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Effect of Regulated Deficit Irrigation and Crop Load on the Antioxidant Compounds of Peaches

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The use of regulated deficit irrigation (RDI) strategies is becoming a common practice in areas with low water availability. Little information is available about the effects of RDI on the antioxidant content of fruits. In this study, the influence of RDI on the content of vitamin C, phenolic compounds and carotenoids was investigated. Two irrigation strategies, fully irrigated (FI) and RDI, were compared at two levels of thinning, commercial and half of the commercial crop load. RDI strategies affected the content of vitamin C, phenolics and carotenoids of Flordastar peaches. RDI caused fruit peel stress lowering the content of vitamin C and carotenoids, while increasing the phenolic content, mainly anthocyanins and procyanidins. Fruit weight was the only quality index influenced by the crop load as it increased in FI fruits at low crop load. In general, fruits from commercial crop load had slightly higher content of antioxidants to fruits from low crop load, although these influences were only observed in the peel. Additionally, the influence of irrigation controlled by two sensors related to plant water level, maximum daily trunk shrinkage (MDS) and sap flow (SF) on the antioxidant constituents of peaches was evaluated. The response of the fruits to SF sensor was similar to that observed for RDI strategy. According to the tested water sensors, SF did not act as a good plant-based water indicator for use in irrigation scheduling, as it caused an increase in the content of phenolics, similar to that observed for fruits subjected to RDI. Therefore, selection of RDI strategies and plant water indicators should be taken into account as they affect the content of antioxidants of peaches.

KEYWORDS: ***Prunus persica*; Flordastar; thinning; anthocyanins; bioactive compounds; ascorbic acid; carotenoids; HPLC; phenolic compounds**

INTRODUCTION

Peaches (*Prunus persica* L.) are one of the most common and economically important fruit tree species of the Mediterranean area, where drought periods are frequent and irrigation water is a limiting factor for productivity (*1*). Mediterranean growers are facing increasing pressure to reduce water use by improving water management (*2*). The search for more efficient use of irrigation water has focused on regulated deficit irrigation (RDI) strategies (*3*). The use of RDI in fruit trees is an agricultural practice based on the reduction of irrigation during certain periods of tree development (*4*). RDI is useful in areas where low water availability is the primary parameter limiting production of fruit trees, such as in the Mediterranean (*5*). Additionally, RDI can also reduce excessive vegetative growth and improve fruit quality (*5, 6*). Sensors that measure some parameters such as maximum daily trunk shrinkage (MDS) and sap flow (SF) are used as control systems to vary the quantity of water supplied to maintain a water status without water stress.

In peaches, the majority of fruit growth occurs in the final 6−8 weeks before harvest when vegetative growth is almost complete (*7*). Additionally, peach quality attributes are reported to be influenced by RDI strategies (*8*). Some authors have found an improvement in fruit quality attributes without affecting fruit size (*9, 10*). For example, peaches from different RDI treatments show higher levels of soluble solid content (SSC) and redder color at harvest than control fruit (*5*). Furthermore, several studies have related fruit quality to changes in fruit composition. For instance, fruit color is related to carotenoid content in apricots (*11*), and for tomato and grapes, fruit color is related to lycopene and anthocyanin, respectively (*12, 13*). In peaches, phenolic compounds have a role in the organoleptic quality such as visual appearance (pigmentation and browning) and taste (astringency) (*14, 15*). Phenolic compounds, ascorbic and dehydroascorbic acids (vitamin C), carotenoids, and α-tocoferol (vitamin E) are bioactive constituents of peaches that exhibit major antioxidant capacity (*16*).

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Table 1. Fresh Weight, SSC, TA, pH, a^*, and H° of the Peel and the Flesh and Firmness of Peaches Cultivated under FI and RDI Strategies at Commercial and Low Crop Loads[a]

irrigation treatments	crop load	weight (g)	SSC (%)	TA (%)	pH	a^* peel	a^* flesh	H° peel	H° flesh	firmness
FI	commercial	128.3 ± 3.3 b	8.6 ± 0.4	1.0 ± 0.1	3.6 ± 0.1	10.5 ± 4.7	−5.9 ± 1.2	74.3 ± 5.0	84.1 ± 1.8	25.8 ± 2.3
	low	163.1 ± 4.5 a	8.9 ± 0.3	1.2 ± 0.1	3.7 ± 0.1	10.3 ± 3.2	−5.8 ± 1.0	73.0 ± 9.6	84.0 ± 1.3	19.5 ± 2.0
RDI	commercial	127.7 ± 6.8 b	9.4 ± 0.1	1.0 ± 0.1	3.8 ± 0.2	9.0 ± 2.7	−6.9 ± 0.4	76.3 ± 4.8	83.5 ± 0.7	23.9 ± 2.5
	low	131.4 ± 7.4 b	9.0 ± 0.3	1.0 ± 0.1	3.7 ± 0.1	7.7 ± 3.9	−8.3 ± 1.2	82.8 ± 5.9	81.8 ± 1.5	29.6 ± 2.6
			ns	ns	ns	ns	ns	ns	ns	ns

[a] Values are the means of three replicates of 10 fruits ± standard deviation. Means in each column followed by the same letter do not differ significantly at $P < 0.01$ ns; no significant differences.

