Day-long Alterations of the Photomorphogenic Light Environment Affect Young Watermelon Plant Growth: Implications for Use with Rowcovers

Dennis R. Decoteau and
Heather A. Hatt Graham¹

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

SUMMARY. The sensitivity of watermelon [*Citrullus lanatus* (Thumb.) Matsum & Naki 'Sugar Baby'] plant growth to day-long alterations in light quality was determined by exposing plants to light transmitted through broad band wavelength selective filters. Of the three acetate filters analyzed (nos. 19, 27, and 74), filter no. 74 transmitted the least amount of photosynthetic photon flux (PPF) (400 to 700 nm), the smallest red light: far-red light ratio (R:FR) (645:735 nm), and the greatest amount of blue light (400 to 500 nm) radiation from metal halide lamps. Plants grown under filter no. 74 were taller, had elongated petioles, and had a greater amount of petiole and stem biomass than plants grown under the other filters. Spectral transmission properties of commercially available rowcover materials were evaluated for variation of PPF, R:FR, and blue light. Clear polyethylene rowcovers were completely permeable to all

measured (330 to 850 nm) wavelengths of radiation from metal halide lamps. White polyethylene rowcovers were the least permeable of the rowcover materials to wavelengths of radiation with decreases in the PPF, R:FR, and blue light. Spunbonded polyester materials slightly reduced PPF, R:FR, and blue light. Plants grown under white polyethylene and spunbonded materials grew taller (longer stems) than plants grown under the clear polyethylene rowcover. Petiole lengths were generally longer for plants grown under white polyethylene. Our results suggests that alterations in the R:FR and blue light due to selected wavelength transmission through commercially available rowcover material alter early watermelon growth.

Plants respond to radiant energy, independent of the uses for photosynthesis, as an indication of the growing environment and for adjusting plant growth (Decoteau et al., 1996). Plant response to the light environment and subsequent adjustment of plant growth and development is termed photomorphogenesis. Photomorphogenesis involves the activation of several receptor (pigment) systems (Senger and Schmidt, 1994). These pigment systems include phytochrome, which absorbs red (R) light (660 to 680 nm) and far-red (FR) light (730 to 740 nm), "cryptochrome", which absorbs UV-A and blue light (400 to 500 nm), and a UV-B receptor (290 nm).

Plant processes that are photomorphogenic include internode elongation, chlorophyll development, flowering, abscission, lateral bud outgrowth, and root and shoot growth. For example, tobacco plants grown with smaller R:FR ratio (R:FR) had longer stems and more axillary shoots (Kasperbauer, 1971), and wheat plants had smaller shoot relative to root biomass (Kasperbauer and Karlen, 1986) than plants grown with greater relative amounts of R:FR. Also, day-long exposures from light sources with varying emission spectrums (including R:FR and blue light) affected plant growth of lettuce and marigold (Krizek and Ormrod, 1980) and lettuce, spinach, mustard, and wheat (Tibbitts et al., 1983).

Using rowcovers for field production of fruits and vegetables increases air and soil temperatures around

the plant (Bonanno and Lamont, 1987; Reed et al., 1989), protects plants from frost damage (Hochmuth et al., 1986; Miller, 1989), excludes insects and diseases (Natwick and Laemmle, 1989), and reduces wind stress (Wells and Loy, 1985). These factors contribute to greater early season production and yields for many vegetable crops including tomato (McCraw, 1986) and watermelons (Miller, 1989). Rowcovers also affect the plant light environment due to selective wavelength transmittance through the cover material (Friend and Decoteau, 1990), condensation on the material (Morison et al., 1989), or both. While reductions in photosynthetic active radiation (PAR) using rowcovers have been reported (Albright et al., 1989; Wells and Loy 1985; Wolfe et al., 1989), to our knowledge, the effects of rowcovers on photomorphogenic light (i.e., R, FR, and blue light) and resulting plant growth are not known.

Our objectives were 1) to establish that the alterations in photomorphogenic light (R:FR and blue light) affects early watermelon growth and 2) to determine if alterations in the R:FR and blue light due to selected wavelength transmission through commercially available rowcover material are sufficient to affect early watermelon growth in a controlled temperature environment.

Materials and methods

YOUNG WATERMELON PLANT SENSITIVITY TO DAY-LONG ALTERATIONS OF LIGHT TRANSMITTED THROUGH BROAD BAND ACETATE FILTERS. Watermelon ('Sugar Baby') seeds were sown into 400-mL pots (one plant/pot and replicate and six replicates/treatment) containing a commercial potting mix (Fafard Soilless Mix No. 3; Fafard, Anderson, S.C.) and were placed in a controlled environment room for seed germination and plant growth. The controlled environment room was equipped with metal halide lamps (Philips Lighting Co., Somerset, N.J.) that provided 250 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ during a 14-h photoperiod with a 27 °C day/21 °C night.

