Phytochrome-regulated Growth of Young Watermelon Plants

Dennis R. Decoteau and Heather H. Friend

Department of Horticulture, Clemson University, Clemson, SC 29634-0375

Additional index words. light, phytochrome, red (far-red) light, *Citrullus lanatus*

Abstract. Phytochrome-regulated growth of watermelon [*Citrullus lanatus* (Thunb.) Matsum & Naki cv. Sugar Baby] was investigated by treating plants with brief exposures of red (R) or far-red (FR) light at the end of the daily photoperiod. Light treatments were initiated when the plants were 2 weeks old (two true-leaf stage). After 4 days of treatment, petiole lengths of leaf 1 (first leaf above the cotyledon) and leaf 2 (second leaf above the cotyledon) were longer, and the angle formed between these two petioles was more acute in plants treated with end-of-day (EOD) FR than in plants treated with EOD R light or non-EOD-treated plants (control). After 7 days of treatment, internodes 2 and 3 and petioles from leaves 1, 2, and 3 were longer from plants treated for 7 days with EOD FR light than from plants treated with EOD R light or from controls. The EOD FR light promotion of internode, petiole angle, and petiole elongation was reversible by immediately following the FR with R, implicating the involvement of phytochrome in the regulation of these growth processes of watermelon. After 21 days of treatment, most of the internodes (six of eight) from the EOD FR-treated plants were longer than the corresponding internodes from the EOD R-treated plants. Plants that were treated with EOD light for 21 days and then grown for an additional 14 days without EOD light treatments exhibited no residual EOD light effect on internode elongation (as compared to plants not exposed to EOD light). Residual EOD FR light treatment effects on elongation of petioles 1, 2, 3, and 4 were suggested for plants treated with EOD light for 21 days and then grown for 14 days without EOD treatments.

Many environmental situations in natural and agricultural plant ecosystems (e.g., canopy shade, high-density plant crowding) affect the fluence ratio of FR to R light (FR : R) of the plant microenvironment and plant morphogenic development (Decoteau et al., 1989; Hunt et al., 1989; Kasperbauer, 1971). For example, tobacco (*Nicotiana tabacum* L.) grown in the shade of a plant canopy received a 700% increase in FR : R as compared to an open-field (no shade) situation, primarily due to the selective absorption of R wavebands of light by chlorophyll pigment of leaves in the upper plant canopy (Kasperbauer, 1971). Plants exposed to greater FR : R during the photoperiod grew taller (Decoteau et al., 1988; Kasperbauer, 1971; Kasperbauer and Karlen, 1986), had thinner leaves (Kasperbauer, 1988), more axillary shoots (Decoteau et al., 1988), and smaller shoot relative to root biomass (Kasperbauer and Karlen, 1986) than plants that were exposed to smaller ratios of FR : R.

Brief exposures (15 min or less) of young actively growing plants to irradiances of monochromatic R or FR light at the end of each photoperiod generated plant growth trends similar to the developmental growth of plants grown in continuous low FR : R or high FR: R, respectively, during the light period (Decoteau et al., 1988; Kasperbauer and Karlen, 1986). These EOD light treatment effects on plant development can be used to demonstrate and categorize phytochrome-mediated growth responses without the often associated microclimate modifications of altered light irradiance levels and/or modified leaf temperatures that occur in ecosystems when light quality is modified (e.g., canopy shade).

Most plants for which phytochrome-mediated growth responses have been categorized are upright-growing annual plants, such as tobacco (Kasperbauer, 1971), soybean (Hunt et al., 1989), wheat (Kasperbauer and Karlen, 1986), and tomato (De-

coteau et al., 1988). Limited research has been directed at demonstrating and categorizing phytochrome-mediated growth effects of relatively horizontal-growing ("runnering" type) plants, as are many members of the Cucurbitaceae. The objective of this research was to document phytochrome-mediated growth effects in watermelon by modifying EOD light quality for plants.