The influence of RDI strategies on the antioxidant content including vitamin C, phenolic compounds, and carotenoids of peaches was evaluated. Two irrigation strategies, fully irrigated (FI) and RDI treatments, were compared at two levels of thinning (commercial and low crop loads). In addition, the effect of irrigation controlled by two sensors related to plant water level, MDS and SF, on the antioxidant content of peaches was studied to determine if these sensors were good indicators for irrigation scheduling.

MATERIALS AND METHODS

Experimental Conditions, Plant Material, and Treatments. Fruits were harvested from five-year-old early ripening peach trees (cv. "Flordastar", grafted on GF677 rootstock) in Santomera, Murcia, Spain (30°06′ N 1°02′ W, elevation 123 m). Tree spacing was 5 × 5 m^2, with a mean ground cover of about 54%. Pest control and fertilization practices were those commonly used by the growers, and no weeds were allowed to develop within the orchard.

Trees were hand-thinned on day of year (DOY) 70 (30 days after full bloom). Two levels of thinning were used to space fruitlets along the fruit bearing stems at 25 cm for the commercial crop load and at 50 cm for the low crop load.

From January 29 (DOY 29) to November 10 (DOY 314) 2006, different irrigation treatments were imposed. One treatment was FI, satisfying the estimated crop evapotranspiration (ETc) according to daily reference evapotranspiration (ETo), calculated using the Penman−Monteith equation (*17*), a crop factor based on the time of the year (FAO 56) and the percentage of ground area shaded by the tree canopy (*18*). A second treatment was an RDI that consisted to maintain a 25% ETc during phases I and II of fruit development and only 100% ETc during the third phase of fruit growth (critical period). Two other plant-based water stress indicators, MDS and SF, were evaluated (*19*). In the first part of the study, FI and RDI irrigation regimes at two levels of thinning were compared. In the second part of the study, three irrigation regimes controlled by ETc, MDS, and SF sensors at commercial crop load were compared.

All irrigation treatments were carried out using a drip irrigation system with one lateral pipe per tree row and eight emitters (each delivering 2 L h^{-1}) per plant. Total water amounts applied to each treatment were measured with inline water meters and were 705 and 196 mm, for FI and RDI treatments, respectively.

Quality Indexes. Titratable acidity (TA), pH, and soluble solid content (SSC) were evaluated. TA was determined by titration of 10 mL of juice with 0.1 mol L^{-1} NaOH to pH 8.1. The pH values were measured using a pH meter, and SSC was measured with an Atago hand-held refractometer. Color values on the peel and flesh were measured with a Minolta chromameter (CR-300) tristimulus color analyzer calibrated with a white porcelain reference plate. The color space coordinates L^*, a^*, and b^* and hue angle [H° = arctg(a^*/b^*)] were determined around the equatorial region in three different positions for 10 fruits by treatment. Fruit firmness was evaluated by compression test using a Lloyd instrument (model LR10K) equipped with two (12 × 18 cm^2) flat plates. The maximum force required to deform 1% of the fruit at a speed of 25 mm min^{-1} was determined.

Extraction and Analysis of Vitamin C. Ascorbic and dehydroascorbic acid contents were determined according to Zapata and Dufour (*20*) with some modifications (*21*). Ten grams of frozen fruit (peel and flesh) (−80 °C) was added to 10 mL of extraction medium (0.1 M citric acid, 0.05% w/v ethylenediaminetetraacetic acid disodium salt, 5% v/v methanol, 95% water, and 4 mM NaF). The mixture was directly homogenized for 30 s and filtered through filter cloth. The filtrate was collected and centrifuged at 10500*g* in an eppendorf centrifuge for 5 min at 2−5 °C. The filtrate was flushed through an activated Sep-Pak C_{18} cartridge (Waters) and was then filtered through a 0.45-μm nylon filter. Then, 250 μL of 1,2-phenylenediamine dihydrochloride solution (35 mg/100 mL) was added to 750 μL of extract for dehydroascorbic acid derivatization into the fluorophore 3-(1,2-dihydroxyethyl)furo[3,4-*b*]quinoxaline-1-one (DFQ). After 37 min in darkness, the samples were analyzed by HPLC.

Ascorbic acid and dehydroascorbic acid were quantified by HPLC (Merck, Hitachi), equipped with an L-6000 pump and coupled with a D-2500 variable-wavelength UV detector. Twenty-microliter samples were injected on a reversed-phase Kromasil 100 C_{18} column (250 mm × 4 mm i.d., 5-μm particle size) (Tecnokroma) with an OSD guard C_{18} precolumn. The flow rate was kept at 0.9 mL/min. The mobile phase was methanol: water (5/5, v/v), 5 mM cetrimide, and 50 mM KH_2PO_4. The detector wavelength was initially set at 348 nm, and after the elution of DFQ, it was manually shifted to 261 nm for ascorbic acid detection. The vitamin C content was calculated adding the content of ascorbic acid and dehydroascorbic acid, and the results were expressed as milligrams per 100 g of fresh weight.

