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Effect of rootstocks and harvesting time on the nutritional quality of peel and flesh of peach fruits

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Abstract

The influence was evaluated of four rootstocks (Ishtara, Mr. S 2/5, GF 677 and Barrier 1) and of harvesting time (early, middle, late) on the quality characteristics and nutritional value (vitamin C, phenols, carotenoids, total antioxidant capacity) of 'Flavorcrest' peach. The better rootstocks were Mr. S 2/5 (low-vigour) and Barrier 1 (high-vigour). In particular, Flavorcrest fruit on Mr. S 2/5 and on Barrier 1 rootstocks had higher antioxidant capacities and also higher phytochemical content, although fruits on Mr. S 2/5 were less firm.

Flesh firmness was best for fruits at mid-harvest (H2, 7 July 2006), whereas phytochemical contents were best at late harvest (H3, 13 July 2006), when, for all rootstocks, the best nutritional characteristics were also recorded. Total antioxidant capacity and phytochemical content were determined for the peel and flesh. The results show that removal of peel from peach results in a significant loss of total antioxidant capacity.

Keywords: Carotenoids; Flesh; Harvesting time; Peach; Peel; Rootstock; Total antioxidant capacity; Vitamin C

1. Introduction

Stone fruits play an important role in human health due to the range of phenolic compounds and carotenoids they contain. Peaches, even though having a total antioxidant capacity (TAC) lower than some other fruits, such as strawberry, kiwifruit, apple, orange (Szeto, Tomlinson, & Benzie, 2002), are economically and nutritionally important because they can form a significant component of the diet during the spring and summer months because serving sizes are often larger (mass consumed per person, per day). Phenolic compounds represent the major sources of antioxidant capacity in peaches (Chang, Tan, Frankel, & Barrett, 2000); vitamin C and carotenoids also contribute to antioxidant activity (Gil, Tomas-Barberan, Hess-Pierce, & Kader, 2002).

The phytochemical content of fruit tissues is influenced by numerous pre-harvest factors, including genotype, rootstock, climatic conditions, agronomic practices and harvesting time, but also by post-harvest factors, including storage conditions and processing procedures (Cevallos-Casals, Byrne, Okie, & Cisneros-Zevallos, 2006; Gil et al., 2002; Lee & Kader, 2000; Tavarini, Degl'Innocenti, Remorini, Massai, & Guidi L., in press). Key to the commercial expansion of peach production is the promotion and maintenance of the highest possible standards of fruit quality. This involves the accurate evaluation of genotype and rootstock responses to growth conditions and management, and the identification of their best combinations (Giorgi et al., 2005). In a recent study, we showed that peach genotype plays an important role in determining total antioxidant capacity in peach fruits (Tavarini et al., in press). Moreover, Gil et al. (2002), in a study of antioxidant composition in a range of peach cultivars, showed that phenolic compounds were the main source of antioxidants. Certainly, also the rootstock is a very important

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factor in determining fruit quality. For example, it is known that dwarf rootstocks are able to direct more nutrients to the fruit because less competition for nutrients is provided by vegetative growth (Chalmers, Mitchell, & Van Heek, 1981). Also Giorgi et al. (2005) reported that rootstock has a significant role in determining the nutritional attributes of peaches.

In peach, the time of harvest influences total antioxidant capacity particularly strongly as during ripening a large number of biochemical, physiological and structural changes takes place. These include changes in background colour, sugar storage, decreases in organic acids, development of volatile and aromatic substances, fruit softening, increases in nutritional and healthful compounds, and, taken together, these determine fruit quality. Meanwhile, to ensure maximum resistance to mechanical damage and good shelf life, fruits are usually harvested well before physiological ripening, and at a stage characterised by high flesh firmness. For these reasons, it is difficult to identify a harvesting time that represents a best compromise between optimal quality and nutritional attributes on the one hand and good resistance to handling damage and shelf life on the other.

