Sensitivity of Shoots and Roots of Young Watermelon Plants to End-of-day Red and Far-red Light

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ADDITIONAL INDEX WORDS. *Citrullus lanatus*, phytochrome, photomorphogenesis

ABSTRACT. The sensitivity of shoots and roots to end-of-day (EOD) red (R) or far-red (FR) light on growth of 'Sugar Baby' watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nakai] was investigated. Plants were grown in full-strength Hoagland solution and treated for 14 days to 15 minutes EOD light in trial 1 and in half-strength Hoagland solution and treated for 10 days to EOD light in trial 2. Exposing shoots to EOD FR resulted in elongated petioles of leaves 1 to 3 (as counted from the cotyledons), internodes 1 to 3, and total stem length in both trials. Exposure to EOD FR resulted in increased stem and petiole dry mass in trial 1, whereas EOD FR resulted in increased root and leaf dry mass in trial 2. EOD FR exposure of roots increased the length of petiole 4 in trial 1. In general, shoots were more responsive than roots to the growth-regulating effects of EOD FR.

Young watermelon (*Citrullus lanatus*) plants are sensitive to exposures of the aerial portions (shoots) to 15 min of end-of-day (EOD) red (R) or far-red (FR) (Decoteau and Friend, 1991b). EOD FR promoted elongation of internodes and petioles and decreased petiole angles. These FR-induced growth responses were reversed by immediately following FR with R, implicating phytochrome as the light-perception pigment (Jabben and Holmes, 1983; Smith, 1982). These EOD light effects on plant development have been used to demonstrate and categorize phytochrome-mediated growth responses without the often-associated microclimate modifications of altered light irradiance levels or modified leaf temperatures that occur in ecosystems when light quality is modified (e.g., canopy shade or soil surface color) (Decoteau et al., 1988; Kasperbauer and Karlen, 1986).

Although many plant growth responses have been attributed to phytochrome regulation (primarily as perceived by shoots), little is known concerning the differential application of the photomorphogenic (R and FR) light to shoots and roots and resulting growth responses of the plant, especially shoots. Roots are not generally considered to be responsive to photomorphogenic light exposures (Cosgrove, 1994), even though they contain phytochrome (Schwarz and Schneider, 1987) and light can penetrate 4 to 5 mm through soil (Tester and Morris, 1987). Exposing shoots to R has stimulated geotropism of roots (Hart and MacDonald, 1980), but a role for R or FR exposure of roots on shoot growth has not been documented.

A better understanding of differential application of EOD light quality to shoots and roots on plant growth and development should help develop more effective plant growing systems that use light as a growth regulator. The objective of this research was to document the differential sensitivity of shoots and roots of young watermelon plants to growth modification by treating them with EOD R or FR light. A hydroponic plant growing system was used to allow maximal light treatment of the roots without the reported near-total light filtering that occurs in soil culture (Kasperbauer and Hunt, 1988).

Materials and Methods

PLANT GROWTH ENVIRONMENT. 'Sugar Baby' watermelon seeds were sown into Speedling flats (4.5 cm cell depth, 39.5 cm³ cell volume) (Speedling, Sun City, Fla.) containing Fafard (Anderson, S.C.) soilless mix no. 3. These flats were placed in a controlled-environment room for seed germination and seedling growth. This room was equipped with metal halide lamps (Philips Lighting Co., Somerset, N.J.) that provided 250 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetic photon flux (PPF) during a 14-h photoperiod with an average day/night temperature of 27/21 °C. Plants were grown for 14 d before transplanting to a hydroponic solution. The medium was washed off the roots before they were transferred to the solution. Five plants per light treatment were arranged in a completely randomized design and were randomized daily following the EOD treatments.