Materials and Methods

Plant material. 'Sugar Baby' watermelon seeds were sown into 1-liter pots one seed per pot) filled with a commercial potting mix (Fafard Soilless Mix No. 3; Fafard, Anderson, S. C.) and placed in a controlled-environment room for seed germination and plant growth. The room was equipped with multi-vapor HID lights (General Electric Corp.) that provided $550 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ during a 12-h photoperiod. The day/night cycle averaged 27/21°C. Fifteen plants were analyzed per light treatment. The plants were placed in the plant-growing area of the controlled-environment room in a completely randomized design.

Light treatments. EOD light treatments began 14 days after germination, when plants were in the two true-leaf stage of development. EOD light treatments consisted of exposing plants to R or FR light for 15 min each day at the end of the photosynthetic period and then returning the plants to darkness in the plant-growing area of the controlled-environment room. All plants received the same light spectra and amount of photosynthetically active radiation during the day, but were influenced by phytochrome regulation of photosynthate partitioning, as described by Kasperbauer (1987). EOD R exposure ($2.8 \text{ W}\cdot\text{m}^{-2}$ 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.). EOD FR light exposure ($10 \text{ W}\cdot\text{m}^{-2}$ in the 700- to 780-nm waveband) was obtained by filtering radiation from two 150-W internal-reflector, incandescent lamps through a polyacrylic sheet of cast acrylic #271 1, dark red (Rohm and Haas, Bristol, Pa.). To test

Received for publication 15 Aug. 1990. Technical contribution no. 3088, South Carolina Experiment Station, Clemson Univ. This research was supported (in part) from South Carolina Experiment Station Project 1187 and a U.S. Dept. of Agriculture Special Grant P.L. 89-106. 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.

Abbreviations: EOD, end-of-day; FR, far red; R, red.

the photoreversibility of light exposures on plant development, one set of plants received 15 min of FR followed immediately by 15 min of R light at the end of each photosynthetic period. A control set of plants was not treated with EOD light.

Plant growth measurements. After 4 days of EOD light treatments, petiole lengths from true leaves 1 and 2 (counted from the cotyledons) were recorded from all plants. The internode between leaf 1 and leaf 2 had not elongated at this time, so the angle formed by leaf petiole 1 to leaf petiole 2 was measured. Leaf petiole lengths were measured with a caliper equipped with a micrometer dial accurate to 0.01 mm, and leaf angles were measured with a protractor.

After 7 and 21 days, five plants from each EOD light treatment were harvested, and leaf area, plant biomass, dry weights, leaf petiole lengths, and internode lengths were measured. Leaf areas were measured with a LI-COR (Lincoln, Neb.) 3100 area meter, and dry weights of all leaves, petioles, and stems were determined after oven-drying for 7 days at 70°C. Internode lengths were measured with the micrometer.

Determination of residual longevity of EOD light effects on plant growth. After 21 days of EOD light treatments, five plants from each light treatment were removed from the controlled-environment room and placed in a nonshaded glass greenhouse and exposed to natural daylight. These plants received no subsequent EOD light. After 14 days in the greenhouse, all plants were harvested for determination of leaf area, dry weight, leaf petiole lengths, and internode lengths using the previously described methods.

Statistical analyses. All results were tested by analysis of variance. LSD values were calculated for use in multiple comparison of treatment means.

Results and Discussion

Light treatment effects on young watermelon plants were observed after 4 days of EOD light exposures. Petioles of leaf 1 and leaf 2 were longer, and angle formed by the junction of these petioles to the stem was more acute in plants treated with

EOD FR light than in plants treated with EOD R light or in non-EOD-treated (control) plants (Table 1). EOD FR light effects on leaf petioles and petiole angles were reversed by following the FR exposure with R. This photoreversion provides supporting evidence that these plant growth effects are mediated by phytochrome.