The peel of fruits and vegetables is commonly rejected because it is thought to be indigestible or possibly contaminated by sprays or by human disease agents. However, it has been reported that apple peels contain a higher amount of phenolic compounds and antioxidant activity (Wolfe, Wu, & Liu, 2003). Meanwhile, tomato skins contain high levels of lycopene, compared to the pulp and the seeds (Al-Wandawi, Abdul-Rahman, & Al-Shaikhly, 1985; Toor & Savage, 2005). This is true for peach too, where it has been reported that the peel contains higher amounts of phenols (Tomas-Barberan et al., 2001), carotenoids and total ascorbic acid than the flesh (Gil et al., 2002) on mass-per-mass basis.

Our objective was to evaluate different rootstocks grafted to Flavorcrest peach scions and different harvesting times on some phytochemical compounds and on the total antioxidant capacity in the peel and flesh fractions of the fruits. Determining the relationship between rootstock and harvesting time and levels of antioxidant compounds in fruits is essential, if we are to understand how to maximise levels of beneficial bioactive compounds in fresh fruits.

2. Materials and methods

2.1. Plant material

The peach rootstocks GF 677 (*Prunus persica* × *Prunus amygdalus*), Barrier 1 (*P. persica* × *Prunus davidiana*), Ishtara [(*Prunus cerasifera* × *P. salicina*) × (*P. cerasifera* × *P. persica*)] and Mr. S 2/5 (natural hybrid of *P. cerasifera*) were grafted to scions of 'Flavorcrest', a common yellow-pulp peach cultivar. The rootstocks GF 677 and Barrier 1 are considered 'high-vigour', while Mr. S 2/5 and Ishtara are considered 'low-vigour'. Trials were performed during 2006 at the experimental farm of the Department of Coltivazione e Difesa delle Specie Legnose "G. Scaramuzzi" of the University of Pisa (Italy), on a peach orchard, cv. 'Flavorcrest', planted in February 2000, having 4.5 × 2.5 m tree spacings and trained to a free spindle. A total of 50 trees were grafted onto each of GF 677, Barrier 1, Mr. S 2/5 and Ishtara rootstocks. In all trees, fruits were thinned 4 weeks after full bloom and before Stage II of fruit growth. Intensity of thinning depended on the size of the trees and on the number of long fruiting shoots remaining after winter pruning (one fruit every 15 cm along the bearing shoots). Conventional commercial irrigation and summer pruning treatments were performed. Fruits were selected for harvest that had been exposed to a 50–70% global solar irradiation, and 20 fruits were picked at three different times: early, 30 June 2006 (H1), middle, 7 July 2006 (H2) and late, 13 July 2006 (H3). The H2 time corresponded to the standard commercial stage for Flavorcrest cultivar. The evaluation of qualitative parameters (fresh weight, flesh firmness, soluble solids content, titratable acidity and skin over colour) was conducted on whole fruits. The nutritional characteristics (total antioxidant capacity, phenols, carotenoids) were determined at the same harvesting time in the same fruits used for quality characteristics, but in two different fractions – peel and flesh. At H1 and H3, vitamin C content was also determined in the two fractions. Fruits were peeled with a sharp knife, peel and flesh were frozen separately in liquid nitrogen, and kept at −80 °C until analysed.

2.2. Quality parameters

Flesh firmness (FF) was measured with a digital penetrometer having an 8-mm probe (Model 53205, TR, Forlì, Italy) on a flat surface, by removing the skin from two sides of the fruit. The measure was performed on two opposite faces in the equatorial zone. Flesh firmness was expressed in kg. Soluble solids content (SSC) was measured with a digital refractometer (Model 53011, TR) at the same sites as FF and was expressed as °Brix. The method for analysis of titratable acidity was based on neutralisation of the acids present in the fruit juice with a basic solution (NaOH 0.1 N). Values of titratable acidity were expressed as meq NaOH/100 mL.

The fruit colour was evaluated by visual assessment and expressed as percentage of skin surface covered by red pigment.