Extraction and Analysis of Phenolic Compounds. Two-gram samples of freeze-dried powder were homogenized with 20 mL of extraction solution (acetone/water/acetic acid, 70/29.5/0.5, v/v/v) with an Ultra Turrax (Ika) for 1 min on ice followed by sonication for 15 min. The obtained homogenates were centrifuged at 3200 rpm (1765*g*) for 10 min (Centromix centrifuge, Selecta). The acetone was evaporated under vacuum at 35 °C using a rotary evaporator. After evaporation, the aqueous residue was flushed through an activated Sep-Pak C_{18} cartridge (Waters), previously activated with methanol followed by water and then eluted with methanol. The methanol was evaporated at 35 °C under vacuum and recovered in 1 mL of extraction solution, filtered through a 0.45-μm nylon filter. Samples of 50 μL were analyzed by HPLC (Merck, Hitachi) equipped with a model L-7100 pump and a model L-7455 photodiode array UV/vis detector. The samples were injected by a model L-7200 autosampler. The separation was achieved on a reversed-phase LiChrocart C_{18} column (250 mm × 4 mm i.d., 5-μm particle size) (Merck) with water/formic acid (95/5, v/v) (A) and methanol (B) as the mobile phases. The linear gradient started with 3% B, at 5 min 5% B, at 10 min 8% B, at 15 min 13% B, at 19 min 15% B, at 47 min 40% B, at 64 min 65% B, at 66 min 98% B, and then it was maintained isocratic up to 70 min. The flow rate was 1 mL min^{-1}, and chromatograms were recorded at 280, 320, 360, and 510 nm. Anthocyanins were quantified by comparisons with an external standard of cyanidin 3-rutinoside at 510 nm, flavonols as quercetin 3-rutinoside at 360 nm, hydroxycinnamic acid derivatives as chlorogenic acid at 320 nm, and flavan-3-ols as catechin at 280 nm. All these markers were purchased from Sigma. The results were expressed as milligrams per kilogram of fresh weight.

The phenolic compounds in fruit extracts were identified by their UV spectra recorded with a diode-array detector and, wherever possible, by chromatographic comparisons with authentic markers.

Analyses of Procyanidins by Normal-Phase HPLC. The separation, detection, and characterization of procyanidins in peach obtained from the preparative system described below were performed by

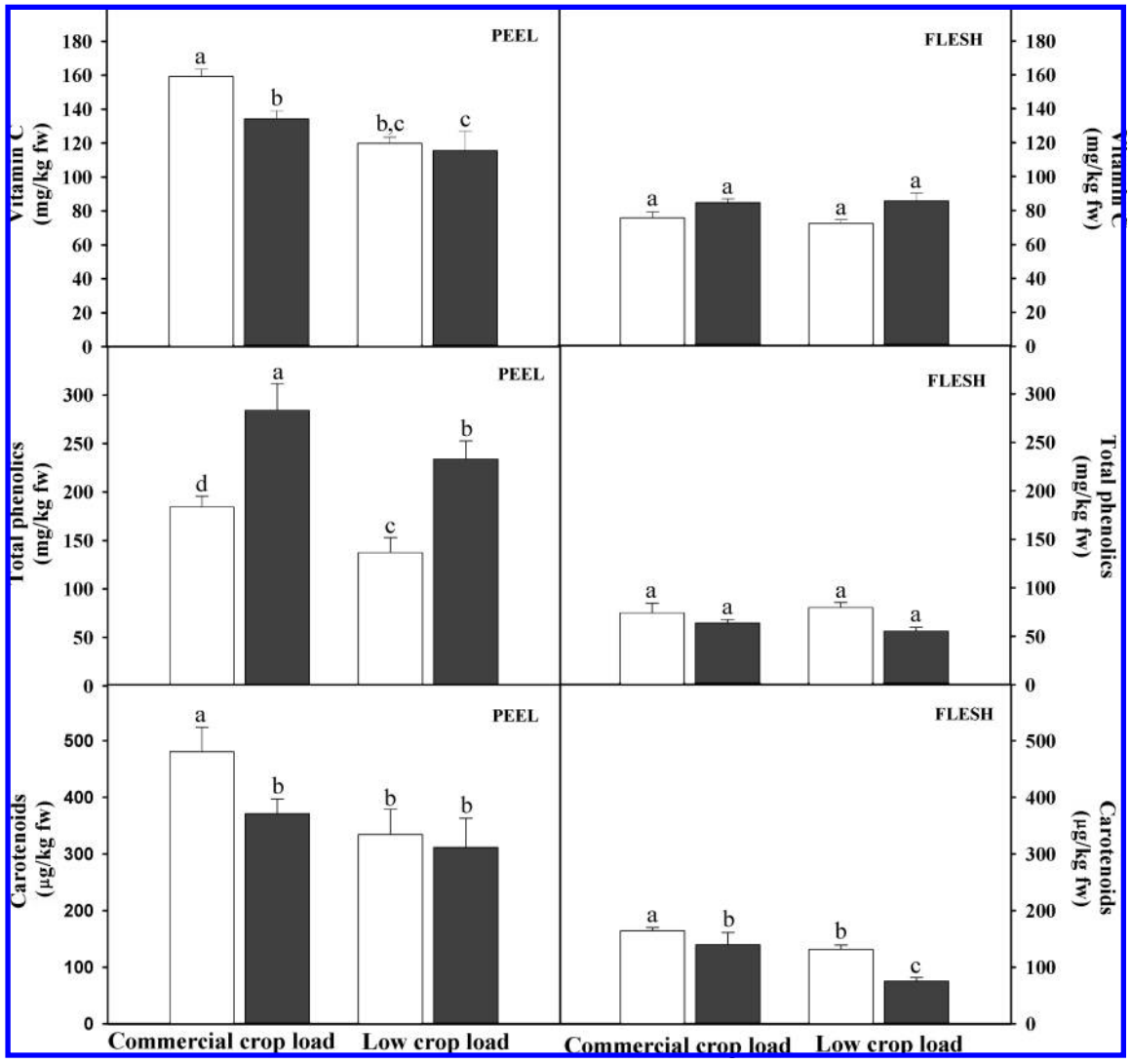

Figure 1. Content of vitamin C, total phenolics, and carotenoids in the peel and the flesh of fully irrigated (white bars) and regulated deficit irrigation (black bars) trees at commercial and low crop loads. Values are the means of three replicates of 10 fruits, and error bars represent the standard deviation. Significant differences between commercial and low crop loads for the same tissue at $P < 0.001$ are represented by different letters.