Petiole elongation has been shown previously to be influenced by EOD light treatments in *Cucurbita pepo* L. (Holmes and Smith, 1977) and *Thlaspi arvense* L. (Metzger, 1988). Such treatments and photoperiod affected petiole elongation of *Glycine max* (Thomas and Raper, 1985). Zack and Loy (1980) reported that EOD incandescent light affected internode elongation of *Cucurbita maxima*. Thomas and Raper (1985) observed that EOD light quality, but not photoperiod, had an effect on internode elongation of *Glycine*. Work by Morgan et al. (1980) on, supplemental FR light during the photoperiod on *Sinapis alba* L. stem extension demonstrated a rapid increase in stem extension rate (≈ 2 to $3 \mu\text{m}\cdot\text{min}^{-1}$) after a 13-min lag period following initiation of FR supplement. In the present experiment, we could not measure such a rapid increase in stem elongation following EOD FR light treatment either because of 1) species differences in sensitivity to light treatments, 2) EOD FR treatments were not as effective as supplemental FR during the photoperiod in enhancing growth, or 3) our inability to measure small increments of growth that may have occurred.

After 7 days, EOD FR light-treated plants had more plant biomass allocated to the petioles, stems, and roots, and had longer stems than plants in the EOD R light treatment (Table 2). These EOD FR light-induced growth effects were photoreversed with EOD R light. EOD light treatments had no effect on leaf biomass, shoot : root biomass ratio, and leaf area per plant. EOD FR light treatments increased lengthening of internodes 2 and 3 and enhanced petiole elongation of the three leaves present on the plant (Table 3).

After 21 days of light exposure, EOD FR light-treated plants had more petiole biomass and longer stems than plants with EOD R light or control plants (Table 4). EOD FR light-treated

Table 1. Influence of EOD light on watermelon growth after 4 days of treatment.

EOD light	Petiole length (cm)		Angle (°) of leaf 1 to leaf 2
	Leaf 1	Leaf 2	
R	4.64 a	5.31 a	63 a
FR	6.43 b	7.34 b	28 b
FR : R	4.68 a	5.29 a	55 a
Control	4.61 a	5.33 a	50 a
Significance	**	**	**

**Significant at $P = 0.01$ by analysis of variance. Mean separation in columns by LSD, $P = 0.01$.

Table 3. EOD light treatment effects on internode and petiole lengths of watermelon after 7 days of treatment.

EOD light	Internode length (cm)			Petiole length (cm)		
	No.			No.		
	1	2	3	1	2	3
R	6.27	0.33 a	0.33 a	4.96 a	5.79 a	4.22 a
FR	6.69	1.21 b	0.80 b	7.45 b	10.81 b	7.25 b
FR : R	6.17	0.51 a	0.53 a	5.05 a	6.62 a	5.10 a
Control	6.33	0.65 a	0.48 a	5.26 a	6.72 a	5.68 a
Significance	NS	**	**	**	**	**

NS,**Nonsignificant or significant at $P = 0.01$ by analysis of variance, respectively. Mean separation in columns by LSD, $P = 0.01$.

Table 2. Influence of EOD light on watermelon growth after 7 days of treatment.

EOD light	Biomass (g dry wt)				Shoot : root dry wt	Leaf area (cm ²)	Stem length (cm)
	Leaf	Petiole	Stem	Root			
R	0.383	0.047 a	0.064 a	0.043 a	11.48	115.2	6.93 a
FR	0.466	0.100 b	0.104 b	0.052 b	12.88	132.4	8.69 b
FR : R	0.435	0.054 a	0.065 a	0.042 a	13.19	126.1	7.22 ab
Control	0.440	0.062 a	0.075 a	0.042 a	13.73	125.2	7.46 ab
Significance	NS	**	**	**	NS	NS	*

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively, by analysis of variance. Mean separation in columns by LSD, $P = 0.05$.