2.3. Total antioxidant capacity evaluation

To determine the total antioxidant capacity, the FRAP (Ferric-reducing antioxidant power) assay was used. The method measures the iron-reducing capacity of antioxidant substances in the extract of the two fractions. The procedure used was reported in Tavarini, Degl'Innocenti, Pardossi and Guidi (2007). The final value of total antioxidant

capacity was expressed as mmol Fe^{2+}/100 g fresh weight (FW).

2.4. Determination of vitamin C

Procedures used were as described by Degl'Innocenti, Guidi, Pardossi and Tognoni (2005), based on the method of Kampfenkel, Van Montagu, and Inzè (1995) for the spectrophotometric determination of ascorbic acid (vitamin C). Vitamin C was expressed as mg/100 g FW.

2.5. Determination of phenols

Total phenols were analysed using the method suggested by Dewanto, Wu, Adom, and Liu (2002), based on Folin-Ciocalteau assay and expressed as mg gallic acid/100 g FW.

2.6. Determination of β-carotene

Procedures used were as described by Reyes, Villarreal, and Cisneros-Zevallos (2007). Absorbance was determined at 470 nm in 1-cm quartz cuvettes of extracts in acetone:ethanol (1:1). Carotenoids were quantified as β-carotene using a standard curve.

2.7. Statistical analysis

Data were subjected to two way analysis of variance, to determine the significance of differences between treatments – namely, harvesting time and rootstocks. Least significant difference at the 5% level was calculated to compare differences among means. Linear regression analysis was carried out for total antioxidant capacity and phytochemicals.

3. Results and discussion

3.1. Quality indices

Fresh weight increased significantly during fruit ripening while still on the plant (Table 1), while flesh firmness decreased significantly with time of harvest, reaching optimal values (in the range 5–6 kg) by H2 (mean 5.60 kg) (Table 1). These firmness values also represent the optimal for a long storage of peach. At H1 differences among FF values were dependent on rootstock while at H2 and at H3 the rootstock influence was not significant.

Soluble solids content reached the highest values at H3 in fruits on rootstocks Ishtara, Mr. S 2/5 and Barrier 1, while on GF 677 no changes were recorded for the three harvesting times (Table 1).

Titratable acidity (TA) diminished in fruits on all rootstocks at different harvesting time (Table 1). In particular, the reduction of TA was evident in fruit on rootstocks Ishtara and Mr. S 2/5, the ratio SSC/TA being higher than one.

In Table 1 the skin over colour (OC) of fruits on different rootstocks is reported also. The higher values of OC were reached in fruits on weakest rootstocks (Ishtara and Mr. S 2/5), probably because these rootstocks received the highest sunlight level inside the canopy. Fruits on rootstock Barrier 1 showed a slow ripening, as evidenced by the higher FF and TA and lowest SSC and OC at the first and second harvesting time (H1 and H2).

Table 1
Fresh weight (FW), flesh firmness (FF), soluble solids content (SSC), titratable acidity (TA) and skin over colour (OC) in peaches of Flavorcrest harvested at three different times [30 June (H1), 7 July (H2) and 13 July (H3)] and grafted on four different rootstocks (Ishtara, Mr. S 2/5, GF 677 and Barrier 1)

		H1	H2	H3
FW (g)	Ishtara	128.0de	168.5bc	198.2a
	Mr. S 2/5	107.3f	143.4d	169.6bc
	GF677	128.1e	163.6c	184.4ab
	Barrier 1	115.7ef	164.0c	186.3ab
FF (kg)	Ishtara	5.6cd	4.4ef	2.4g
	Mr. S 2/5	7.0b	4.9de	2.4g
	GF677	6.0c	4.5ef	2.5g
	Barrier 1	8.3a	5.9cd	3.1fg
SSC (°Brix)	Ishtara	10.5b	10.6bc	11.7a
	Mr. S 2/5	10.5b	10.8b	11.5ab
	GF677	10.0c	10.2c	10.3bc
	Barrier 1	9.8c	10.3c	12.0a
TA (meq/100 mL)	Ishtara	13.0c	12.1d	9.1f
	Mr. S 2/5	13.3c	11.5de	10.5e
	GF677	14.6b	13.4c	12.0d
	Barrier 1	16.7a	14.7b	12.4cd
OC (%)	Ishtara	60.0c	70.3b	80.7a
	Mr. S 2/5	53.7d	61.3bc	76.9a
	GF677	57.7cd	66.0b	70.4b
	Barrier 1	27.3e	50.7d	69.3b