Three broad band Roscolux (Rosco, Port Chester, N.Y.) acetate filters (no. 19, Fire; no. 27, Medium red; and no. 74, Night blue) were used to determine if day-long exposure to light quality transmitted through these materials affected mor-

Department of Horticulture, Box 340375, Clemson University, Clemson, SC 29634-0375.

Technical contribution no. 4224 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.

¹Current address: P.O. Box 307, Calhoun, LA 71225.

phogenic development of young watermelon plants. These filters were chosen because the manufacturer's specifications indicated that they had varying spectral transmittance properties of photosynthetic photon flux (PPF), R:FR, and blue light.

The amount and quality of light transmitted through each acetate filter was measured using a spectroradiometer (model 1800; LI-COR, Lincoln, Neb.) with a remote light collector on a 1.5-m fiber optic probe. Transmitted light from the metal halide lamps of the plant growing room was measured 2.5 cm below one sheet of material. PPF (400 to 700 nm), R:FR (645:735 nm), and blue light (400 to 500 nm) were calculated from spectral outputs. Spectral irradiance at 645 and 735 nm (the peaks for phytochrome action spectra in green plants) was used to calculate the R:FRs (Kasperbauer et al., 1964). Preliminary experiments indicated that transmission properties of the filters did not differ significantly from day to day. Results, therefore, are presented from a representative day and are expressed as percent transmitted light relative to the metal halide lamp emission.

Seven days after seeding, the acetate filters were placed horizontally on supports 46 cm above the plants (measured from soil surface to the filter) in each treatment. Only one filter (50 × 50 cm)/support was used, and each filter represented a treatment. The treatments were spaced ≈ 1.5 m apart. The metal halide lamps were raised or lowered so that transmitted light intensity through the acetate filters at the soil surface of the pots was 125 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Lateral air movement was not hindered across plants and treatments, and there were no significant differences in ambient temperatures at the foliage level among the treatments. Spacing of plants within treatments was 15 × 15 cm. Plants were randomized within treatments daily at watering.

After 3 weeks of treatments, petiole lengths of true leaves (counted from the cotyledons), internode lengths, and stem length were measured with a caliper equipped with a micrometer. Leaf areas were measured with a area meter (model 3100; LI-COR), and dry mass of leaves, petioles, and stems were determined after drying at 70 °C.

Data were analyzed using the

analysis of variance (general linear models program) of the Statistical Analysis System (SAS Institute, Cary, N.C.) and least significant difference values were calculated for use in multiple comparison of treatment means.

YOUNG WATERMELON PLANT SENSITIVITY TO DAY-LONG ALTERATION OF TRANSMITTED LIGHT THROUGH SELECTED ROWCOVER MATERIALS. White and clear polyethylene (0.04 mm) and spunbonded fabric (Ken-Bar, Reading, Mass.) rowcover materials were evaluated in a controlled temperature environment to determine if light transmitted through these materials was altered to influence early watermelon growth. These rowcover materials were chosen because they had been previously reported to vary in spectral transmission properties (Friend and Decoteau, 1990). Plant growing conditions, measurement of the spectral transmittance properties of the materials, light filtered treatment initiation and conditions, determination of growth measurements, and statistical design and analysis were the same as in acetate filter evaluations.

Results and discussion

Broad band wavelength selective filters altered the light environment, which affected plant growth in a controlled temperature environment. Radiation filtered through the no. 74 filter had the smallest R:FR (40% relative to metal halide lamp emission) and the greatest amount of blue light (31%) of the filters tested (Table 1). This light environment stimulated elongation of internodes 1 and 2, total stem length, and petioles from leaves 1 and 2 (Table 2) and increased stem dry mass (Table 3). The plants grown with radiation filtered through the no. 19 filter (which had low amounts of blue light and the greatest PPF and R:FR) had the shortest internode 1 and stem length and the greatest leaf and root dry mass. Internode 2 and petioles from leaves 1 and 2 were comparable in length for plants grown under acetate filter nos. 19 and 27. Although biomass partitioning was different for plants grown under nos. 19 and 74 filters, total plant biomass was equivalent. Biomass partitioning was affected

Table 1. Spectral transmittance properties of Roscolux acetate filters and rowcover materials as a percentage of irradiance from metal halide lamps of the growth room.

Treatment	Transmitted light (% relative to metal halide lamp emission ^a)		
	PPF ^b	Blue	R:FR ^c
Acetate filter (no.)			
19	36	7	100
27	16	6	65
74	13	31	40
Rowcover material			
Clear polyethylene	100	100	100
Spunbonded fabric	93	90	97
White polyethylene	52	41	86

^aThe metal halide lamp emission for the acetate filter evaluation was 330 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetically active radiation (PAR), 19 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ blue light, and 2.9 R:FR; for the row cover materials, evaluation was 238 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PAR, 14 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ blue light, and 2.9 R:FR.