HYDROPONIC CULTURE. Fourteen-day-old seedlings with two true leaves were placed in Magenta GA7 tissue culture vessels (7.6 cm vessel depth, 300 cm³ vessel volume) (Magenta Corp., Chicago) containing Hoagland's #1 nutrient solution with micronutrients added at pH 6.0 (Hoagland and Arnon, 1939). The culture vessels were placed in a black-painted wooden stand. Black opaque polyethylene was wrapped around the sides of the stand, and the covers of the vessels were painted black to prevent exposure of roots to light. Tygon tubing was inserted through a hole in the vessel lid and into the nutrient solution. The other end of the tubing was connected to an aquarium pump that aerated the nutrient solution. The roots of the watermelon seedlings were inserted through a second hole in the lid. A black-painted sponge was also inserted into the second hole to support the seedling and prevent light transmission through the hole.

Two trials that differed in concentration of the hydroponic solution and EOD treatments were conducted: plants were grown in full-strength Hoagland solution and treated for 14 d of EOD light (trial 1) and in half-strength Hoagland solution and treated for 10 d of EOD light (trial 2). The hydroponic solution was replaced every other day in both trials.

LIGHT TREATMENTS. Light treatments began 1 d after plants were placed in hydroponic culture. The R and FR treatments were applied for 15 min each day at the end of the photoperiod. The EOD R (7 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of photons in the 600 to 700 nm waveband) was obtained by filtering radiation from six cool-white 40-W fluorescent lamps through a Roscolux #19 acetate filter (Rosco, Port Chester, N.Y.). The EOD FR (44 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of photons in the 700 to 780 nm waveband) was obtained by filtering radiation from two 150-W internal reflector incandescent lamps through a

Received for publication 27 June 1996. Accepted for publication 20 Mar. 1997. Technical contribution no. 4212 of the South Carolina Agricultural Experiment Station, Clemson Univ. No endorsement of the products named is implied by Clemson Univ. or the South Carolina Experiment Station. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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Table 1. Influence of end-of-day (EOD) red (R), far-red (FR), or far-red followed by red (FR/R) light treatment of shoots on petiole lengths of watermelon after 14 d of treatment (trial 1).

EOD light	Petiole length (cm)			
	Leaf no.			
	1	2	3	4
R	3.38 b ²	4.84 c	5.46 c	4.96 c
FR	5.46 a	8.18 a	9.92 a	7.04 a
FR/R	3.82 b	5.66 bc	6.86 b	5.92 b
Control ³	3.72 b	5.56 bc	6.56 b	5.34 bc

²Mean separation in columns by LSD, $P = 0.05$.

³Shoots and roots were exposed to 15 min of EOD light from the metal halide lamps.

polyacrylic sheet of cast acrylic #2711, dark red (Rohm and Haas, Bristol, Pa.). The R and FR light spectra have been reported by Decoteau and Friend (1991a), and treatments with these intensities and durations have effectively regulated the growth and development of young watermelon plants (Decoteau and Friend, 1991b).

The Magenta boxes containing the plants were placed into support racks (similar to those used previously in the hydroponic plant growing system) in the light-treatment chambers for exposure to a specific light quality. Orientation of the light source, the design of the Magenta boxes, and the design of the support racks in the exposure chamber allowed selective exposure of shoot or roots to EOD light treatments. Light source and filters were positioned 60 cm above the plants for shoot treatments and 45 cm below the roots for root treatments. Roots were treated through the polyacrylic surface of the Magenta box and hydroponic solution. At the end of each EOD treatment, the vessels were randomly placed into the growth racks in the dark for the rest of the dark period.

Plants were treated with EOD light for 14 d in trial 1. Shoots were exposed to 15 min of R or FR or 15 min of FR followed by 15 min of R (FR/R). Roots were exposed to 15 min of R, FR, or FR/R. In addition, the shoots and roots of one set of plants were exposed to 15 min of light from the metal halide lamps (250 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF) of the growth room (control).

Plants were treated with EOD light (15 min) for 10 d in trial 2. Shoots and roots were exposure to R, FR, or FR/R. In addition, one set of plants was treated as a control as described above. In another treatment, the shoot was exposed to 15 min of EOD FR (while the roots were maintained in the dark) after which the roots were exposed to 15 min of EOD FR (while the shoots were maintained in the dark) (FR + FR).