Each value represents the mean of 20 replicates. Means followed by the same letters are not significantly different for $p = 0.05$ in a two way ANOVA test with harvest time and rootstock as variability factors.

3.2. Total antioxidant capacity

The total antioxidant capacity was measured in flesh (Fig. 1A) and peel (Fig. 1B). The range of values of total antioxidant capacity found in the two fruit fractions was similar. FRAP values increased in a significant way in flesh and peel of fruits collected at H3 only in Mr. S 2/5 and Barrier 1 (Fig. 1A and B). These results showed the importance of both rootstock and harvesting time on the nutritional characteristics. Bielicki, Czynczyk, and Chlebowska (2000) and Chun and Fallahi (2001) reported that rootstocks influenced yield and also quality in apples. There are not many reports which deal with the influence of rootstock on nutritional and antioxidant properties of fruit. Our results showed that Mr. S 2/5 produced fruits having highest total antioxidant capacity at the third harvest, probably because of its low-vigour properties. Ishtara, another dwarfing rootstock, showed lower values of total antioxidant capacity at H1 and H3 compared with Mr. S 2/5. Also, on Barrier 1 (high-vigour) FRAP values were higher than on Ishtara at H2 and H3. From our results,

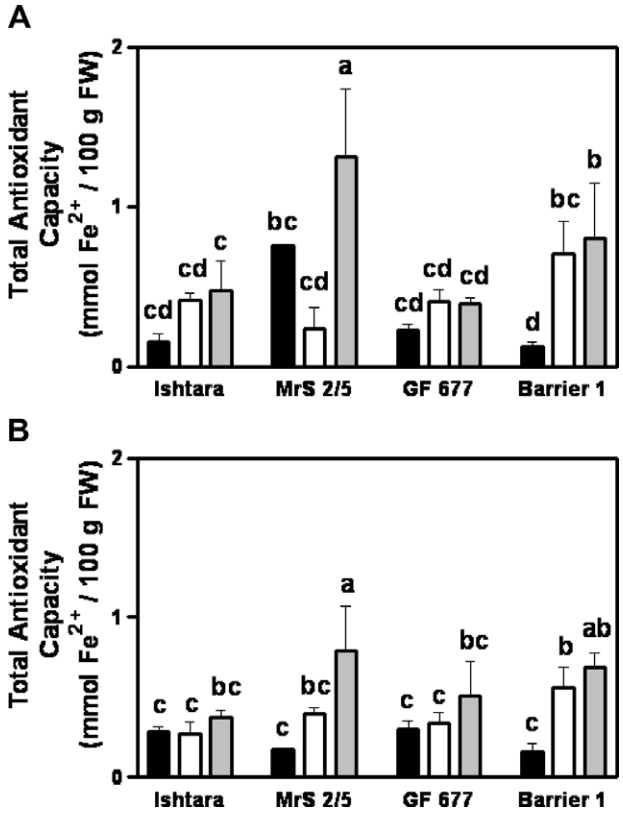

Fig. 1. Total antioxidant capacity determined by FRAP assay in flesh (A) and peel (B) of peach fruits, cv. Flavorcrest, grafted on four rootstocks (Ishtara, Mr. S 2/5, GF 677 and Barrier 1) and harvested at three different times [30 June (black bar), 7 July (white bar) and 13 July (grey bar)]. Values are the means of four replicates and the standard deviation is also shown. Means followed by the same letters are not significantly different ($p = 0.05$).