Table 4. Influence of EOD light on watermelon growth after 21 days of treatment.

EOD light	Biomass (g dry wt)				Shoot : root dry wt	Leaf area (cm ²)	Stem length (cm)
	Leaf	Petiole	Stem	Root			
R	1.156	0.108 a	0.447	0.105 a	17.50 a	252.9	29.38 a
FR	1.047	0.186 b	0.455	0.059 b	29.82 b	223.6	42.07 c
FR : R	1.191	0.160 ab	0.448	0.090 a	20.47 a	244.5	35.03 b
Control	0.953	0.118 a	0.308	0.069 ab	20.40 a	203.9	34.65 b
Significance	NS	*	NS	**	**	NS	**

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively, by analysis of variance. Mean separation in columns by LSD, $P = 0.05$.

Table 5. EOD light effects on internode lengths of watermelon after 21 days of treatment.

EOD light	Internode length (cm)							
	No.							
	1	2	3	4	5	6	7	8
R	5.54 a	0.74 a	3.40 a	6.34 a	4.33	3.92 a	4.28 a	3.93
FR	13.78 b	2.16 b	6.34 b	9.77 b	5.19	5.48 b	5.76 b	4.77
FR : R	9.00 a	1.88 ab	5.16 ab	7.49 ab	5.48	4.95 ab	4.31 a	3.52
Control	6.10 a	0.66 a	3.82 ab	8.26 ab	5.89	4.95 ab	4.50 a	4.00
Significance	**	*	*	*	NS	*	*	NS

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01 by analysis of variance, respectively. Mean separation in columns by LSD, $P = 0.05$.

Table 6. EOD light effects on petiole lengths of watermelon after 21 days of treatment.

EOD light	Petiole length (cm)							
	No.							
	1	2	3	4	5	6	7	8
R	5.52 a	7.27 a	7.74 a	6.84 a	4.94	3.40	2.68	2.03
FR	7.74 b	10.17 b	10.27 b	9.36 b	5.50	3.87	2.96	1.88
FR : R	5.28 a	6.38 a	6.38 a	6.89 a	5.37	3.79	2.98	2.36
Control	4.96 a	6.42 a	6.42 a	6.10 a	4.26	3.23	2.53	1.60
Significance	**	**	**	**	NS	NS	NS	NS

NS,*,**Nonsignificant or significant at $P = 0.01$ by analysis of variance, respectively. Mean separation in columns by LSD, $P = 0.01$.

plants had less root biomass and greater shoot : root biomass ratios than plants treated with EOD R light. No significant EOD light treatment effects on leaf biomass, stem biomass, and leaf area per plant were recorded. Internodes 1, 2, 3, 4, 6, and 7 were longer in plants treated with EOD FR light than in plants treated with EOD R light (Table 5). EOD FR light-induced lengthening of leaf petioles 1, 2, 3, and 4 was also photoreversible by treatment with EOD R (Table 6).

Increase in the relative shoot : root biomass ratio was a relatively late phytochrome-mediated growth response to EOD FR light treatment in this experiment. More biomass had been allocated to petioles and less to roots after 21 days of EOD FR light treatment, causing a relative increase in shoot : root biomass ratios in such plants. This observation is in agreement with previous research on wheat (Kasperbauer and Karlen, 1986). EOD light treatment had not affected leaf area at any of the days when plants were harvested. These results suggest that leaf area is not under the influence of EOD light treatments and may not be phytochrome-mediated.

Plants that were treated with EOD light for 21 days and then placed in the greenhouse for an additional 2 weeks of growth without EOD light exhibited no residual light treatment effects on partitioned biomass, shoot : root biomass ratios, leaf area per plant, or stem length (data not shown). No residual light

treatment effects on internode lengths were noted, but petioles of leaves 1, 2, 3, and 4 were longer in the EOD FR-treated plants than in EOD R or EOD FR : R-treated plants or in the controls.

