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Orchard Cooling with Overtree Sprinkler Irrigation to Improve Fruit Color of 'Delicious' Apples

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Abstract. **The influence of supplemental sprinkler irrigation on fruit color of 'Oregon Spur Delicious' (Trumdor) apples (*Malus* ×*domestica* Borkh.) was evaluated in the area of Lleida (NE Spain) over a 3-year period. Cooling irrigation was applied for 2 hours daily for 25–30 days preceding the harvest. Three treatments were evaluated: 1) control without overtree sprinkler irrigation; 2) sprinkler irrigation applied at midday; and 3) sprinkler irrigation applied at sunset. Fruit color was significantly affected by the cooling irrigation and also by the weather of the particular year. Increased red color and higher anthocyanin content resulted from sprinkler irrigation, especially when applied at sunset. At harvest, anthocyanin content was correlated with a*/b* and hue angle, suggesting that the colorimeter measurements could provide a nondestructive estimate of anthocyanin content.**

Red color and fruit size are the primary grading standards for European Union countries. Even with adequate size, poor fruit color is an important cause for reduction in grade and is generally associated with poor consumer acceptance. One way to compensate for poor color is by developing new strains with high coloring potential, even in hot areas (Curry, 1997; Iglesias, 1990; Iglesias et al., 1999a). Overtree or microjet sprinkling has been used in the warmer areas of eastern Washington State for evaporative cooling to enhance color formation. Trials conducted with 'Delicious' strains showed that this technique significantly improved fruit color and size (Iglesias et al., 1999c; Recasens, 1982; Unrath, 1972a, b), especially in locations having high temperatures and low relative humidity.

Materials and Methods

Plant material, experimental design, sample collection. This study was conducted in 1992, 1993, and 1994 using 'Oregon Spur Delicious' apple trees on MM·106 rootstock in a commercial orchard (Lleida, NE Spain). The cooling schedule started in early August, 25–30 d before harvest. Water was applied daily, independent of orchard temperature, for 2 h at two different times. Treatments were: 1) control without sprinkler irrigation for cooling; 2) sprinkler irrigation applied at midday (1500–1700 HR); and 3) sprinkler irrigation applied at sunset (2100–2300 HR). Sprinklers were spaced 18 × 16 m, to deliver 1110 $L \cdot h^{-1}$ (≈3.6 $mm \cdot h^{-1}$).

The experimental design was a randomized complete-block with three blocks, each 80 m long. One third of each block was evaporatively cooled with sprinkler irrigation at midday, another third was cooled at sunset, and the other served as a control. There were 12 guard trees between each block. Five trees were chosen from the middle portion of each plot for recording data. Eight fruit were randomly selected and marked on each of five trees per block on 4 Aug. for fruit color measurements. An additional five fruit per tree were harvested for determination of anthocyanin content. At harvest, 14 fruits per tree were harvested for color and anthocyanin determination.

Fruit color measurement. Apple color was measured with a Minolta Chroma Meter CR-200 portable tristimulus colorimeter (Minolta Corp, Osaka, Japan) and fruit chromaticity was recorded in C.I.E. L*, a*, and b* color space coordinates (Hunter, 1975; McGuire, 1992). Color was measured on each fruit at two equatorial locations 180° apart the side exposed to sunlight (ES), and the shaded side (SS).

Anthocyanin content. Anthocyanin content was evaluated after color measurement at the same locations where chromaticity values were recorded. The anthocyanin concentration was determined in two 11-mm diameter skin discs from each location using a spectrophotometer at 532 nm (Chalmers et al., 1973).

Data analysis. Data for chromaticity values and anthocyanin content were subjected to analysis of variance with the Statistical Analysis System software (SAS Institute, 1997). Mean separation was performed with Duncan's new multiple range test when the F values were significant.

Results and Discussion

The effects of evaporative cooling chromaticity values. Chromaticity values just before starting the treatments, were essentially the same in all treatments (data not shown). In 1992 and 1994 color parameters for each side, ES and SS, indicated that irrigation applied at sunset hastened and intensified fruit color (Table 1). Midday cooling gave values intermediate between those for the control and sunset cooling. Treatments applied in 1993 were less effective, probably because of lower temperatures than in 1992 and 1994. Values of L* and hue (°) for the ES were significantly lower than those for the SS, whereas the a*/b* ratio was higher. Treatment × fruit side interaction was in general nonsignificant (Table 1). Thus, evaporative cooling increased fruit color equally on both sides.