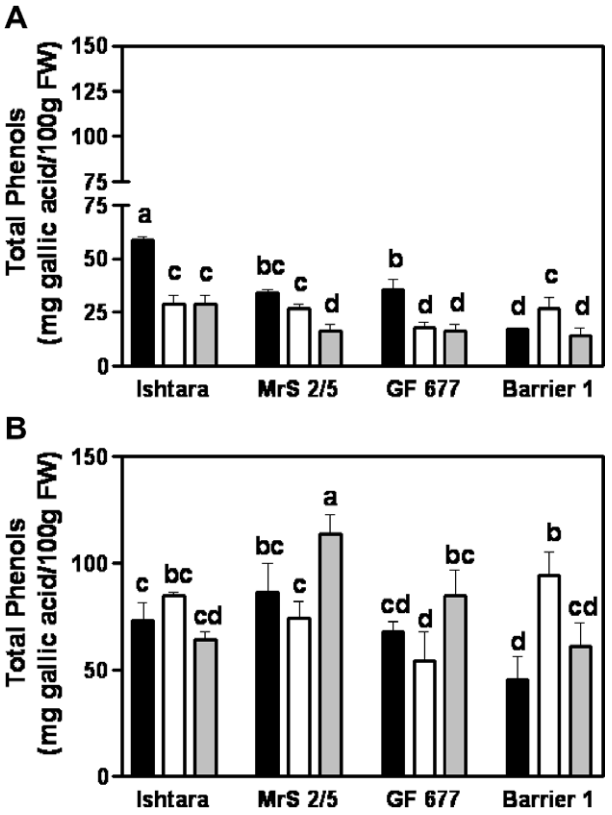

Fig. 2. Total phenols content determined in flesh (A) and peel (B) of peach fruits, cv. Flavorcrest, grafted on four different rootstocks (Ishtara, Mr. S 2/5, GF 677 and Barrier 1) and harvested at three different times [30 June (black bar), 7 July (white bar) and 13 July (grey bar)]. Values are the means of four replicates and the standard deviation is also shown. Means followed by the same letters are not significantly different ($p = 0.05$).

it is not possible to discern a link between rootstock vigour and total antioxidant capacity.

Harvesting time influenced total antioxidant capacity of Flavorcrest fruits on the four different rootstocks in a similar way. In both flesh and peel fractions the FRAP values were higher at H3 than at the two earlier harvests H1 and H2. These results indicate that the maturity of peach fruits at harvest is an important factor in determining their nutritional quality, so the choice of the harvesting time is important. Harvesting time must take into account these parameters, along with the quality characteristics essential for post-harvest technology but also for consumer acceptance. The middle and the late harvest times, H2 and H3, seem best in respect of both the quality and nutritional criteria.

3.3. Total phenols

The phenol content in the peel was two times higher than in the flesh (Fig. 2). Flesh phenols decreased during ripening on the tree so that the highest values were found at H1, except for trees on Barrier 1 (Fig. 2A). The decrease of flesh phenol content can be attributed to a series of chemical and enzymatic alterations of some of the phenols during ripening. These include hydrolysis of glycosides by glycosidases, oxidation of phenols by phenol oxidases and polymerisation of free phenols (Robards, Prenzler, Tucker, Swatsitang, & Glover, 1999). It is not possible to generalise regarding the synthesis of phenols in the peel. In Barrier 1 an increase in phenol content was recorded at H2, whereas in Mr. S 2/5 and GF 677 the increase was observed at H3 (Fig. 2B). In fruit from Ishtara rootstock, no significant differences in phenols content were observed during ripening. The highest phenol content was in peel on Mr. S 2/5 at H3 (Fig. 2B). Because no clear trends were discernable, it is not possible to identify for the different rootstocks some general behaviour in relation to phenolic content and the ripening process. This is in line with previous reports that show no general rule correlating phenolic amount with ripening stage (Tomas-Barberan et al., 2001). The only clear result was the higher content of phenols in peel as compared with flesh. Our results are in agreement with the literature. Tomas-Barberan et al. (2001) found that peel tissues usually contain larger amounts of phenolics, anthocyanins and flavonols than flesh tissues in nectarines, peaches and plums. These authors also found that the phytochemical content in peel was generally 2–3 times higher than that in flesh. Toor and Savage (2005) found

