayed vase and Y-shape. Data are verages of two seasons (2006, 2007)

| Source of variation | Fruit weight | Fruit TSS | Fruit firmness |
|---|---|---|---|
| Within-trees | 20.1[b] | 15.4 n.s. | 22.1[b] |
| Between trees | 29.7[a] | 16.1 | 34.2[a] |

[a,b]significant differences within the column at $P \leq 0.05$

ripening of sun exposed fruit compared to those located in the bottom layer of the canopy (Caruso et al. 2001; Farina et al. 2005, 2006). Firmness and TSS had a greater variability than fruit weight and it seems that this variability is not related to fruit size, being more difficult to be controlled by crop management techniques. TSS had about half the variability of fruit firmness that changed with harvest time and training system. Indeed, the variability of quality components increased with fruit ripening, and delaying harvest time to reach optimal commercial harvest maturity standards may involve an increase of variability, particularly of fruit weight, TSS and firmness. Peach fruit weight increases, even during the late stages of fruit ripening, when the accumulation of sugars reaches a plateau and flesh firmness rapidly decreases (Farina et al. 2006; Ramina et al. 2008). The significant differences in fruit weight and firmness that occurred between the training systems one week after the first take reflect a different rate pattern of fruit ripening, which could depend on a different light environment or on a different fruit density (Génard, Bruchou 1992; Caruso et al. 2001; Forlani et al. 2002). The rapid decrease of fruit firmness coupled with its dramatic increase of variability makes the correct choice of harvest time more difficult for farmers. They usually face this problem either by increasing the number of takes, which, in turn, increases the cost of the whole crop, or advancing harvest time, thus reducing its sensory components (Di Miceli et al. 2010). Field variability of fruit quality is to be addressed more carefully and this is the ultimate goal of precision farming management, involving orchard layout and management as well as planting material and local environmental conditions (soil uniformity, alley management, etc.). Ultimately, other quality components, such as aroma, taste and flavour, change greatly with genotype and within a genotype with fruit ripening stage at commercial harvest (Di Miceli et al. 2010). The variability of such components should be more carefully investigated to increase consumers' satisfaction. For instance, antioxidant capacities of peach fruit also do not change only with genotype, but also with training system and fruit position within the canopy, likely because of the interaction with different canopy light environments.

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Received for publication March 13, 2012
Acceped after corrections December 21, 2012

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