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Sensory Quality and Consumer Acceptance of 'Tardibelle' Peach Are Improved by Deficit Irrigation Applied During Stage II of Fruit Development

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***Abstract*. Deficit irrigation (DI) applied during Stage II of fruit development has the potential of improving fruit quality in peach (*Prunus persica*). Existing information only covers instrumental assessment of quality. No report is available on how sensory attributes and consumer acceptance are affected. We applied DI at Stage II to 'Tardibelle' peach and evaluated fruit composition, sensory attributes, and consumer acceptance during the growing seasons of 2009 and 2010. Results were compared with those from trees that received conventional irrigation (CI). Stem water potential in DI trees was indicative of a moderate water stress during Stage II. In 2010, water stress persisted at the beginning of Stage III and average fruit weight was reduced in DI trees. A panel of trained judges decided that DI increased sweetness, juiciness, and the intensity of peach flavor but it reduced fruit firmness and crispness. A panel of consumers indicated increased preference for DI fruit. The higher appeal for DI fruit could have been partially the result of their more advanced maturity. Improvement of fruit quality could be an important incentive for the application of DI during Stage II because growers may expect to receive a premium price for their higher quality fruit.**

In many production areas of the world, peach trees require irrigation to maximize yield and optimize fruit quality. However, the dwindling water supply on a global scale (Postel, 1998) is making DI more of a necessity than a choice. The stage of fruit development when pit hardening occurs (Stage II) has been considered an adequate period for applying DI in peach (Behboudian et al., 2011). Besides saving of water, DI during Stage II reduces excessive tree vigor, maintains the yield, and may improve fruit quality (Behboudian et al., 2011). Improvement in fruit quality has been mainly expressed in terms of an increase in fruit soluble solids concentrations (SSCs). Some authors have surmised that DI fruit would be preferred by consumers because of the higher SSC (Ben Mechlia et al., 2002; Crisosto et al., 1994; Li et al., 1989). However, increases in SSC in response to DI do not necessarily ensure a better organoleptic fruit quality (Lopez et al., 2011). More research is required for reaching firm conclusions about sensory quality and consumers' perception of peach grown under DI. To the best of our knowledge, this information does not exist for any deciduous fruit crop including peach. In this research, DI was applied during Stage II to 'Tardibelle' peach in a commercial orchard over two growing seasons (2009 and 2010) and sensory attributes and consumer acceptance of the fruit were evaluated. Water stress imposed in this study was moderate. Results were compared with those from trees that received full irrigation. The objective was to determine if DI during Stage II could improve fruit quality in terms of better sensory attributes and higher consumer acceptance.

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Materials and Methods

Experimental orchard and fruit growth stages. The study was conducted over the growing seasons of 2009 and 2010 in a commercial 'Tardibelle' peach (*Prunus persica* L. Batsch) orchard located in Aitona, Lleida, Spain (lat. 41°29′ N, long. 0°26′ E, 154 m elevation). The trees were 7 years old and grafted onto 'GF-677® INRA' rootstock. They were planted 2.5 m apart in rows 5 m apart and trained to an open vase system. Sixty trees within 1 ha were chosen for the experiment. To determine fruit growth stages, two fruit per tree (120 fruit in total) were sampled and weighed on a weekly basis from fruit set to harvest. Harvest was based on visual observation of fruit's ground skin color. This maturity index was used in the commercial orchard because it is a useful, non-destructive method of estimating fruit maturity and it can be easily used and understood by field workers during harvesting operations (Crisosto and Valero, 2008). There were two harvests in each year (8 and 15 Sept. in 2009; 10 and 16 Sept. in 2010). All fruit harvested per tree were counted and weighed.

Irrigation treatments and experimental design. Trees were drip-irrigated daily with five emitters per tree (4 $L \cdot h^{-1}$ per dripper). There was a single pipeline per tree row, which passed close to the tree trunks. Tree water requirements were calculated using a water balance technique to replace crop evapotranspiration (ETc) as follows: ETc = (ETo × Kc) – rainfall. ETo and Kc represent the reference evapotranspiration and crop coefficient, respectively. The Penman-Monteith method was used to determine ETo (Allen et al., 1998) and Kc values were obtained from Doorenbos and Pruitt (1977). All trees received CI during Stage I, Stage III, and postharvest. This was done by watering them with their calculated ETc values. Half of the trees received DI during Stage II by stopping irrigation until an average midday stem water potential (SWP) of –1.8 MPa was measured. Below this threshold, CI was applied for several days to maintain SWP at ≈–1.8 MPa. Based on our previous experience, at a SWP of lower than –1.8 MPa, leaf wilting occurs in peach (Lopez et al., 2006). A randomized complete block design with three block replicates was used. Each plot contained two plots, CI and DI. Each plot consisted of three rows of 12 trees each. Ten central trees from the middle row were monitored and all other trees served as guard trees.

