Dose and Timing of Brushing to Control Excessive Hypocotyl Elongation in Cucumber Transplants

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ADDITIONAL INDEX WORDS. **stretching, mechanical conditioning, height control, *Cucumis sativus***

SUMMARY. Brushing is an effective method to control hypocotyl elongation in cucumbers (*Cucumis sativus* L. 'Turbo') grown in plug trays for transplanting. The amount of daily brushing and the number of days to brush for best performance was determined. Treatment with 10 strokes per day for the 4 days of maximal hypocotyl elongation was sufficient to reduce final hypocotyl length by 25%. More brushing did not meaningfully reduce elongation further. Inhibition of dry weight gain, which is detrimental, was minor (<10%) compared with the height control achieved. Despite seasonal differences in absolute elongation, the effects of brushing were the same.

Stretching is the excessive elongation of stems during the production of high-density transplants. Overly long stems make transplants susceptible to injury during handling and after transplanting. Mechanical stimulation has been successfully applied to control stretching and improve posttransplant performance in cucumbers (Latimer and Beverly, 1994), squash (*Cucurbita pepo*

L.) (Latimer and Beverly, 1994), tomatoes (*Lycopersicon esculentum* Mill.) (Garner and Björkman, 1996; Latimer and Beverly, 1993; Latimer and Thomas, 1991), eggplant (*Solanum melongena* var. *esculentum* L. Nees.) (Baden and Latimer, 1992) aster [*Callistephus chinensis* (L.) Nees], petunia (*Petunia* Juss.) (Autio et al. 1994) and pansies (*Viola tricolor* L.) (Garner and Langton, 1997). Brushing is the preferred method for mechanical conditioning (Latimer, 1998). Transplant growers in the northeastern U.S. frequently request information from extension about using this technique to control hypocotyl elongation in cucumbers. For this crop, there is no dose recommendation available. The minimum treatment to obtain height control is the economically important parameter. Also, the treatment must avoid injury, which can occur in cucumbers (Latimer et al., 1991). The detrimental side effects of mechanical treatment can be limited if the minimum effective stimulation is applied (Garner and Björkman, 1996). This paper reports the conditions that produce the optimal height control of cucumbers with the minimum treatment and injury.

Materials and methods

CONDITIONS FOR PLANT GROWTH. 'Turbo' cucumber seeds were sown in a peat-vermiculite growing medium (Boodley and Sheldrake, 1977) containing 0.35N–0.15P–0.15K kg·m⁻³ (0.6N–0.26P–0.25K lb/yd³). The plastic 50-cell plug flats (Landmark, Akron, Ohio) had cells were 44 mm (1.75 inches) square and 66 mm (2.5 inches) deep holding 66 mL (4 inches³). Nondwarf hybrid varieties like Turbo are especially prone to stretching. The plants were raised in a greenhouse without supplemental lighting, with two sowing dates: 9 and 28 Apr. 1998. The second planting grew when the risk of stretching is highest due to frequent high temperatures and cloudy days. The greenhouse temperature was maintained at a minimum of 18/22 °C (65/73 °F) (night/day). The daytime maximum was higher, up to 32 °C (90 °F) on sunny days. Plants were irrigated each morning and, if necessary, in the afternoon. Supplemental fertilization was included with the irrigation on days 7, 14, and 18 using soluble fertilizer at 100N–44P–83K ppm. Plants were grown for 7 d, until

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The skilled technical assistance of Karen Pearson is gratefully acknowledged. This research was supported by Hatch project NY.G623-512. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper must hereby be marked *advertisement* solely to indicate this fact.

Fig. 1. Effect of the number of daily strokes on hypocotyl elongation in cucumber seedlings. The treatments were applied for 10 d. Open circles = early-season trial [100% = 63 mm (2.5 inches)]. Closed circles = late-season trial [100% = 117 mm (4.6 inches)]. Points with different letters are significantly different by Tukey's pairwise comparisons test ($P < 0.05$). Bars are the standard error of the mean; $n = 4$ flats.

Fig. 2. Effect of the duration of brushing treatments on hypocotyl elongation in cucumber seedlings. The seedlings were brushed with 10 strokes per day. Open circles = early-season trial [100% = 74 mm (2.9 inches)]. Closed circles = late-season trial [100% = 117 mm (4.6 inches)]. Points with different letters are significantly different by Tukey's pairwise comparisons test ($P < 0.05$). Bars are the standard error of the mean; $n = 4$ flats.

the cotyledons had unfolded before being brushed the first time. This is the earliest that the canopy is uniform enough for brushing.

EXPERIMENTAL TREATMENTS. Brushing was performed by stroking back and forth with a near-vertical piece of Styrofoam held gently to cause the tops of the plants to move ≈ 2 cm (1 inch) sideways. The experimental units were flats of 50 seedlings. There were four flats per treatment with all the

flats distributed in a completely randomized design on the greenhouse bench. The experiment to determine the effect of daily intensity of brushing consisted of 0, 5, 10, or 20 strokes applied each morning for 10 days. The experiment to determine the effect of duration of brushing treatment consisted of treating the plants with 10 strokes/d for 0, 2, 4, 6, 8, and 10 d, all beginning on the same day. The plants were harvested 12 d after brushing began, at which time hypocotyl elongation was complete.