normal-phase HPLC (Merck, Hitachi) with fluorescence detection. The column was a Develosil diol (250 mm × 4.6 mm i.d., 5-μm particle size) (Phenomenex). The binary mobile phase consisted of (A) acetonitrile/acetic acid (98/2, v/v) and (B) methanol/water/acetic acid (95/3/2, v/v/v/). Elution was performed using a gradient ranging from 0% B in A to reach 40% B after 35 min, 40% B at 40 min, 0% B at 45 min followed by a 5-min equilibration time. The flow rate was 0.8 mL min^{-1}, and chromatograms were obtained by fluorescence detection with excitation at 276 nm and emission at 316 nm.

Extraction and Analysis of Carotenoids. The followed procedures were as described by Minguez-Mosquera and Garrido-Fernández (*22*). Samples of 10 g were homogenized with 10 mL of methanol. The obtained homogenate was vacuum filtered, adding acetone (70 mL for flesh and 100 mL for peel) until no color was observed. The extracts were transferred to a decanting funnel and treated with 50 mL of ethyl ether, shaken, and left to settle. A solution of 10% NaCl (20 mL) was added to separate the phases and to transfer the pigments to the ether. This solution was treated several times with 20 mL of anhydrous Na_2SO_4 (2%) to remove the water. Then, the ether phase, containing the pigments in different states of esterification with fatty acids, was saponified with 50 mL of KOH/MeOH (20%, w/v) and 20 mL of MeOH and left for 1 h with periodic shaking. Before the aqueous phase was removed, 100 mL (peel samples) and 150 mL (flesh samples) of NaCl were added with periodic shaking. The organic phase was washed several times with distilled water until pH = 7, then filtered through a bed of anhydrous Na_2SO_4, and evaporated to dryness in the rotary evaporator at a temperature always lower than 35 °C. The pigments were collected with acetone to a volume of 5 mL and kept refrigerated until their analysis by HPLC.

β-Apo-8′ carotene (Sigma Chemical Co.) (1 mg/10 g of sample) was added as an internal standard as this pigment is absent in peach and, under the proposed conditions, separates well from the other carotenoids. Lutein and β-criptoxanthin were obtained from a saponified extract of mint (*Mentha piperita*) by thin-layer chromatography (TLC) (*23*). For this purpose, thick plates of silica gel 60 F254 (20 cm × 20 cm of 0.5 mm, Merck) were used. Each compound was identified on the basis of its TLC R_f values and compared with isolated standards and UV/vis spectra.

Carotenoids were evaluated by HPLC equipped with a model L-6200 pump (Merck, Hitachi) and SPD-M6A photodiode array UV/vis detector (Shimazu). Separations were achieved on a LiChrocart C_{18} column (250 mm × 4 mm i.d., 5-μm particle size) (Merck) using a gradient program previously described (*23*). Elution was performed at a solvent flow rate of 1.5 mL min^{-1} with an injection volume of 20 μL and detection at 450 nm. Multicomponent mixtures were used for calibration. Once the pigments were purified, the concentration was determined spectrophotometrically, using the corresponding values of ε_0 (*24*). The concentrations were calculated and expressed as micrograms per 100 mg of fresh weight.

