Leaf Epinasty Induced by Reflection of Light from Beneath Marigold Plants

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Abstract. The cotyledons of marigold, *Tagetes erecta* L., developed epinasty when reflective surfaces were maintained under the seedlings. Plain aluminum foil or white-painted foil induced up to 360° curvature as the cotyledons extended, whereas no epinasty occurred over the exposed surface of potting mix or black-painted foil. A gray-painted foil induced intermediate epinasty. Dry-weight accumulation of the seedlings was not significantly affected by the epinasty.

We have observed epinasty of cotyledonary leaves on seedlings developing in controlled environments. This response is associated with the use of reflective coverings over the medium to reduce evaporative water loss. Epinasty occurred when white foam plugs were utilized to support lettuce (*Lactuca sativa* L.) seedlings in nutrient-culture studies. The cotyledons developed epinasty during each light period and then regained a horizontal orientation during each dark period (authors' observation). We observed an apparent related epinastic response in tomato (*Lycopersicon esculentum* Mill.) plants growing in containers widely-spaced on a flooded greenhouse bed in Naaldwijk, Netherlands. Several true leaves developed severe epinasty. The water apparently reflected sunlight unto the lower surfaces of the leaves. This study was undertaken with marigolds, *Tagetes erecta* L., to quantify the epinastic response of leaves to varying levels of reflectivity and to determine if epinasty inhibited dry-weight accumulation.

Materials and Methods

Experiments were conducted with the marigold cultivar *Petite Gold*, since this plant develops long, narrow cotyledons that have a high degree of epinasty when subjected to reflected light. Six seeds were planted in each pot containing 50 peat : 50 vermiculite (v/v) potting mix. In order to encourage hypocotyl elongation and thus avoid inhibition of downward curvature of the cotyledons, additional potting mix was added over the seeds to produce a convex mound ≈2-cm high that extended above the rim of the pot. The contain-

ers were placed in a growth chamber with a lamp barrier (model M-3; Environmental Growth Chambers, Chagrin Falls, Ohio). Temperature was maintained at 23 ± 1 °C and photosynthetic photon flux (PPF) was provided continuously (no dark period) at 170 ± 5 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ with cool-white fluorescent lamps. The containers were watered to excess with a modified 1/2× Hoagland's nutrient solution (Hammer et al., 1978) four times each day.

Two experiments were conducted with different types of painted coverings. In the first experiment, 7.6-cm-diameter (0.20-L) plastic pots were covered either with unpainted aluminum foil or with foil sprayed with flat-black

enamel (Effecto B66; Pratt & Lambert, Buffalo, N.Y.). In the second experiment, 8.9-cm-diameter (0.25-L) pots were covered with aluminum foil painted with a 40:60 mixture of flat black and glossy white acrylic automobile paint to produce a gray, glossy color; others with black only; and others with white paint only. Four containers of each treatment were prepared in each experiment.

Seedlings emerged on day 4 after planting in both experiments. The mounded medium was then removed, exposing 2 cm of hypocotyl. The plants were thinned to one uniform-sized plant per container. The media surface coverings were applied around the seedlings on day 5 after planting just as the cotyledons began unfolding. After placement of the coverings, the PPF reflected from the coverings was measured with a model LI-190 quantum sensor (LI-COR, Lincoln, Nebr.) mounted in a holder that was directed toward the center of the container surface. The sensor was positioned at a 45° angle to the surface of the covering, 10.0 cm above and 2.5 cm out from the edge of the container. Thermocouples were used to record temperatures 0.5 cm below the surface of the medium.

On day 13 after seeding in both experiments, the seedlings were photographed (Fig. 1) and then harvested. The extent of epinasty was determined by visually scoring each leaf according to the following scale: 1.0 = no epinasty with cotyledons horizontal (Fig. 1C); 1.5 = observable epinasty (Fig. 1D); 2.0 = curved downward with the tip 45° from horizontal (Fig. 1E); 2.5 = curved down-

Fig. 1. Effects of covering the growth medium with aluminum foil sprayed with various reflective paints on curvature of marigold cotyledons. (A) Nonpainted foil; (B) white foil; (C) uncovered soil; (D) black foil; (E) gray foil.

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ward with tip 90° from horizontal; 3.0 = curved 180° with tip inverted and pointed horizontally (Fig. 1 A and E); 3.5 = curved 360° with tip curled back to initial horizontal orientation (Fig. 1B); 4.0 = curved with tip curled 540° or more from initial horizontal orientation.

The dry weight of the cotyledon pairs from each plant in the second experiment was obtained after drying in a forced-air oven at 70 °C for 48 h.

Results and Discussion

Epinasty became apparent on the third day after covers were applied. Day 4 was critical, for no further epinasty developed thereafter.