Measurements of applied water and tree water status. The amount of water applied to each plot was measured with water volume meters (Model D85; Wehrle, Emmendingen, Germany). Midday SWP was measured weekly before the application of DI. Once DI started, midday SWP was measured two or three times per week. This was done with a pressure chamber (Model 3005; Soil Moisture Equipment Corp., Santa Barbara, CA). Measurements were taken from leaves located near the bases of the two central trees in each plot (one leaf per tree) using the procedure outlined by McCutchan and Shackel (1992).

Instrumental and sensory evaluation of fruit quality. The following fruit quality attributes were determined at each harvest: dry matter concentration (DMC), skin and pulp color, flesh firmness (FF), juice SSC, and juice titratable acidity (TA). Two fruit per tree (10 trees per plot) were sampled for quality analysis. The fruit were measured immediately after harvest. For each experimental year, skin and pulp color were determined using a photoelectric tristimulus colorimeter (CR-200; Minolta Co., Osaka, Japan). FF from two opposite fruit cheeks (most exposed and least exposed to light) was measured using a manual penetrometer with an 8-mm tip fixed in a drill stand (Penefel; Copa-Technology, CTIFL, Saint Etienne du Gres, France). SSC and TA were determined from a mixture of juice obtained from the fruit. SSC was determined using a digital calibrated refractometer (PR-32α Palette Series; Atago Co. Ltd., Tokyo, Japan). TA was determined by titrating with 0.1 N sodium hydroxide to a pH end point of 8.2. The remaining fruit were used to calculate DMC. DMC of each sample was calculated as 100 × (dry weight/fresh weight). The dry weight of each sample was obtained after drying to a constant weight in a forced-air draft oven at 65 °C.

The sensory evaluation involved two panels: a panel of 44 consumers and a panel of nine trained judges. In 2010, both panels were provided with fruit samples taken at harvest and stored for 1 week in cold storage (0.5 °C and 90% relative humidity). After cold storage, fruit were kept in a room at 20 °C for 1 d. We made an effort to provide both panels with uniform fruit based on visual color. For the panel of consumers, each fruit was divided into four pieces and was evaluated separately by four consumers. The quarterfruit (without skin) were placed on a white plate and immediately presented to a consumer. Samples were numbered in three digits and were presented to each consumer in a randomized order. The consumers were asked to rate overall fruit acceptability according to a hedonic test (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely). Consumer acceptance was expressed as the average degree of liking (1–9) and in three acceptance categories using the procedures outlined by Crisosto and Crisosto (2005): acceptance (percentage of consumer with score higher than 5), neither like nor dislike (percentage of consumer with score equal to 5), and dislike (percentage of consumers with score lower than 5). For the panel of trained judges, one sample consisted of three fruit pieces of 1.5 cm^3 (without skin). Samples were presented in a random order in 100-mL beakers numbered with three random digits. The trained judges were asked to rate the intensity of the following attributes on 150-mm unstructured line scales: sweetness, sourness, intensity of flavor, juiciness (the amount of juice released by the sample when chewing with the back teeth), firmness (the force required to compress the sample between the back teeth), crispness (the amount and pitch of sound when sample is first bitten with the front teeth), ease of breakdown (the amount of chewing required to break down the flesh so that it can be swallowed), and fibrousness (the presence of wet and soft fibrous structures detected in the mouth during chewing). Terms of references used to ensure panel consistency are presented in Lopez et al. (2011). Further details about sensory attributes used by the panel of judges could be found in Harker et al. (2002a, 2002b).

Data analysis. Treatment effects on SWP, cropload (fruits per tree), yield (kilograms per tree), average fruit weight at harvest, percentage of fruit harvested at each harvest date, instrumental quality attributes, degree of liking, and sensory attributes were evaluated by analysis of variance. Analyses were performed using SAS (enterprise guide 4.2;

Table 1. Duration of the different phenological stages and water applied in conventional irrigated (CI) and deficit irrigated (DI) treatments for ‘Tardibelle’ peach trees in 2009 and 2010.