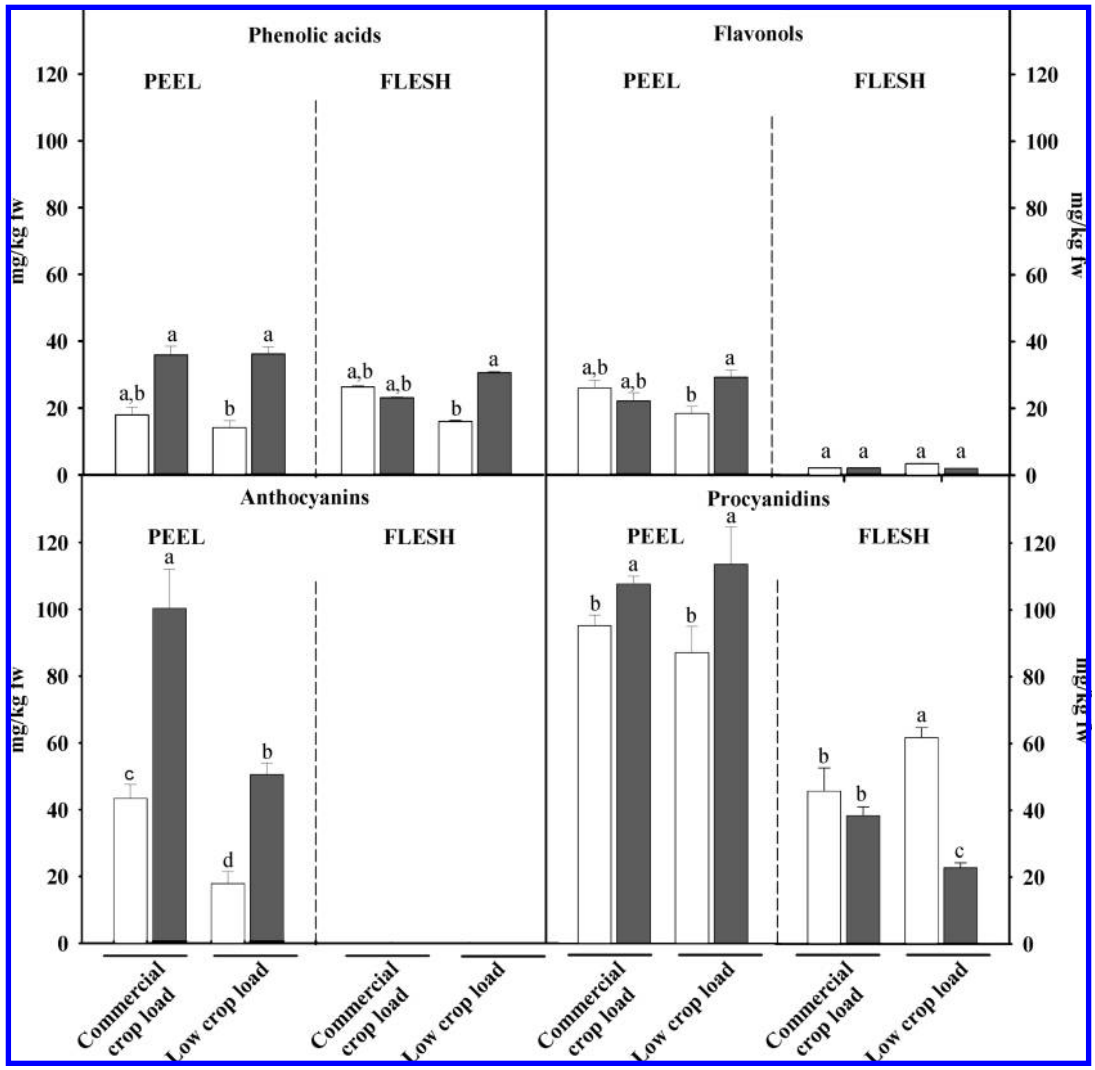

Figure 2. Individual content of phenolic groups as phenolic acids, flavonols, anthocyanins, and procyanidins in the peel and flesh of fully irrigated (white bars) and regulated deficit irrigation (black bars) trees at commercial and low crop loads. Values are the means of three replicates of 10 fruits, and error bars represent the standard deviation. Significant differences between commercial and low crop loads for the same tissue at $P < 0.001$ are represented by different letters.

Statistical Analysis. Ten fruits per replicate and three replicates per water irrigation treatments and thinning were analyzed. Analysis of variance was performed to assess the significance of irrigation treatments and thinning, and differences between means were compared using the Tukey's multiple range test at $P < 0.01$.

RESULTS

Influence of RDI on the Antioxidant Constituents of Peaches at Commercial and Low Crop Loads. The quality characteristics of Flordastar peaches including fruit weight, SSC, TA, pH, color, and firmness of peaches cultivated under FI and RDI strategies at two levels of thinning are shown in **Table 1**. RDI did not influence negatively the quality characteristics of the peaches when compared to FI fruits. Only FI of fruit at low crop load caused a significant increase in fresh weight whereas SSC, TA, and pH as well as the color of the peel and the flesh were not affected by the irrigation treatments and crop load (**Table 1**).

The peel of early ripe yellow-flesh peaches contained higher amounts of antioxidants, including vitamin C, phenolics, and carotenoids, than the flesh. The peel was the tissue largely influenced by the RDI strategies and thinning (**Figure 1**). RDI strategy significantly decreased the content of vitamin C in the peel when comparing with FI at commercial crop load. However, at low crop load, no significant differences in the content of vitamin C between the peel of FI and RDI fruits were observed. In addition, the content of vitamin C in the flesh of early ripe peaches was not influenced by RDI and thinning (**Figure 1**).

On the other hand, significant differences in the phenolic content of the peel between FI and RDI fruits were observed at both commercial and low crop loads (**Figure 1**). Phenolic content in the peel of RDI fruits was higher than that of FI. However, no differences were observed between the flesh of FI and RDI peaches at either commercial or low crop load. The analysis of the individual phenolic compounds showed four main groups: phenolic acids, flavonols, anthocyanins, and procyanidins. Among these groups, anthocyanins and procyanidins were the main phenolic compounds, whereas phenolic acids and flavonols were present in lower levels (**Figure 2**). RDI significantly increased the content of anthocyanins, procyanidins, and phenolic acids in the peel. Additionally, crop load did not influence the content of phenolics, except anthocyanins, which was the only group affected by the thinning. Thus, the peel of