For the intensity experiment, the cotyledon length, leaf length and dry mass were measured on 10 seedlings per flat. In addition, the lengths of 15 hypocotyls per flat were measured. A calibration curve was created for cotyledon and leaf area using an Agvision leaf area meter (Decagon Devices, Pullman, Wash). For cotyledons, area = $0.43 \times \text{length}^2$, and for leaves, area = $0.90 \times \text{length}^2$. For the duration experiment, the hypocotyl length was measured on 10 randomly selected seedlings per flat each day. At the end of the experiment, cotyledon length and leaf length of 10 seedlings and the dry mass of 20 shoots were measured for each flat.

Hypocotyl elongation responded nonlinearly to treatment intensity and duration ($P < 3\%$), so Tukey's pairwise comparisons were used to indicate significant differences in hypocotyl length. The statistical analysis for possible detrimental effects (reduced leaf or cotyledon length, or reduced dry mass) consisted of determining whether the treatment had a significant negative effect on the response using simple linear regression. There was no interaction between trials, so the tests were performed on the pooled data with trials as a blocks.

Results and discussion

DAILY BRUSHING INTENSITY. Stretching was maximally inhibited by 10 strokes/d (Fig. 1). As with tomatoes (Garner and Björkman, 1996), elongation is highly responsive to small doses of mechanical stimulation, while further increasing the daily dose had no effect.

BRUSHING DURATION. Hypocotyls were progressively shorter with a greater number of days that the seedlings were brushed. The first 4 d had the greatest effect (Fig. 2). Hypocotyl elongation follows a sigmoidal pattern

(Fig. 3), so elongation is best inhibited during the rapid elongation phase, which lasts ≈ 7 d. Therefore, brushing should begin as soon as the cotyledons have unfolded and before the first leaf begins to expand. Continuing brushing after hypocotyl elongation has ceased has no value for producing short-stemmed transplants. Elongation ceased by the time the second leaf was visible (day 10 on Fig. 3). Thus, the effective period for brushing is ≈ 6 to 8 d long. Nearly the full effect can be obtained by brushing on 4 of these days.

DETRIMENTAL EFFECTS. Leaf area was not markedly affected by this mechanical treatment. Reduction of leaf or cotyledon area would reduce the amount of photosynthetic area, thereby reducing the transplant's potential for carbon assimilation. The treatment is applied directly to the cotyledons and, later, the first leaf. Therefore a reduction in size might be expected. The comparison was made in both early and late experiments, as well as in duration and intensity experiments.

Linear regression showed a small but significant ($P < 0.05$) reduction in cotyledon and leaf length as well as biomass in response to increasing the daily dose (Fig. 4a and c). From the regression equation, a dose of 10

Fig. 3. Stem elongation of cucumber hypocotyls while receiving brushing treatment (25.4 mm = 1.0 inch). The legend indicates the duration of the brushing treatment. A heavy line is used to indicate the last day of brushing for individual curves. The standard error is indicated by the vertical line in the upper right corner. These data are from the late trial, the early trial had qualitatively the same response.

Fig. 4. Detrimental effects of brushing on cucumber seedlings. Effect of daily intensity of brushing (a and c) and the number of days treated (b and d) on the length (25.4 mm = 1.0 inch) of cotyledons and first leaf (a and b) and on shoot dry weight (28,350 mg = 1.0 oz) (c and d). All data were collected 11 d after the first brushing treatment. Vertical bars are the standard error.

strokes/d is predicted to make the cotyledons 4% shorter, the leaves 10% shorter and the plants 12% lighter at 19 d. The response to increasing treatment duration was similar, though most of the difference was between controls and any treatment (Fig. 4b and d). The leaf length was affected by brushing that occurred when that leaf was <5 mm (0.4 inches) long (before day 4). Surprisingly, additional brushing while the leaf was expanding had no further effect (Fig. 4b). A duration of 6 d is predicted to make the cotyledons only 3% shorter, the leaves 7% shorter and the plants 9% lighter. The undesirable growth inhibition was consistently smaller than the 25% reduction in hypocotyl length obtained by brushing.

Plant damage occurred only in the 20-stroke/d treatment, and it was rare. In this treatment, 5% of the seedlings tipped over, though the hypocotyls did not break. This malady ap-

peared to affect only seedlings with a poorly developed radicle. There was no damage in other treatments.

Undesirable side effects have been reported with greater treatment intensity. Cucumber transplants treated with 80 strokes/d at a comparable growth stage showed a similar reduction in stem length, but leaf area was reduced by 30% to 40% and dry weight by 15% to 25% (Latimer and Beverly, 1994). The same treatment, begun once the second true leaf was visible, still reduced leaf area, dry weight and subsequent yield (Latimer et al., 1991). The treatment indicated in the present paper is only 1/24 as much; only hypocotyl elongation was meaningfully inhibited. No damage to the seedlings should occur with the optimal dose of 10 strokes.

The response to varying the amount of brushing in cucumbers was qualitatively similar to that in tomatoes (Garner and Björkman, 1996), aster and petunia (Autio et al., 1994). I expect it to be similar in all rapidly elongating stems that are prone to stretching. The common features are that the response to increasing the daily dose is easily saturated, and the minimum daily dose to saturate the response is mild. In addition, the response is greater when plants are brushed for more days. Further evidence of a consistent response to brushing is that the best brushing regimen

for cucumber transplant production was the same in the two trials, even though longer, warmer days made the seedlings in the later trial nearly twice as tall.

These results indicate that the optimal brushing treatment to limit stretching in cucumber transplants is to begin brushing when the cotyledons have unfolded, and to apply 10 strokes each morning for the following 6 d. This optimal treatment should reduce elongation ≈25% with no detrimental effect.

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