PLANT GROWTH MEASUREMENTS AND STATISTICAL ANALYSIS. Immediately following the dark period after the last EOD light treatment in each experiment, petiole lengths of all true leaves (counted from the cotyledons) and internode lengths were measured with a caliper equipped with a micrometer dial read to 0.01 mm. Leaf areas were measured with an area meter (LI-3100; LI-COR,

Lincoln, Neb.). Intact plants were oven dried for 5 d at 70 °C. After being dried, the individual plants were separated into petioles, roots, shoots, leaves, and stems. Data were analyzed using SAS's analysis of variance and contrast procedures (general linear models) (SAS Institute Inc., Cary, N.C.). Least significant difference (LSD) values were calculated for use in multiple comparison of treatment means.

Results

TRIAL 1. The FR treatment of shoots induced elongation of all petioles compared to R and FR/R treatments of shoots and the control (white light) (Table 1). The light-quality treatment of roots had no effect on petiole elongation (data not shown) compared to control.

Shoots that were treated with FR had longer internodes 1 to 4 and total stem length than shoots treated with R or FR/R and shoots of the control (Table 2). Internode lengths from the R and FR/R treatment of shoots were not significantly different from those of the control. Treating roots with various light qualities had no effect on internode length (data not shown).

Shoots treated with FR had increased stem and petiole dry mass compared to shoots treated with R or FR/R and the control (Table 3). Light-quality treatment of shoots had no effect on root and leaf biomass compared to control. Light-quality treatment of roots had no effect on biomass production and partitioning compared to the control. Plants whose roots were treated with FR had more biomass partitioned to petioles and leaves than those treated with R. Plants whose roots were treated with R had less leaf biomass than the control.

TRIAL 2. Shoots that received FR treatment had longer petioles of leaves 1 and 2 than corresponding petioles of plants in shoots in the R and FR/R treatments and the control (Table 4). Petiole length of leaf 3 from the FR shoot treatment was greater than the corresponding petiole length of leaf 3 from the R shoot treatment and the control, but was similar to petiole length of leaf 3 from the

Table 2. Influence of end-of-day (EOD) red (R), far-red (FR), or far-red followed by red (FR/R) light treatment of shoots on internode lengths of watermelon after 14 d of treatment (trial 1).

EOD light	Internode length (cm)				
	No.				
	1	2	3	4	Total
R	0.34 b ²	0.22 c	0.56 b	1.56 b	13.28 b
FR	0.88 a	1.12 a	4.60 a	4.52 a	20.82 a
FR/R	0.26 b	0.58 b	1.06 b	2.02 b	13.40 b
Control ³	0.22 b	0.32 c	0.94 b	1.76 b	13.48 b

²Mean separation in columns by LSD, $P = 0.05$.

³Shoots and roots were exposed to 15 min of EOD light from the metal halide lamps.

Table 3. Influence of end-of-day (EOD) red (R), far-red (FR), or far-red followed by red (FR/R) light treatment of shoots and roots on dry biomass partitioning of watermelon after 14 d of treatment (trial 1).

Exposure	Light	Dry biomass (g)			
		Root	Stem	Petiole	Leaves
Shoot	R	0.098 abc ^a	0.116 b	0.080 bc	0.542 abc
	FR	0.099 abc	0.184 a	0.121 a	0.550 abc
	FR/R	0.120 a	0.136 b	0.096 b	0.639 a
Root	R	0.074 c	0.099 b	0.069 c	0.445 c
	FR	0.103 abc	0.118 b	0.093 b	0.601 ab
	FR/R	0.084 bc	0.101 b	0.068 c	0.503 bc
Control ^y		0.105 abc	0.118 b	0.086 bc	0.607 ab

^aMean separation in columns by LSD, $P = 0.05$.

^yShoots and roots were exposed to 15 min of EOD light from the metal halide lamps.

