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Using Impedance for Mechanical Conditioning of Tomato Transplants to Control Excessive Stem Elongation

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Abstract. **Mechanical stimulation is known to control excessive stem elongation in high-density tomato (*Lycopersicon esculentum* Mill.) transplants. Mechanical stimulation using physical impedance provided height control equivalent to that obtained using brushing. Low-cost materials can be used to apply the impedance. Mylar film in a plastic frame was equivalent to expensive acrylic sheets in its effect on plant height (40 mm shorter than nontreated, a 40% reduction in the elongation rate during the treatment period), stem diameter (18% thicker), and biomass (14% lighter) when they applied a pressure of 66 N·m^{-2}. Stem elongation was not reduced if less pressure was applied (25 or 50 N·m^{-2}). Height control was equally effective with a solid material (mylar film) and a permeable material (fiberglass insect screen), indicating that restricting air movement is not an important mechanism for the growth response. Overnight treatments resulted in the desired growth response (27 mm shorter than nontreated, a 30% reduction in elongation rate), but 0.5-h treatments had insufficient effect for commercial use (11 mm shorter, 10% reduction in elongation rate). These experiments demonstrate that impedance can be used in commercial production conditions to control tomato transplant height with inexpensive materials. However, satisfactory height control requires a large applied force and a long daily treatment period.**

The use of mechanical stimulation to control excessive stem elongation in greenhouse-grown plug transplants is a promising replacement for chemical growth regulators, which are no longer permitted on food crops. Two kinds of mechanical stimulation could be easily adapted for commercial use. Brushing is a well-studied method to control tomato transplant height (Garner and Björkman, 1996; Latimer and Thomas, 1991). Impeding the plant canopy overnight with a sheet of 5-mm-thick acrylic sheet has also been reported (Samimy, 1993). This method has the disadvantages of the high expense and weight of acrylic sheet (\$40/m^2, 70 N·m^{-2}) and its impermeability to water vapor. Treatment for shorter durations (<15 h·d^{-1}), such that the impedance equipment could be used on several sets of plants each day, would make physical impedance more commercially applicable.

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This series of experiments was designed to determine how tomato plants respond to changes in the following variables of impedance: the amount of force applied to the seedlings, the composition and permeability of the material providing the impedance, and the duration of the daily treatment period.

Materials and Methods

Plant culture. Seeds of 'Ohio 8245' tomato (Sunseeds, Hollister, Calif.) were sown one per cell into a soilless growing medium (Pro-Mix BX; Premier Brands, Red Hill, Pa.) in plug trays (#288 square deep; Landmark Plastics Corp., Akron, Ohio) with an individual cell volume of 6.5 mL and a plant density of 2100/m^2. Plants were grown in a greenhouse at 22 °C day /16 °C night. Beginning at emergence they were fertilized two to three times per week with soluble fertilizer (20N–8.7P–16.6K) with N at 100 mg·L^{-1} (Peters Professional 20–20–20; Grace-Sierra Horticultural Products Co., Milpitas, Calif.). The trays were placed on metal mesh benches to air prune the roots. Unless noted, experiments were conducted during the regular spring production season with natural light.

Impedance treatments. To compare impedance with brushing, concurrent treatments were applied. Impedance was provided by a 5-mm-thick acrylic sheet (Plexiglas; Rohm and Haas, Philadelphia) applying a pressure of 66 N·m^{-2} overnight; brushing was applied each morning by stroking 20 times with a piece of Styrofoam (Garner and Björkman, 1996). Seeding for this experiment was on 9 Apr. in each of 3 years. The treatments were replicated three times in 1993 and four times in 1994 and 1995.

To compare several materials, plants were impeded with the acrylic sheet, or with rectangular frames the size of a planting flat (27 × 54 cm) made from 22 mm o.d. CPVC pipe (3/4" CTS; Genova Plastics, Davison, Mich.). The frames were covered either with fiberglass screening (Hanover Wire, Hanover, Pa.) or 0.15-mm-thick mylar film (Warp's Brothers, Chicago). Three pressures were provided by sand in the tubing. These frames had masses of 380, 750, and 970 g; the resulting pressure was 25, 50 and 66 N·m^{-2}, respectively. One experiment was performed to compare acrylic sheet with mylar film using equivalent pressure. Experiments testing the light frames and the acrylic sheet were conducted between November and April; for these, supplemental light (12 h·d^{-1}, photosynthetically active radiation = 500 μmol·m^{-2}·s^{-1}) was provided by 1000-W metal halide lamps. The various durations of daily treatment and the comparison of mylar film with open screen were tested as a single experiment. This design was tested once with each of the two lower pressures and twice with the high pressure.

Treatment application began when the canopy height was 7 cm (21 to 24 days after seeding, stem length = 4 cm) and continued for 7 to 10 days until the average canopy height was ≈15 cm. For the first 4 to 6 days of treatment, the frames were supported on each side by small wooden stakes to prevent the plants from collapsing, while permitting the canopy to be compressed 1 to 2 cm. To compare different daily durations of treatment, impedance was applied either for 15 h overnight or for 0.5 h between 8:00 and 9:00 AM. Treating at these times avoided covering the plants during midday, which would have reduced the amount of light intercepted by the canopy, and could have resulted in plant damage with impermeable materials.

Design and measurements. A completely randomized design was used for all experiments, with an experimental unit consisting of one flat (288 plants). Each treatment was replicated four times. All the trays in a given experiment were placed together so that there were no gaps between adjacent trays. Because edge plants become stunted and unable to support the frames, the entire experiment was surrounded by a band of guard plants four cells wide.