	2009			2010		
		Water applied (mm)			Water applied (mm)	
	Duration	CI	DI	Duration	CI	DI
Stage I	28 Mar. to 19 May	51	48	28 Mar. to 26 May	65	61
Stage II	19 May to 7 July	203	81	26 May to 19 July	258	72
Stage III	7 July to 15 Sept.	388	365	19 July to 16 Sept.	270	245
Post-harvest	15 Sept. to 15 Oct.	28	29	16 Sept. to 15 Oct.	Not measured	Not measured

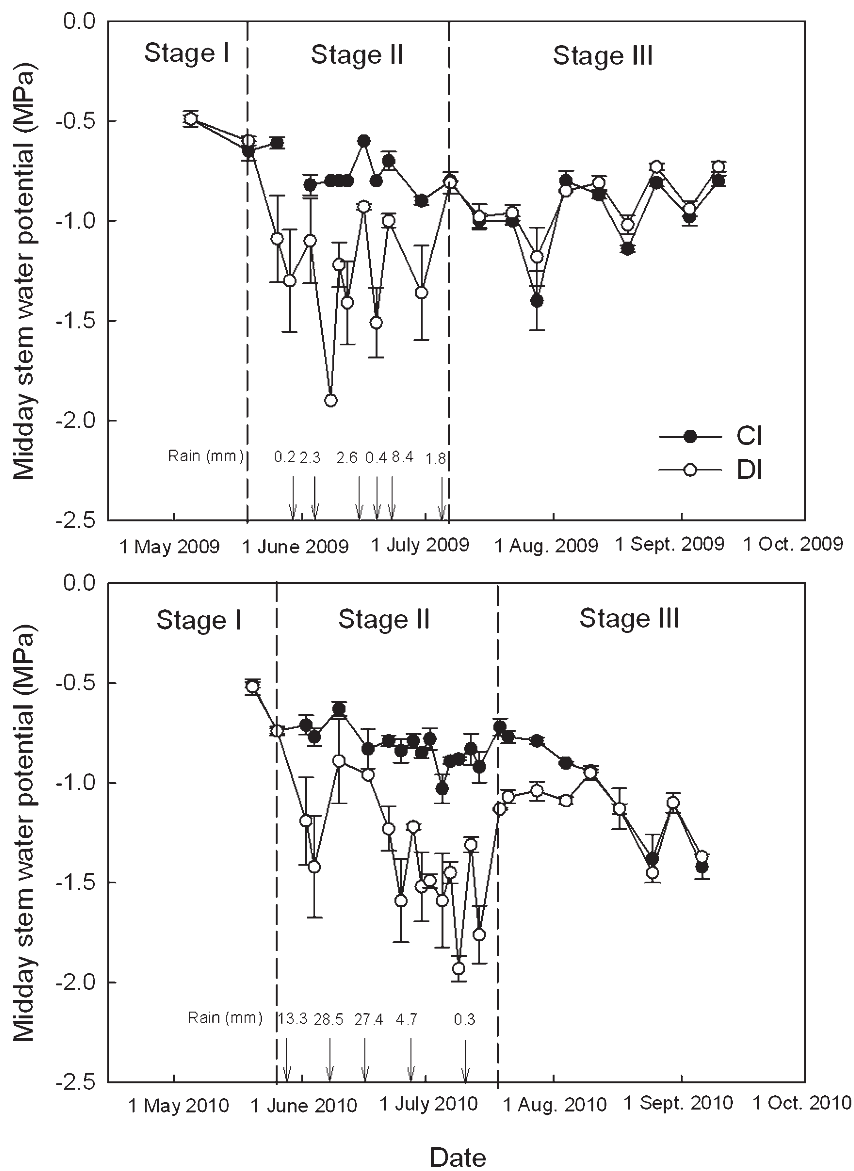

Fig. 1. Seasonal patterns of midday stem water potential for ‘Tardibelle’ peach trees in 2009 (upper panel) and in 2010 (lower panel). CI = conventional irrigation; DI = deficit irrigation. Bars indicate SE.

SAS Institute, Cary, NC). Statistical significance was established for $P < 0.05$. Tukey's test was applied to separate least square means that differed significantly.

Results

Applied water, tree water status, and yield components. Amount of water applied to trees for each experimental year is presented in Table 1. DI trees received similar amounts of water to CI trees in Stage I, Stage III, and post-harvest. During Stage II, DI trees received 81 mm (40% of CI) in 2009 and 72 mm (28% of CI) in 2010. Accumulated precipitation in Stage II was 16 mm in 2009 and 74 mm in 2010. DI trees had significantly lower SWP than CI trees during Stage II (Fig. 1). For DI trees, SWP decreased to a minimum value of –1.8 MPa for each experimental year. Partial recovery in SWP was observed (Fig. 1) when DI trees received some irrigation to avoid severe levels of water stress during Stage II. In 2009, CI and DI trees had similar SWP values during Stage III. In 2010, DI trees required 2 weeks during Stage III to reach similar values of SWP as CI trees.