^bPPF = photosynthetic photon flux, R:FR = red light : far-red light.

Table 2. Influence of exposure to light from metal halide lamps transmitted through Roscolux acetate filters for 3 weeks on internode and petiole growth of watermelons.

Acetate filter (no.)	Internode length (cm)		Stem length (cm)	Petiole length (cm)	
	1	2		Leaf 1	Leaf 2
19	0.3 c ^d	0.9 b	14.3 c	3.6 b	3.6 b
27	3.8 b	1.9 b	18.1 b	4.0 b	3.7 b
74	8.4 a	4.9 a	27.6 a	5.9 a	4.6 a

^dMean separation within columns by least significant difference at $P \leq 0.05$.

by varying light characteristics, which may affect subsequent fruit yields (Decoteau et al., 1990).

Rowcovers allow the transmission of radiant energy from the sun and the accumulation of thermal radiation within the rowcover environment (Albright et al., 1989). Our results suggest that rowcovers also affect the plant light environment by acting as selective light filters. The amount of light filtering by the rowcover is influenced by the material used and can range from no variation in spectral distribution using clear polyethylene to reduction in the amounts of PPF and R:FR using white polyethylene (Table 1). The white polyethylene rowcover decreased PPF and blue light by 48% in contrast to metal halide emission. The white polyethylene decreased R:FR by 14%. The spunbonded rowcover decreased the PPF and blue light by $\approx 10\%$ in contrast to metal halide lamps. The R:FR was decreased by 3% with spunbonded material.

Light transmitted through rowcover materials with the same intensity but with varying spectral distributions affected lengths of stem and leaf petioles of watermelon seedlings. Stems of plants grown under materials that transmitted smaller amounts of R:FR (white polyethylene and spunbonded fabric) were longer than the stems of plants grown under clear polyethylene (Table 4). These plant responses are consistent with media-

tion by phytochrome (Decoteau et al., 1990). Petioles of leaves 1, 2, 3, and 4 from plants grown the white polyethylene were generally longer than the corresponding petioles of leaves from plants grown under the spunbonded and under the clear polyethylene. Leaf area and plant biomass were not affected by rowcover treatments (data not shown).

While phytochrome mediated plant responses (such as petiole and internode elongation with reduced R:FR) could be implicated with the selective wavelength transmission through rowcover materials, other plant responses, such as phototropism, chloroplast development, and stomatal closure, have been attributed to activation by radiation in the blue portion (400 to 500 nm) of the electromagnetic spectrum (Senger and Schmidt, 1994). Alterations in the blue light may be affecting plant growth under rowcovers. Unfortunately, our knowledge on the action or even isolation of this hypothesized pigment ("cryptochrome") that is activated by blue light is not as advanced as it is for phytochrome. In addition, some of the plant's responsiveness to blue light may be attributed to perception and activation of phytochrome in these wavelengths (Mohr et al., 1984).

The desirability of plant growth modifications using rowcovers will depend on the crop and growing environment. For example, longer stems

may not be desirable for crops that may be susceptible to lodging after the removal of the rowcover. We do not know if the plant growth modification associated with altered light environments during rowcover use will affect subsequent fruiting, but previous research has indicated that an altered light-quality environment during the transplant production, regardless of observed effects on seedling development before transplanting to the field, affects subsequent growth but not fruiting of peppers (Graham and Decoteau, 1995).

Recommendations

The ability of rowcovers to modify ambient temperatures around plants will continue to be the primary reason for selecting rowcover materials. However, our results in a controlled temperature setting suggest that modifying the plant light environment using rowcover materials may affect plant growth. Future research should be directed at determining if the altered light environment using rowcovers affects photomorphogenic plant growth in a field setting. We suggest that the influence of rowcover material on spectral transmission (especially as it relates to photomorphogenic growth) should be considered in the development, evaluation, and selection of rowcover materials.

Literature cited

- Albright, L.D., D. Wolfe, and S. Novak. 1989. Modeling rowcover effects on microclimate and yield: II. Thermal model and simulations. *J. Amer. Soc. Hort. Sci.* 114:569-578.
- Bonanno, A.R. and W.J. Lamont, Jr. 1987. Effect of polyethylene mulches, irrigation method, and rowcovers on soil and air temperature and yield of muskmelon. *J. Amer. Soc. Hort. Sci.* 112:735-738.
- Decoteau, D.R., M.J. Kasperbauer, and P.G. Hunt. 1990. Bell pepper plant development over mulches of diverse colors. *HortScience* 25:460-462.
- Decoteau, D.R., S.B. Wilson, C.L. Ray, and H.A.H. Graham. 1996. A plant physiologist's view of the perception of light and color by plants. *Proc. Natl. Agr. Plastics Congr.* 26:158-163.
- Friend, H.H. and D.R. Decoteau. 1990. Transmission properties of selected rowcover materials and implications in early plant development. *Proc. Natl. Agr. Plastics Congr.* 22:1-6.