Plant photoreceptors have been proposed to have specific, identifiable functions (Smith, 1986). The phytochrome photoreceptor appears to function in perceiving light stimulus as an indicator of particular environmental situations (such as shade) and stimulating metabolic processes that result in growth responses that attempt to maximize plant survival (Holmes and Smith, 1977; Kasperbauer, 1987). Our previous work with tomato (Decoteau et al., 1988) and bell pepper (Decoteau et al., 1990) has indicated that plants treated with EOD FR light had similar growth to those grown in relatively high FR : R light environments. We suggest that the response of watermelon in this experiment to EOD FR (petiole elongation, internode elongation, etc.) would be similar to growth in high FR : R light environments in the field.

In summary, early watermelon plant growth is affected by subtle changes in light quality as perceived by the phytochrome photoreceptor. Growth characteristics that were affected by EOD FR light include petiole elongation, internode elongation, leaf petiole angles, and biomass distribution. This information should be useful in determining survival growth mechanisms of watermelon in response to shade or crowding and may assist in the development of agricultural production practices (e.g., reflective mulches, spectral-wavelength-selective rowcovers) that modify environmental variables, such as light, to generate desirable plant growth responses.

Literature Cited

- Decoteau, D. R., M.J. Kasperbauer, D.D. Daniels, and P.G. Hunt. 1988. Plastic mulch color effects on reflected light and tomato plant growth. *Scientia Hort.* 34:169-175.
- Decoteau, D. R., M.J. Kasperbauer, and P.G. Hunt. 1989. Mulch surface color affects yield of fresh-market tomatoes. *J. Amer. Soc. Hort. Sci.* 114:220-224.
- Decoteau, D. R., M.J. Kasperbauer, and P.G. Hunt. 1990. Bell pepper

- development over mulches of diverse colors. HortScience 25:460-462.
- Holmes, M.G and H. Smith. 1977. The function of phytochrome in the natural environment. IV. Light quality and plant development. Photochem. & Photobiol. 25:551-557.
- Hunt, P. G., M.J. Kasperbauer, and T.A. Matheny. 1989. Soybean seedling growth responses to light reflected from different colored soil surfaces. Crop Sci. 29:130-133.
- Kasperbauer, M.J. 1971. Spectral distribution of light in a tobacco canopy and effects of end-of-day light quality on growth and development. Plant Physiol. 47:775-778.
- Kasperbauer, M.J. 1987. Far-red light reflection from green leaves and effects of phytochrome-mediated partitioning under field conditions. Plant Physiol. 85:350-354.
- Kasperbauer, M.J. 1988. Phytochrome involvement in the regulation of the photosynthetic apparatus and plant adaptation. Plant Physiol. Biochem. 26:519-524.
- Kasperbauer, M.J. and D.L. Karlen. 1986. Light-mediated bioregulation of tillering and photosynthate partitioning in wheat. Physiol. Plant. 66:159-163.
- Metzger, J.D. 1988. Gibberellins and light regulated petiole growth in *Thlaspi arvense* L. Plant Physiol. 86:237-240.
- Morgan, D. C., T. O'Brien, and H. Smith. 1980. Rapid photomodulation of stem extension in light-grown *Sinapis alba* L. Studies on kinetics, site of perception and photoreceptor. Planta 150:95-101.
- Smith, H. 1986. The perception of light quality, p. 187-217. In: R.E. Kendrick and G.H.M. Kronenberg (eds.). Martinus Nijhoff Publishers, The Netherlands.
- Thomas, J.F. and C.D. Raper. 1985. Internode and petiole elongation of soybeans in response to photoperiod and end-of-day light quality. Bet. Gaz. 146:495-500.
- Zack, C.D. and J.B. Loy. 1980. The effect of light quality and photoperiod on vegetative growth of *Cucurbita maxima*. J. Amer. Soc. Hort. Sci. 105:939-945.