higher levels of total phenols and flavonoids in the peel of tomatoes. Kondo, Tsuda, Muto, and Ueda (2002) reported a lower polyphenols concentration in the flesh than in the skin of different apple cultivars. Li et al. (2006) showed that the contents of phenols, flavonoids and proanthocyanidins were higher in skin extract than in pulp extract in pomegranate. Probably, phenolic compounds tend to accumulate in the epidermal tissue of plants because of their potential roles in protection against ultraviolet radiation, in acting as attractants in support of seeds dispersal, and as defence chemicals against certain pathogens and predators (Dixon & Paiva, 1995).

3.4. Vitamin C

Vitamin C was determined only at the start and at the end of the harvest period (at H1 and at H3) and the results obtained are reported in Fig. 3. Also for this compound the content was about 25 times ($p < 0.05$) higher in the peel than in the flesh. The highest flesh values were recorded at H3 on Mr. S 2/5 (Fig. 3A) and the highest peel values were at H3 on Barrier 1. In general, vitamin C content in the peel increased gradually towards harvest for each rootstock, while, in the flesh, it did not increase towards harvest for any rootstock. However, for peach, both peel and flesh contained quite small amounts of vitamin C, compared with other fruits, such as kiwifruit and orange, in which vitamin C represents the most important antioxidant. The results show that rootstock vigour does not influence vitamin C content, whereas harvesting time is an important factor. Overall, vitamin C content in peel increased as fruit ripened. This is already well known for other fruits, such as strawberry, in which ascorbic acid content increases from essentially nil when fruit is still green, to a maximum when the fruit is fully ripe (Maas, Wang, & Galletta, 1995).

3.5. β-Carotene

As for the other phytochemicals, the highest levels of β-carotene were found in peel. In comparison to the flesh, the content in the peel was about 4–5 times higher (Fig. 4). This result is widely known, as reported also by Rodriguez-Amaya (1993).

In flesh extracts, the highest β-carotene values were recorded in fruits on Ishtara, Mr. S 2/5 and on Barrier 1 (Fig. 4A), while, in the peel, the highest value was recorded on Mr. S 2/5 at H3 (Fig. 4B). Less easily understood is the behaviour observed on Ishtara and on GF 677, in which