Epinasty of the cotyledons increased with increasing light reflected from the covering materials (Table 1), reaching a maximum on seedlings developing over either unpainted aluminum foil or white-painted aluminum foil (Fig. 1 A and B). The average epinastic response of the cotyledons was between 90° and 180°, but the tips of some cotyledons made a complete 360° curvature (Fig. 1B). The cotyledons of seedlings without coverings (Fig. 1C) or with black-painted coverings (Fig. 1D) were nearly horizontal. Cotyledons developing over gray coverings (40% black : 60% white mixture) were intermediate in curvature (Fig. 1E), epinasty was variable, and frequently one cotyledon would be nearly horizontal while the other would have a high degree of epinasty.

Medium temperature varied with the type of covering. The exposed medium was coolest,

and that under the black-painted covering was 2 °C warmer in both experiments (Table 2). The temperature of the medium under the white covering was 1 °C warmer and under unpainted-aluminum foil only 0.2 °C warmer than the exposed medium.

Differences in temperature of the medium can be attributed to the reflectivity of the coverings, for, as reflectivity decreased, a larger amount of the incident *PPF* was absorbed; this heated the covering, which radiated and conducted heat to warm the medium. The lower soil temperature of the uncovered medium, which was quite dark in color, can be attributed to the evaporation of water from the moist surface, causing a cooling that offset the heating effect of the absorbed radiation. Thus, there was no evidence for a correlation between medium temperature and the extent of epinasty. The coolest medium, uncovered soil, and the warmest medium, under the black painted covering, both produced no significant epinasty. Although leaf temperatures were not taken, this factor was apparently nonsignificant, for cotyledons enlarging over black covers would have been the warmest and those over the exposed soil would probably have been the coolest, yet neither exhibited significant epinasty.

Dry weight of the cotyledons did not differ significantly among treatments (Table 2), even though epinasty should have reduced the incident *PPF* absorbed by the epinastic cotyledons. However, cotyledons exhibiting epinasty apparently absorbed sufficient *PPF* reflected from the coverings to offset this.

Leaf epinasty did not continue on successive developing leaves of marigolds, probably the leaves provided sufficient shading to minimize the intensity of reflected light from the surface of the media. In contrast, downward bending of leaf blades about the midrib occurred on successive developing leaves of lettuce (*Lactuca sativa* L.) plants just after respacing and transplanting into light-colored reflective foam sheets (personal communication, David De Villers).

The physiological mechanisms for the epinasty were not studied, but extensive research with phototropic movement of leaves and stems has demonstrated that light causes a redistribution of auxin, causing unequal growth of cells on opposite sides of the organs (Salisbury and Ross, 1992).

Although this study was limited to investigating a response of plants growing in controlled experiments, there are other situations in which plants may be exposed to reflected light and leaf epinasty may be observed. The use of reflective plastic mulches or light-colored, reflective soils may induce epinasty on young seedlings. Also, lights often are used to highlight plants growing indoors. Lamps located so as to illuminate the undersurface of the leaves, may cause epinasty in species that are growing rapidly.

Epinasty from undersurface lighting may be very species-specific; in studies with within-canopy lighting of potatoes (*Solanum tuberosum*, L.) and cowpeas [*Vigna unguiculata* (L.) Walp.], the leaves of potatoes did not exhibit any observable epinasty (Tibbitts et al., 1994), whereas the primary and trifoliate leaves of cowpeas became reoriented so that their adaxial sides were exposed to the brightest source of intracanopy lighting (Frantz et al., 1998; and Cary Mitchell, personal communication). We hope that this report will generate further research to establish wavelength sensitivity, possible phytochrome involvement, and the varied responses of different species.

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Table 1. Curvature of marigold cotyledons after 5 d of growth over coverings with varied amounts of reflected *PPF*.

Covering		Expt. 1		Expt. 2	
Type	Paint black : white	<i>PPF</i> reflection (%)	Cotyledon curvature ^a	<i>PPF</i> reflection (%)	Cotyledon curvature ^a
None	None	8.1	1.1 a ^y	8.4	1.0 a ^y
Al foil	100:0	8.9	1.4 a	7.1	1.1 a
Al foil	40:60	---	---	20.0	1.7 a
Al foil	0:100	---	---	42.7	2.7 b
Al foil	None	54.2	3.1 b	---	---

^aScale: 1 = no epinasty, and 4 = maximum epinasty as outlined in the text.

^yMean separation within columns by Duncan's multiple range test, *P* ≤ 0.05.

Table 2. Effects of medium covering on medium temperature and on dry weight of cotyledons.

Covering		Expt. 1	Expt. 2	Expt. 1
Type	Paint black : white	Temperature of medium (°C)		Cotyledon dry wt (mg)
None	None	21.7 a ^a	23.2 a ^a	1.22 a
Al foil	100:0	24.1 c	25.1 d	1.18 a
Al foil	40:60	---	24.9 c	1.31 a
Al foil	0:100	---	24.2 b	1.33 a
Al foil	None	22.9 b	---	---

^aMean separation within columns by Duncan's multiple range test, *P* ≤ 0.05.