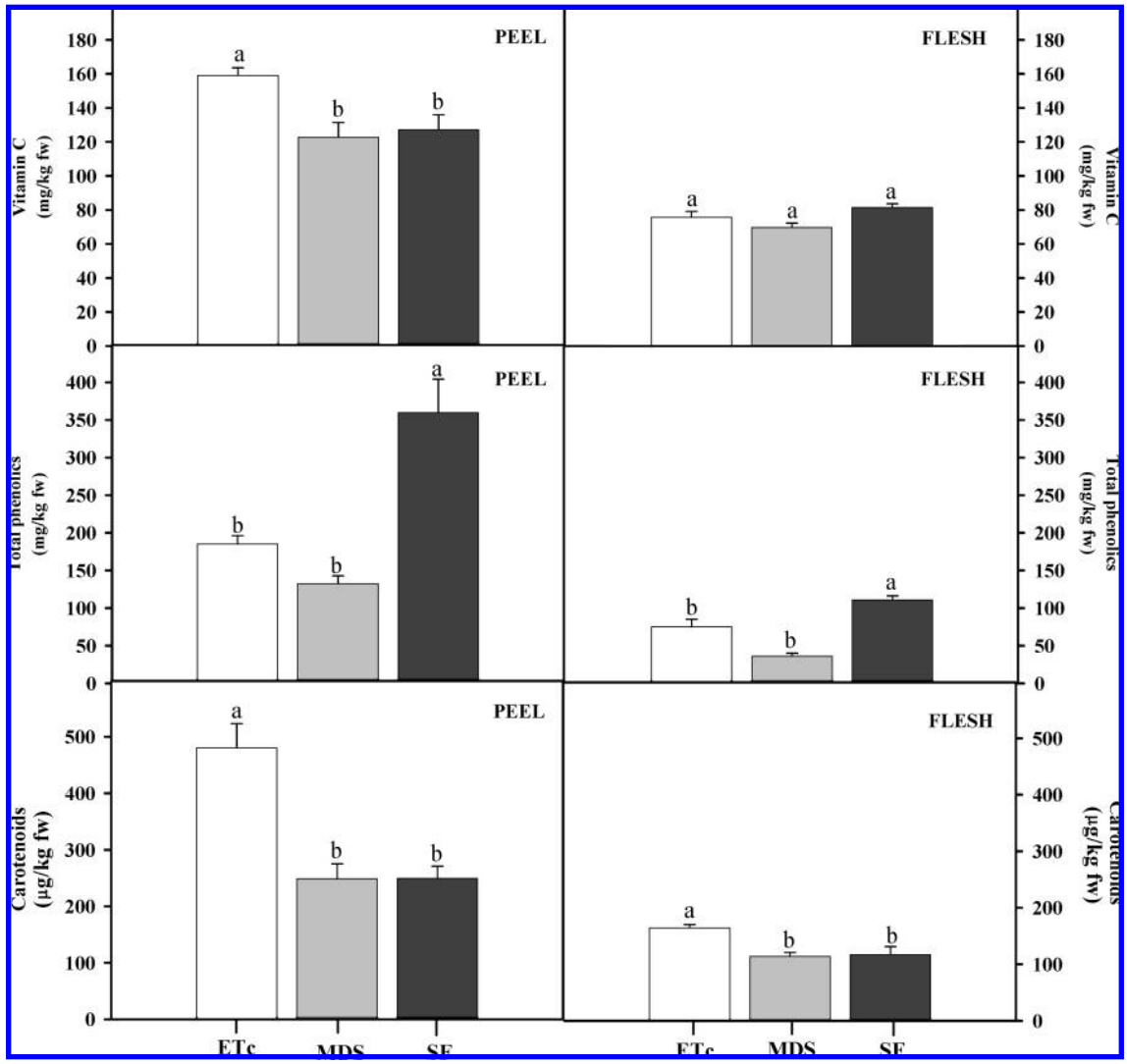

Figure 3. Content of vitamin C, total phenolics, and carotenoids in the peel and flesh of fully irrigated peaches (ETc) and peaches irrigated based on plant-based water indicators: MDS and SF. Values are the means of three replicates of 10 fruits, and error bars represent the standard deviation. Significant differences between plant-based water indicators for the same tissue at $P < 0.001$ are represented by different letters.

fruits at commercial crop load contained higher concentrations of anthocyanins than those at low crop load (**Figure 2**).

In addition, the influence of RDI on the carotenoid content was similar to that observed for vitamin C (**Figure 1**). Thus, at commercial crop load, the peel of RDI fruits showed a lower content of carotenoids than the peel of FI peaches. However, at low crop load, no significant differences were observed between the peel of FI and RDI fruits. When the flesh of peaches subjected to RDI strategies was studied, it was seen that the content of carotenoids in the flesh of FI fruits was always higher than that of RDI fruits, particularly at low crop load.

Influence of Irrigation Controlled by Plant-Based Water Sensors on the Antioxidant Content of Peaches. The influence of irrigation controlled by two sensors related to plant water level, MDS and SF, on the quality indexes and antioxidant constituents of peaches was evaluated. The quantities of the water supplied to maintain a specific value of MDS and SF were 655 and 463 mm, respectively. ETc fruits received more water (705 mm) during the experimental period. No significant differences were observed in the quality indexes (weight, SSC, TA, pH, and color) of peaches irrigated based on different plant-based indicators (data no shown).

However, the content of vitamin C in the fruits obtained from trees irrigated based on MDS and SF measurements was similar for both sensors, with an average value of 125 mg/kg of peel and 80 mg/kg of flesh (**Figure 3**). Only the peel of ETc fruits showed a content of vitamin C higher than that of fruits irrigated with MDS and SF sensors, whereas no differences among the flesh of fruits irrigated with the three different amounts of water were observed.