In 2009, cropload and yield were similar between CI and DI trees but DI fruit had higher average weight (Table 2). In 2010, cropload was similar between CI and DI trees but yield and average fruit weight were higher in CI trees. In both years, significantly more fruit were harvested during the first pick in DI trees than in CI trees.

Instrumental and sensory evaluation of fruit quality. In 2009, SSC and SSC/TA ratio were higher in the second harvest than in the first harvest regardless of irrigation treatment (Table 3). However, TA was higher for both treatments in the first harvest. CI fruit were also firmer and their red skin color was less intense in the first harvest than in the second harvest. CI and DI fruit had similar quality attributes in 2009 (Table 3). Exceptions were for CI having higher FF and lesser intensities of the skin's red color and the pulp's yellow color in the first harvest.

For the first harvest of 2010, CI fruit differed from DI fruit by having a higher FF, higher TA, lower SSC/TA ratio, and lesser intensities of red skin color and pulp yellow color. For the second harvest of 2010, the last two attributes differed in the same way between CI and DI fruit as they did in the first harvest (Table 3).

For both harvests in 2010, DI fruit had higher consumer acceptance and lower dislike degrees values than CI fruit (Table 4). DI fruit had higher degrees of liking values than CI fruit but the differences were only significant in the first harvest (Table 4). DI fruit had lower fruit firmness, lower crispness, higher sweetness, intensity of peach flavor, juiciness, and ease of breakdown in comparison with CI fruit regardless of harvest date (Table 5).

Table 2. Effects of irrigation treatments on yield components for 'Tardibelle' peach in 2009 and 2010.

Treatments[z]	Cropload (fruit/tree)	Yield (kg/tree)	Fruit wt (g)	Fruit at each harvest (%)	
				First	Second
2009					
CI	368 a[y]	74.7 a	204.4 b	43 b	57 a
DI	329 a	73.6 a	224.7 a	73 a	27 b
2010					
CI	397 a	72.4 a	182.5 a	53 b	47 a
DI	382 a	64.7 b	170.2 b	75 a	25 b

[z]CI = conventional irrigation; DI = deficit irrigation.
[y]For a given year, means followed by different letters in the same column are significantly different at 5% according to Tukey's test.

Table 3. Effect of irrigation treatments on fruit quality attributes at harvest for 'Tardibelle' peach in 2009 and 2010.

Parameter/treatments[z]	First harvest		Second harvest	
	CI	DI	CI	DI
2009				
Dry mater concentration (%)	13.4 a[x]	13.1 a	13.1 a	13.3 a
Flesh firmness (N)	65.5 a	61.0 b	58.9 b	56.8 b
Titratable acidity (g malic acid/L)	11.9 a	10.7 a	8.8 b	9.2 b
Soluble solids concentration (%)	11.6 b	11.3 b	12.1 a	12.1 a
SSC/TA ratio	0.9 b	1.1 b	1.4 a	1.3 a
Skin color (hue°)[y]	74.5 a	61.6 b	63.1 b	59.3 b
Pulp color (hue°)	98.9 a	97.2 c	98.2 b	97.4 c
2010				
Dry mater concentration (%)	13.6 a	13.6 a	13.9 a	13.6 a
Flesh firmness (N)	69.1 a	62.7 b	68.7 ab	68.5 ab
Titratable acidity (g malic acid/L)	9.1 a	8.2 b	8.3 ab	8.2 b
Soluble solids concentration (%)	12.3 a	12.4 a	12.4 a	12.4 a
SSC/TA ratio	1.3 b	1.6 a	1.5 ab	1.5 ab
Skin color (hue°)	66.7 ab	58.0 c	70.5 a	65.2 b
Pulp color (hue°)	99.2 a	96.6 b	99.2 a	97.7 b

[z]CI = conventional irrigation; DI = deficit irrigation; SSC = soluble solids concentration; TA = titratable acidity.
[y]A 90° hue angle represents yellow, 180° represents bluish green, and 0° represents reddish purple.
[x]Means in the same row followed by different letters are significantly different at 5% according to Tukey's test.