FR/R shoot treatment. Light-quality treatment of roots had no effect on petiole length (data not shown). Plants in the FR combination treatment of shoots and roots (FR + FR) had greater petiole lengths of leaves 1 to 4 than corresponding petioles of plants in the control. The first three petioles from the FR shoot and root treatment were similar in length to the corresponding petioles from the FR shoot treatment. Petiole length of leaf 4 from the FR shoot and root treatment was greater by 178% than corresponding petioles from FR shoot treatment.

Lengths of internodes 1, 2, and 3 and total stem length from plants in the FR shoot treatment were greater than corresponding internodes from plants in the R and FR/R shoot treatment and the control (Table 5). Internodes 1, 2, and 3 from plants in the FR shoot treatment averaged 400% to 336% greater than corresponding internode lengths for the EOD R shoot treatment and the control, respectively. Treating shoots with R resulted in similar internode lengths as treating shoots with FR/R. Light-quality treatment of roots had no effect on internode elongation and total stem length compared to the control (data not shown). Plants treated with FR + FR had longer internodes of 1, 2, 4 and greater total stem length than corresponding internodes of the control. Internodes 1 and 4 from the FR + FR treatment were longer than corresponding internodes from plants treated with FR to shoots. Internode 3 from the FR + FR treatment was shorter than internode 3 from the FR shoot treatment.

Shoots treated with FR resulted in plants lower root and leaf dry mass compared to shoots treated with R and FR/R and the control (Table 6). Root and leaf dry mass from the shoot light treatment were similar to the FR combination shoot and root treatment (FR + FR). Treating shoots with FR increased stem and petiole dry mass by 59% and 45%, respectively, compared to treating shoots with R. Dry mass of stems and petioles from plants in the FR shoot

treatment were not significantly different from the control. Biomass plant responses to treating shoots or roots with R or FR/R light were not significantly different. The FR root treatment resulted in lower stem and leaf biomass compared to the control.

Discussion

Shoot exposure to EOD FR affected the early growth of watermelon. All petioles and internodes were affected by the FR shoot treatment in trial 1, and all but the youngest petiole and internode were affected by the FR shoot treatment in trial 2. The lack of response in the youngest petiole and internode in trial 2 may have been due to the fact that younger plants were harvested and plants had fewer days of EOD light treatment than in trial 1. Petiole and internode elongation of watermelon (Decoteau and Friend, 1991b) and other crops (Holmes and Smith, 1977, Thomas and Raper, 1985) has been induced similarly by EOD FR. The sequential exposure of the plants with FR followed by R reversed FR-induced elongation of petioles and internodes. This photo-reversibility is similar to what was previously reported for watermelon (Decoteau and Friend, 1991b) and indicates mediation by phytochrome (Mancinelli, 1994; Smith, 1994).

Shoots treated with FR had increased stem and petiole dry mass compared to shoots treated with R or FR/R and the control in trial 1. This relative increase in stem and petiole dry mass is similar to previous observations with watermelons after 7 d of EOD treatment (Decoteau and Friend, 1991b). Shoots treated with FR had lower root and leaf dry mass compared to shoots treated with R and FR/R and the control in trial 2. Reduced root biomass as a consequence of EOD FR treatments has been reported for watermelon (Decoteau and Friend, 1991b) and wheat (Kasperbauer and Karlen, 1986).

Table 4. Influence of end-of-day (EOD) red (R), far-red (FR), or far-red followed by red (FR/R) light treatment of shoots on petiole lengths of watermelon after 10 d of treatment (trial 2).

EOD light	Petiole length (cm)			
	Leaf no.			
	1	2	3	4
R	3.98 b ²	4.78 c	5.44 c	3.06 b
FR	6.08 a	9.60 a	6.98 ab	2.36 b
FR/R	4.52 b	5.92 b	5.96 b	3.44 b
FR + FR ^y	6.42 a	9.28 a	8.12 a	6.56 a
Control ^x	4.28 b	5.44 bc	5.20 c	2.68 b

²Mean separation in columns by LSD, $P = 0.05$.