Effect of evaporative cooling on anthocyanin content. Mean anthocyanin content increased continuously on both sides of the fruit (data not shown) in the last 2 weeks before harvest. In late August and at harvest, anthocyanin content was significantly higher in fruit that were cooled at sunset than in the control, whereas cooling at midday was less effective. Anthocyanin content for ES was higher than for SS (Table 1). Both cooling treatments improved red pigmentation significantly, in accordance with results reported by several researchers with 'Delicious' strains using continuous or pulsed overtree sprinkler irrigation in warm regions (Iglesias et al., 1999c; Recasens, 1982; Unrath, 1972b). Phenylalanine ammonia-lyase (PAL) activity, and consequently the synthesis of anthocyanin, is also greater at lower temperature (Faragher, 1983; Iglesias et al., 1999b; Tan, 1980).

Relationship between anthocyanin content and chromaticity values. Simple nonlinear models were used to relate anthocyanin content with chromaticity values. The R^2 values obtained with a*/b* ratio (0.84) and hue (0.81) were best; that with L* (0.78) was intermediate. These results are similar to those reported by several researchers relating chromaticity values to anthocyanin content (Iglesias et al., 1999a; Singha et al., 1991).

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Table 1. Main effects of cooling irrigation of 'Oregon Spur Delicious' apple during August and September on colormetric values and anthocyanin content.

Treatment	L* Aug.[z]	L* Sept.[y]	a*/b* Aug.	a*/b* Sept.	hue (°) Aug.	hue (°) Sept.	Anthocyanin (nmoles·cm^{-2}) Aug.	Anthocyanin (nmoles·cm^{-2}) Sept.
1992								
A. Timing[x]								
Sunset	55.7 b[w]	41.2	0.47 a	1.2 a	73.9 b	42.4 b	15.4 a	21.7 a
Midday	56.5 b	42.1	0.34 b	1.1 b	77.0 b	45.5 ab	13.2 b	19.1 ab
Control	57.9 a	41.0[NS]	0.16 c	0.9 c	83.9 a	50.0 a	12.1 b	17.4 b
B. Position on fruit[v]								
ES	51.9 b	36.7 b	0.74 a	1.5 a	63.9 b	34.1 b	20.2 a	27.3 a
SS	60.9 a	48.2 a	–0.11 b	0.6 b	92.5 a	58.2 a	7.0 b	11.6 b
Interaction A × B	NS	NS	*	*	NS	NS	NS	NS
1993								
A. Timing[x]								
Sunset	48.9	40.8 b		all NS			17.6 a	39.3 a
Midday	49.0	41.3 b		all NS			13.3 b	33.4 b
Control	51.0[NS]	48.1 a		all NS			12.0 b	31.3 b
B. Position on fruit[v]								
ES	41.1 b	36.5 b	1.8 a	2.6 a	31.0 b	21.5 b	22.8 a	52.2 a
SS	58.1 a	50.3 a	0.1 b	1.1 b	83.6 a	43.4 a	5.8 b	17.2 b
Interaction A × B	NS	NS	NS	NS	NS	NS	NS	NS
1994								
A. Timing[x]								
Sunset	58.3 b	46.3 b	0.3 a	1.0 a	75.9 b	50.3 b	7.8 a	24.0 a
Midday	59.1 b	52.9 ab	0.2 b	0.6 b	79.5 b	59.3 a	6.6 ab	19.3 b
Control	60.4 a	55.3 a	0.2 b	0.5 b	84.5 a	64.1 a	5.7 b	17.7 b
B. Position on fruit[v]								
ES	54.2 b	45.3 b	0.5 a	1.2 a	64.6 b	38.6 b	9.8 a	30.1 a
SS	64.3 a	60.0 a	–0.1 b	0.2 b	95.4 a	77.2 a	3.8 b	10.5 b
Interaction A × B	NS	NS	*	*	NS	NS	**	**

[z]Data recorded 25 Aug. in 1992 and 1993, 22 Aug. in 1994.
[y]Data recorded 8 Sept. in 1992 and 1993, 5 Sept. in 1994.
[x]Sunset: 2100 –2300 HR; Midday: 1500–1700 HR.
[w]Mean separation within columns, chromaticity parameters, anthocyanin content and years by Duncan's new multiple range test ($P \leq 0.05$).
[v]ES = exposed side; SS = shaded side of fruit.
[NS, *, **]Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

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