Discussion

Stopping irrigation during Stage II resulted in moderate water stress in DI trees (Fig. 1). In 2009, water stress was less intense than in 2010 and DI trees recovered from water stress before Stage III (Fig. 1). This encouraged fruit growth recovery in DI trees and led to higher fruit weight at harvest (Table 2). In 2010, DI did not realize its potential fruit size and yield (Table 2) because some water stress persisted during Stage III (Fig. 1). Fruit growth is very sensitive to water stress during Stage III (Lopez et al., 2006). This highlights the importance of recovering trees before the onset of Stage III (Johnson and Handley, 2000). Another factor that can explain differences in growth recovery between years in DI fruit is cropload. Lower cropload in DI trees in 2009 may have facilitated fruit growth recovery after rewatering leading to higher fruit weight at harvest. Reducing cropload under DI could be an adequate practice as demonstrated for plum by Intrigliolo and Castel (2010).

Regarding fruit quality, in 2010, DI fruit had similar SSC values to CI fruit (Table 3) but consumer acceptance was higher in DI for both harvest times (Table 4). Using SSC to assess consumer acceptance in response to DI is not recommended when other important quality attributes such as fruit acidity are altered by water stress. DI reduced fruit TA and consequently increased the SSC/TA ratio (Table 3). This ratio could therefore be a better indicator of consumer acceptance in peach (Crisosto and Crisosto, 2005). Although the SSC/TA ratio is also a potential indicator of sweetness (Crisosto et al., 2006; Di Miceli et al., 2010), other important organoleptic parameters such as peach flavor, juiciness, firmness, crispness, and ease of breakdown are not always adequately predicted by instrumental analysis (Lopez et al., 2011). For example, in our study, DI fruit had higher juiciness than CI fruit (Table 5) but their DMC values were similar (Table 3). The use of sensory evaluation techniques in DI studies could therefore help gain a better understanding of the effect of different levels of water stress on fruit organoleptic quality. In our study, the panel of judges decided that DI fruit had lower firmness and crispness but higher sweetness, juiciness, and intensity of peach flavor (Table 5). DI during Stage II showed a potential for improving fruit organoleptic quality. We think that the higher appeal for DI fruit could have been partially the result of their more advanced maturity as demonstrated by the higher percentage of fruit picked during the first harvest (Table 2). However, improvements in the quality of DI fruit have also been related to their higher exposure to sunlight as a result of lower vegetative growth in DI trees (Buendía et al., 2008; Gelly et al., 2003, 2004).

Conclusions

One negative effect of DI during Stage II would be smaller fruit size if water stress

Table 4. Effects of irrigation treatments on acceptance of 'Tardibelle' peach by a panel of 44 consumers in 2010.

Treatments[z]	First harvest		Second harvest	
	CI	DI	CI	DI
Acceptance (%)	42	59	55	64
Neither like nor dislike (%)	18	32	14	18
Dislike (%)	40	9	31	18
Degree of liking (1–9)	5.2 b[y]	6.04 a	5.3 ab	5.84 ab

[z]CI = conventional irrigation; DI = deficit irrigation.

[y]Means in the last row followed by different letters are significantly different at 5% according to Tukey's test.

Table 5. Effect of irrigation treatments on sensory attributes for 'Tardibelle' peach in 2010.[z]

Treatment[y]	Sweetness[x]	Sourness	Flavor intensity	Juiciness	Firmness	Crispness	Ease of breakdown	Fibrousness
First harvest								
CI	5.3 b[w]	8.2 ab	4.9 b	4.3 c	10.9 a	10.1 a	4.9 b	1.1 a
DI	8.3 a	5.3 b	7.3 a	6.3 ab	8.0 b	6.6 b	7.5 a	2.3 a
Second harvest								
CI	4.9 b	9.3 a	4.3 b	5.4 bc	10.1 a	9.7 a	6.1 ab	1.4 a
DI	7.9 a	6.5 ab	8.4 a	7.6 a	5.5 c	4.7 b	8.2 a	2.7 a

[z]The panel consisted of nine trained judges.

[y]CI = conventional irrigation; DI = deficit irrigation.

[x]The intensity of each sensory attribute was recorded on 150 mm unstructured line scales, anchored at 0 = absent and 15 = extreme.

[w]Means followed by different letters in the same column are significantly different at 5% according to Tukey's test.

persisted at the onset of Stage III. We did not identify any other negative effects of DI applied during Stage II in 'Tardibelle' peach. DI advanced fruit maturity, increased the consumer acceptance of fruit, and improved important sensory attributes such as sweetness and flavor intensity. This could be an important incentive for the application of DI during Stage II because fruit growers may expect to receive a premium price for their high-quality fruit. Similar research in other cultivars is needed to confirm the suitability of DI during Stage II as a technique for improving peach fruit quality.

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