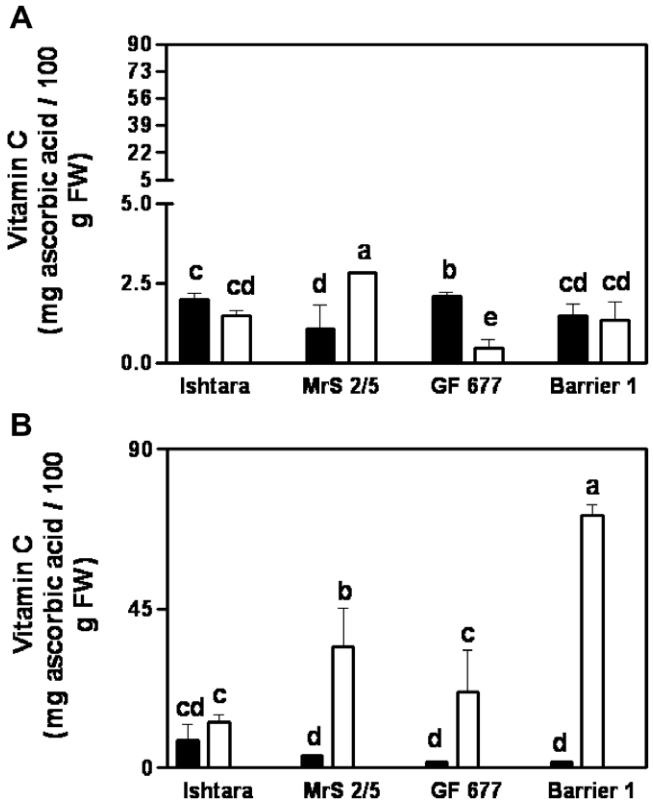

Fig. 3. Ascorbic acid content determined in flesh (A) and peel (B) of peach fruits, cv. Flavorcrest, grafted on four different rootstocks (Ishtara, Mr. S 2/5, GF 677 and Barrier 1) and harvested at two different times [30 June (black bar) and 13 July (white bar)]. Values are the means of four replicates and the standard deviation is also shown. Means followed by the same letters are not significantly different ($p = 0.05$).

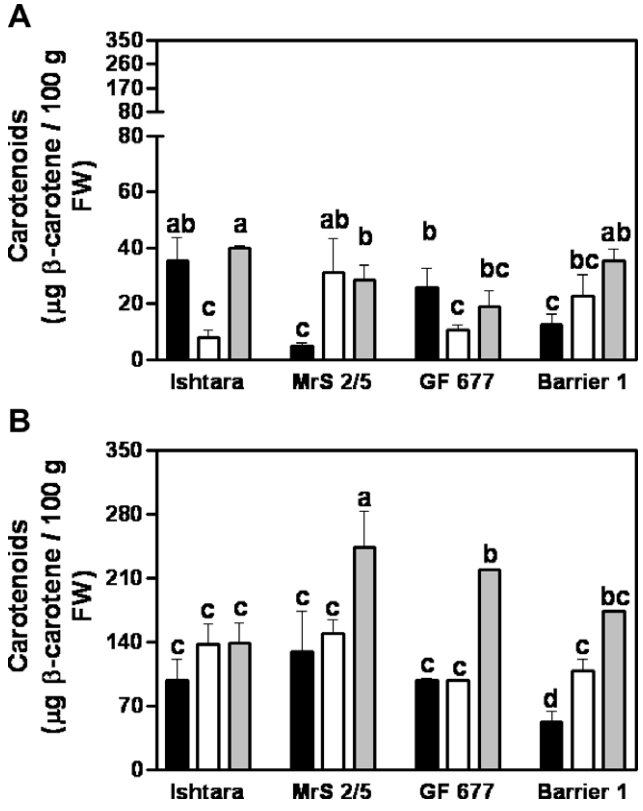

Fig. 4. β-Carotene content determined in flesh (A) and peel (B) of peach fruits, cv. Flavorcrest, grafted on four different rootstocks (Ishtara, Mr. S 2/5, GF 677 and Barrier 1) and harvested at three different times [30 June (black bar), 7 July (white bar) and 13 July (grey bar)]. Values are the means of four replicates and the standard deviation is also shown. Means followed by the same letters are not significantly different ($p = 0.05$).

significant decreases in carotenoids content were recorded at H2.

The qualitative and quantitative composition of carotenoids is influenced by many factors, including genotype, stage of maturity, climatic conditions, fraction of fruit, post-harvest handling, processing and storage conditions. Nevertheless, maturity stage is one factor that strongly affects carotenoid amount in peach, which increases during ripening in line fruits in general, due to an enhanced carotenogenesis during this period (Rodriguez-Amaya, 1993).

3.6. Correlation among total antioxidant capacity and phytochemicals

A correlation analysis between total antioxidant capacity and phytochemical constituents in fruit was carried out, to determine the contribution of each bioactive compound to total antioxidant capacity. Phenolic compounds and β-carotene were the only flesh constituents that correlated significantly with total antioxidant capacity in Barrier 1 (Table 2). This result is interesting because fruits on Barrier 1 were low in total phenols, compared to those on the other rootstocks. It indicates that phenols synthesised in fruits on Barrier 1 showed higher antioxidant properties, compared with phenols in fruit on the other rootstocks. It suggests that it is not only the total mass content of phenols but also their chemical structure that is important in determining total antioxidant capacity. It is known that the antioxidative properties of phenols are generally related to their chemical structures, with their capacities increasing with the number of hydroxyl groups (Leontowicz et al., 2002). For the other rootstocks no significant correlation between FRAP values and phytochemicals was found in the flesh.