^yShoot was exposed to 15 min of EOD FR (while the roots were maintained in the dark) after which the roots were exposed to 15 min of EOD FR (while the shoots were maintained in the dark).

^xShoots and roots were exposed to 15 min of EOD light from the metal halide lamps.

Table 5. Influence of end-of-day (EOD) red (R), far-red (FR), or far-red followed by red (FR/R) light treatment of shoots on internode lengths of watermelon after 10 d of treatment (trial 2).

EOD light	Internode length (cm)				Total
	1	2	3	4	
R	0.44 c ^z	0.24 b	0.56 b	0.32 b	8.50 b
FR	1.46 b	1.92 a	2.10 a	1.00 b	14.66 a
FR/R	0.50 c	0.50 b	0.80 b	0.52 b	9.36 b
FR + FR ^y	1.94 a	1.72 a	0.74 b	2.46 a	15.10 a
Control ^x	0.42 c	0.28 b	0.76 b	0.56 b	10.32 b

^zMean separation in columns by LSD, $P = 0.05$.

^yShoot was exposed to 15 min of EOD FR (while the roots were maintained in the dark) after which the roots were exposed to 15 min of EOD FR (while the shoots were maintained in the dark).

^xShoots and roots were exposed to 15 min of EOD light from the metal halide lamps.

Exposing roots to EOD light did not affect petiole and internode elongation. While some root sensitivity to EOD FR light (compared to the controls) was suggested for biomass partitioning (leaves in trial 1 and stems and leaves in trial 2), these effects were considerably less than when the shoots were treated with FR light. In previous work on root elongation of *Dracaena fragrans* Ker-Gawl (Vinterhalter et al., 1990), in vitro cultures were indifferent to light exposure of roots, while shoots were demonstrated to be the site of light perception for root elongation.

The relative insensitivity of the roots to EOD light also may have been partially due to the light-treatment conditions in the hydroponic system. Watermelon roots were exposed to light through the polyacrylic vessel and hydroponic solution. Underwater radiation is affected by reflection and refraction of light at the surface and absorption and scattering of light beneath the surface (Smith, 1982). In addition, water molecules will absorb FR light; therefore, the EOD FR light the roots received may not have been of the same quality and quantity as that received by the shoots.

A combination of shoot and root exposure to FR (FR + FR) had a cumulative affect on growth of petiole 4 and internodes 1 and 4. These results support a previous suggestion by Cosgrove (1994) that a light-induced growth response could be affected by simultaneously perceived light at two or more regions of the plant, thus causing an additive growth response.

Our results indicate that watermelon shoots are more responsive than roots to the growth-regulating effects of EOD FR. Other root exposure methods may be necessary to elucidate further the differential sensitivity of shoots and roots to growth-regulating EOD light.

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Table 6. Influence of end-of-day (EOD) red (R), far-red (FR), or far-red followed by red (FR/R) light treatment of shoots and roots on dry biomass partitioning of watermelon after 10 d of treatment (trial 2).

Exposure	Light	Dry biomass (g)			
		Root	Stem	Petiole	Leaves
Shoot	R	0.061 a ^z	0.063 cd	0.044 bc	0.352 b
	FR	0.043 bc	0.100 a	0.064 a	0.259 c
	FR/R	0.064 a	0.077 abcd	0.053 ab	0.356 b
Root	R	0.057 ab	0.063 cd	0.040 bc	0.326 bc
	FR	0.052 abc	0.056 d	0.035 c	0.299 bc
	FR/R	0.063 a	0.070 bcd	0.045 bc	0.373 ab
Shoot + root ^y	FR + FR	0.036 c	0.091 ab	0.068 a	0.261 c
Control ^x		0.066 a	0.084 abc	0.050 abc	0.433 a

^zMean separation in columns by LSD, $P = 0.05$.

^yShoot was exposed to 15 min of EOD FR (while the roots were maintained in the dark) after which the roots were exposed to 15 min of EOD FR (while the shoots were maintained in the dark).

^xShoots and roots were exposed to 15 min of EOD light from the metal halide lamps.