On the other hand, significant differences were observed among the content of total phenolics in peaches whose irrigation was controlled by SF compared with that of ETc and MDS (**Figure 3**). It was observed that the total phenolic content of fruits controlled by MDS was similar to that of ETc fruit. Furthermore, the response of irrigation based on the SF sensor showed that the changes in individual phenolics of SF peaches followed a pattern similar to that of RDI fruits. The content of the individual groups of phenolics in SF fruits was almost double that for ETc and MDS fruits both for the peel and for the flesh (**Figure 4**). In the case of anthocyanins, the content in the peel of SF fruits was three times higher than that of MDS fruits.

Changes in the carotenoid content among ETc fruits and those controlled by MDS and SF sensors were similar to that observed for vitamin C (**Figure 3**). No significant differences in the content of carotenoids between fruits obtained from trees whose irrigation was based on MDS and SF measurements were found.

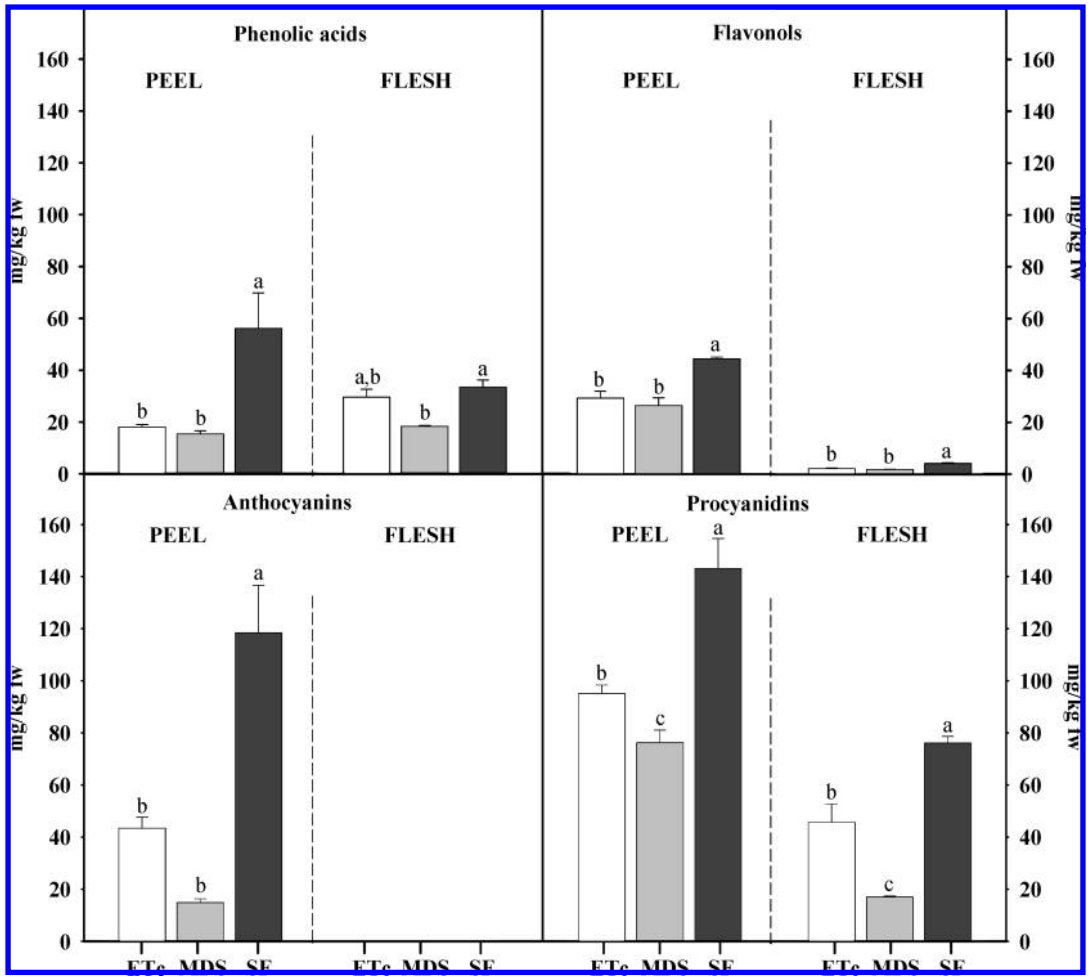

Figure 4. Individual content of phenolic groups as phenolic acids, flavonols, anthocyanins, and procyanidins in the peel and flesh of fully irrigated peaches (ETc) and peaches irrigated based on plant-based water indicators: MDS and SF. Values are the mean of three replicates of 10 fruits, and error bars represent the standard deviation. Significant differences between plant-based water indicators for the same tissue at $P < 0.001$ are represented by different letters.

These fruits contained an average value of 249 μg/kg of peel and 116 μg/kg of flesh. However, the content of carotenoids in the peel and flesh of ETc fruits was significantly higher than that of fruits whose irrigation was controlled by either MSD or SF measurements.

DISCUSSION

FI and low crop load caused a significant increase in fruit weight, meaning that the reduction in the number of fruits in well-irrigated trees increased the size of the remaining fruit. Previous studies have reported that peaches from trees carrying heavy crop load (unthinned) had lower fruit turgor compared with trees carrying a light crop load (*25, 26*). However, in our study, peach firmness was unaffected by water deficit treatment in agreement with the report by Gelly et al. (*8*), who observed that, in stage II of the fruit growth period, peach firmness was unaffected by water deficit.