In peel a very good correlation was found between FRAP values and different phytochemicals in all rootstocks, with the exception of Ishatara, which was characterised by having a low vitamin C and total phenols content. The fact that the correlations are significant in the peel of fruit on the other rootstocks indicates that the peel fraction of the fruits plays a key role in determining the antioxidant properties of the whole fruit. As we reported above, phytochemicals responsible for total antioxidant capacity are located mainly in the peel.

Table 2
Correlations between total antioxidant capacity (FRAP values; mmol Fe^{2+}/100 g FW) and vitamin C (mg/100 g FW), phenols (mg gallic acid/100 g FW) and β-carotene (μg/100 g FW) in flesh and peel of Flavorcrest peach fruit grown on four different rootstocks (Ishtara, Mr. S 2/5, GF 677 and Barrier 1)

		Vitamin C	Phenols	β-Carotene
$FRAP_{flesh}$	Ishtara	NS	NS	NS
	Mr. S 2/5	NS	NS	NS
	GF 677	NS	NS	NS
	Barrier 1	NS	$(r = 0.82)^{*}$	$(r = 0.79)^{*}$
$FRAP_{peel}$	Ishtara NS	NS	NS	$(r = 0.77)^{*}$
	Mr. S 2/5	$(r = 0.97)^{**}$	$(r = 0.82)^{*}$	$(r = 0.96)^{***}$
	GF 677	$(r = 0.94)^{*}$	$(r = 0.82)^{*}$	$(r = 0.87)^{*}$
	Barrier 1	$(r = 0.99)^{***}$	$(r = 0.81)^{*}$	$(r = 0.98)^{***}$

In the table the significance of correlation is reported as NS: $p > 0.05$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$. When the correlation is significant the correlation coefficient is reported.

4. Conclusions

The results show that the quality of peach fruits depends strongly on harvesting time. At present, harvesting time is determined on the basis of physical and chemical parameters (flesh firmness, background colour, titratable acidity, SSC). Our results indicate that total antioxidant capacity also represents an important parameter that should be taken into account if fruits are to develop elevated nutritional characteristics. Several authors (Gil et al., 2002; Giorgi et al., 2005) have shown that total antioxidant capacity changes as a function of cultivar and rootstock. In the same way, our results demonstrate that total antioxidant capacity and the levels of some phytochemicals (phenols, ascorbic acid and β-carotene) are significantly influenced by rootstock, even if it is not possible to define a common behaviour in terms of rootstock vigour. Indeed, rootstocks of similar vigour produced fruits with very different nutritional characteristics, indicating that the rootstock effect is more complex than just vigour. Previous studies (Giorgi et al., 2005; Tsipouridis & Thomidis, 2005) have underlined the key role of rootstock in determining the quality of production and the nutraceutical characteristics of fruits. As reported by Scalzo, Politi, Pellegrini, Mezzetti, and Battini (2005) the effect of rootstock on nutritive quality of fruits is strictly related to the interaction of rootstock with water and nutrient availability in the soil. Hence, an equilibrated and well balanced growth is reached at different soil fertility levels for different rootstocks.

In addition, the results of the present study suggest that peel represents an important source of antioxidant substances in the fruit. In fact, the amount of phenols, vitamin C and carotenoids in peach was higher in the peel than in the flesh, even if the ratio of the peel to the rest of the peach fruit is generally very low (<3% on mass basis). Also, the peel in peach fruits is not always eaten because it is not appreciated by all consumers.

These results underline the important relation between pre-harvest factors, such as rootstocks and harvesting time, and the quality and nutritional value of the fruit. It is well known that a higher consumption of fruits and vegetables with high phytochemical content can inhibit, prevent or retard chronic disease (Birth, Henrich, & Wang, 2001). However, it is difficult to link nutritional characteristics with the quality parameters (appearance, flavour, firmness, etc.) that define consumer acceptance.

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