Table 3. Influence of exposure to light from metal halide lamps transmitted through Roscolux acetate filters for 3 weeks on biomass distribution of watermelons.

Acetate filter (no.)	Dry mass (g)				
	Stem	Petiole	Leaf	Root	Total
19	0.024 b ^a	0.009 ab	0.084 a	0.006 a	0.123 a
27	0.026 b	0.008 b	0.053 b	0.004 ab	0.090 b
74	0.038 a	0.012 a	0.067 ab	0.003 b	0.120 ab

^aMean separation within columns by least significant difference at $P \leq 0.05$.

Table 4. Influence of exposure to light from metal halide lamps transmitted through row cover materials for 1 week on stem and petiole growth of watermelons.

Row cover materials	Stem length (cm)	Petiole length (cm)			
		Leaf			
		1	2	3	4
Clear polyethylene	11.6 b ^a	3.6 ab	4.5 ab	5.1 b	3.1 b
Spunbonded fabric	16.3 a	3.4 b	4.2 b	5.0 b	4.4 ab
White polyethylene	14.7 a	3.9 a	4.8 a	5.4 a	5.1 a

^aMean separation within columns by least significant difference at $P \leq 0.05$.

- Graham, H.A.H. and D.R. Decoteau. 1995. Regulation of bell pepper seedling growth with end-of-day supplemental fluorescent light. *HortScience* 30:487-489.
- Hochmuth, G.J., S.R. Kostewicz, S.J. Locascio, E.E. Albreghts, C.M. Howard, and C.D. Stanley. 1986. Freeze protection of strawberries with floating rowcovers. *Proc. Fla. State Hort. Soc.* 99:307-311.
- 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., H.A. Borthwick, and S.B. Hendricks. 1964. Reversion of phytochrome 730 (Pfr) to P600 (Pr) assayed by flowering in *Chenopodium rubrum*. *Bot. Gaz.* 125:75-80.
- Kasperbauer, M.J. and D.L. Karlen. 1986. Light-mediated bioregulation of tillering and photosynthetic partitioning in wheat. *Physiol. Plant.* 66:159-163.
- Krizek, D.T. and D.P. Ormrod. 1980. Growth response of 'Grand Rapids' lettuce and 'First Lady' marigold to increased far-red and infrared radiation under controlled environments. *J. Amer. Soc. Hort. Sci.* 105:936-939.
- McCraw, D. 1986. Rowcovers increase earliness, yield and value of fresh market tomatoes. *Proc. Natl. Agr. Plastics Cong.* 19:348-356.
- Miller, G.A. 1989. Rowcover effects on harvest date of watermelons. *Proc. Natl. Agr. Plastics Cong.* 21:123-126.
- Mohr, H., H. Drumm-Herrel, and R. Oelmüller. 1984. Coaction of phytochrome and blue/UV light photoreceptors, p. 13-42. In: H. Smith and M.G. Holmes (eds.). *Techniques in photomorphogenesis*, Academic Press, London.
- Morison, J.I.L., W.T. Green, and P. Hadley. 1989. Energy exchange by plastic rowcovers. *Proc. Natl. Agr. Plastics Cong.* 21:269-275.
- Natwick, E.T. and F.F. Laemmle. 1989. Selected rowcover materials: Insect exclusion, virus disease suppression and yield enhancement. *Proc. Natl. Agr. Plastics Cong.* 21:288-296.
- Reed, G.L., G. Clough, D.E. Hemphill, Jr., and R.C. Wilson. 1989. The effect of slit, perforated and net rowcovers on mulched soil and crop temperatures and periodicity of muskmelon yield. *Proc. Natl. Agr. Plastics Cong.* 21:116-122.
- Senger H. and W. Schmidt. 1994. Diversity of photoreceptors, p. 301-322. In: R.E. Kendrick and G.H.M. Kronenberg (eds.). *Photomorphogenesis in plants*. 2nd ed. Kluwer Acad. Publ., The Netherlands.
- Tibbitts, T.W., D.C. Morgan, and I.J. Warrington. 1983. Growth of lettuce, spinach, mustard, and wheat plants under combinations of high-pressure sodium, metal halide, and tungsten halogen lamps at equal PPFD. *J. Amer. Soc. Hort. Sci.* 108:622-630.
- Wells, O.S. and J.B. Loy. 1985. Intensive vegetable production with rowcovers. *HortScience* 20:822-826.
- Wolfe, D.W., L.D. Albright, and J. Wyland. 1989. Modeling rowcover effects on microclimate and yield: I. Growth response of tomato and cucumber. *J. Amer. Soc. Hort. Sci.* 114:562-568.