The peel of early ripe yellow-flesh peaches contained a higher antioxidant content than the flesh, as was already observed in a study on the antioxidant composition of stone fruit where 25 yellow and white flesh cultivars were evaluated (*27*). These authors observed that the peel of both white- and yellow-flesh peaches always contained higher concentration of vitamin C, phenolics, and carotenoids than the flesh, although there was a wide variation in the content of these antioxidants (*27*). In our study, the content of vitamin C in FI peaches was 159 mg/kg of peel and 76 mg/kg of flesh at commercial crop load. The reduction in the content of vitamin C observed in the peel of RDI fruits could be explained by the decrease in the driving force of water flow into the fruits, which has already been described by Berman and DeJong (*28*). In our study, fresh weight of FI fruits was higher in low crop load than in commercial crop load because of the higher water content. Thus, differences observed in the content of vitamin C and carotenoids between commercial and low crop load fruits could be associated with a dilution effect of the constituents. In addition, the number of growing fruits, clearly higher in commercial crop load trees, could also have a positive effect on the photosynthetic activity of leaves (*29–31*). This effect could be more relevant under RDI and when competition between vegetative and fruit growth occurs, as is the case with early maturing cultivars (*32–34*).

The phenolic content of FI peaches at commercial crop load was 185 mg/kg of peel and 75 mg/kg of flesh. This content was almost four times lower than values reported for other cultivars (*27, 35*). According to Romero et al. (*36*) in olive trees and Roby et al. (*37*) in grapevines, the water stress implies an activation of the phenolic compounds biosynthesis in the peel of fruit suffering RDI. This fact was associated with an increase in the activity of L-phenylalanine ammonia lyase (PAL) as a response to water stress. Tovar et al. (*38*) associated a high PAL

activity with the accumulation of anthocyanins and other phenolic compounds in olives.

On the other hand, the total carotenoid content in FI Flordastar peaches was 480 μg/kg of peel and 164 μg/kg of flesh (**Figure 1**), even though higher contents have been reported for other early ripe cultivars (*26*). Bindon et al. (*39*) found that increasing the incidence of sunlight in developing grape bunches accelerated the decrease in carotenoids. As RDI is related to a reduction in the vegetative growth and low crop load is associated to a lower amount of fruits per tree, both events imply a high light exposure of peaches. Thus, the reduction in the content of vitamin C and carotenoids in peaches subjected to RDI at low crop load could be attributed to the oxidation by the light exposure.

The analysis of the individual phenolic compounds revealed that procyanidins and anthocyanins were the main phenolic compounds, whereas phenolic acids and flavonols were present in low levels. These findings are consistent with those already reported by Tomás-Barberán et al. in other peach cultivars (*35*). The content of anthocyanins was higher in the peel of RDI fruits than in the peel of FI peaches for both commercial and low crop loads. This agrees with Chaves et al. (*40*), who also detected high accumulation of anthocyanins in grapes subjected to RDI. The anthocyanin content was also influenced by the thinning as higher concentrations were observed in the commercial crop load fruit than in the low crop load. Anthocyanins were not detected in the flesh, which confirms that anthocyanins are one of the phenolic groups significantly affected by solar radiation as these compounds act as UV screens (*41*).

When the influence of irrigation controlled by two sensors related to plant water level, MDS and SF, on the antioxidant constituents of peaches was evaluated, the response of SF was similar to that observed for RDI treatment. A reduced irrigation strategy promoted a decrease in the content of vitamin C in the peel, whereas no differences were found in the flesh. The highest phenolic content found in the peel of SF peaches compared to that of MDS peaches could be associated with a response of the fruit to the water stress which was previously found for RDI peaches. Furthermore, the response of irrigation based on the SF sensor showed that the changes in individual phenolics of SF peaches followed a pattern similar to that of the RDI fruits. If the increase in the content of phenolics was related to water stress, it can be concluded that MDS is a good plant water sensor. These results confirm previous studies in lemon (*2*) and peach trees (*19, 42*), which showed that MDS is the most suitable plant-based water indicator for use in irrigation scheduling practices.

In conclusion, the RDI strategies evaluated in this study caused fruit peel stress, lowering the content of vitamin C and carotenoids, while increasing the phenolic content, mainly anthocyanins and procyanidins. The decrease in the antioxidant constituents could be due to a higher sunlight exposure of fruits collected from RDI trees as a result of a low vegetative growth of those trees. The increase in the anthocyanin content could be also explained as a response mechanism of peaches against UV irradiation, to mitigate the photooxidative injury of plant tissue. Fruits from a commercial crop load had slightly higher antioxidant contents than fruits from a low crop load. The peach peel was the only tissue influenced by the thinning. According to the plant-based water sensors, SF did not act as a good water indicator for use in irrigation scheduling, as it caused water stress detected by an increase in the content of phenolics, similar to that observed for fruits subjected to RDI.

ABBREVIATIONS USED

RDI, regulated deficit irrigation; FI, fully irrigated; ET_0, reference evapotranspiration; ETc, crop evapotranspiration; MDS, maximum daily trunk shrinkage; SF, sap flow; TA, titratable acidity; SSC, soluble solid content; PAL, L-phenylalanine ammonia lyase.

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