At the end of each experiment, the stem length, stem diameter and shoot biomass were measured on 25 sample plants per flat. Stem length was measured from the soil level to the growing point. Stem diameter was measured with a caliper 1 cm above the point of attachment of the cotyledons. Shoot dry mass was measured after drying in a forced air oven at 80 °C for at least 48 h. The number of sample plants with visible adventitious roots was also recorded. Root dry mass was obtained from 10 sample plants per flat in the control and the overnight mylar-film treatment of the last experiment.

Data were analyzed by one-way analysis

Table 1. Effect of mechanical conditioning using brushing or impedance on tomato transplant growth.

Treatment	Growth characteristic		
	Stem length ± SE (cm)	Stem diam (mm)	Shoot dry mass (mg)
		1993	
Control	15.4 ± 0.8	2.5 ± 0.1	121 ± 11
Brushed[z]	10.6 ± 0.3	3.0 ± 0.1	112 ± 10
Impeded[y]	11.1 ± 0.6	3.6 ± 0.1	113 ± 5
LSD[x]	2.0	0.3	NS
		1994	
Control	13.3 ± 0.5	2.7 ± 0.1	113 ± 11
Brushed	11.7 ± 0.5	2.8 ± 0.1	100 ± 3
Impeded	10.1 ± 0.4	3.3 ± 0.1	91 ± 2
LSD 1.9	0.3	NS	
		1995	
Control	15.4 ± 0.4	2.3 ± 0.0	111 ± 3
Brushed	12.4 ± 0.3	2.6 ± 0.1	103 ± 2
Impeded	12.4 ± 0.3	2.9 ± 0.1	97 ± 3
LSD	1.1	0.2	9
Orthogonal contrasts			
Treated vs. nontreated	***	NS	*
Brushed vs. impeded	NS	**	NS

[z]Brushing was applied as 20 strokes each morning.
[y]Impedance treatments were applied overnight with 66 $N \cdot m^{-2}$ acrylic sheets.
[x]Mean separation within columns and years by Fisher's protected LSD, $P = 0.05$.
NS, *, **, ***Contrasts nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

of variance (Schaefer and Farber, 1992). Treatment differences were detected by orthogonal contrasts and Fisher's protected LSD.

Results and Discussion

Physical impedance was as effective as brushing for reducing excessive elongation of tomato transplants (Table 1). Both treatments consistently reduced stem length by 3 to 4 cm. This reduction in stem length corresponds to a 40% reduction in the elongation rate during the 7 to 10 days that the plants were being treated. Reducing elongation by 3 to 4 cm is sufficient to counteract the amount of excessive elongation reported to us by local transplant producers and buyers. Impedance resulted in shorter and thicker stems, and more-horizontally oriented leaves (Fig. 1).

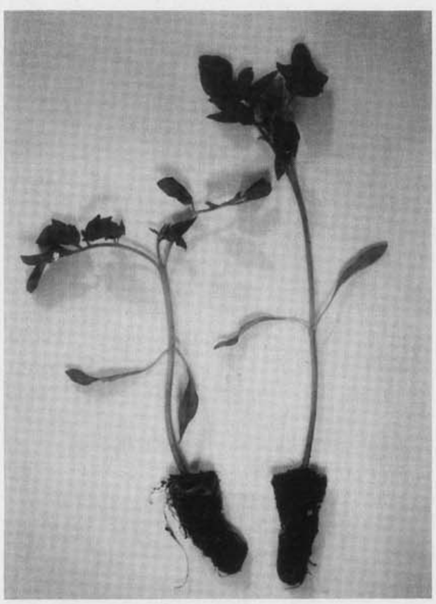

Fig. 1. Appearance of tomato seedlings in which excessive elongation was controlled by impedance. (**left**) impeded for 10 days with fiberglass screen weighted to produce 66 $N \cdot m^2$; (**right**) nontreated. The major differences were a shorter and thicker stem, stimulation of adventitious root growth at the base of the stem, a curve near the base of the stem, and a more horizontal leaf angle.

Methods of impedance application that would be easier to use commercially were tested to determine which were essential for obtaining the desired response.

Lower-cost materials. Impeding with a frame of plastic tubing supporting mylar film controlled elongation as effectively as a sheet of acrylic that applied the same pressure (Table 2). Fiberglass screen reduced the height and increased the stem diameter as well as did mylar film, without reducing the shoot dry mass (Table 3). The cost of the materials was \$40/m² for the acrylic sheet, \$17/m² for the mylar-covered frame, and \$9/m² for the fiberglass-screen frame. Thus, an impedance treatment can be applied effectively using materials less expensive that the original acrylic sheet. We further suggest that any sheet material having the necessary rigidity can be used for impedance of tomato transplants.

Gas-permeable material. An impermeable film prevents air movement from the canopy to the air above. Mass flow of air through a fiberglass screen allows such gas exchange. The permeable screen was as effective at reducing excessive elongation as impermeable mylar film (Table 3). Elevated ethylene causes swelling of stems and other tissues (Biro and Jaffe, 1984; Pressman et al., 1983). Mechanical conditioning can cause ethylene evolution, and ethylene would, therefore, accumulate to higher concentrations under an impermeable barrier. However, stem diameter was increased with both the permeable screen and the solid film (Table 3), suggesting that the larger diameter does not depend on trapping ethylene.

Lighter material. It would be advantageous to use materials lighter than the acrylic sheet used by Samimy (1993), which applied a pressure of 66 $N \cdot m^{-2}$. For example, a 2 m² unit for commercial use would have a mass of over 13 kg. A lighter unit would be easier to move into place over the growing bench and to set evenly on the flats.

Frames applying 25 or 50 $N \cdot m^{-2}$ overnight did not reduce the stem length significantly (data not shown). However, stem diameter was increased from 1.9 to 2.1 mm ($t = 4.8$, $P < 0.05$) by 25 $N \cdot m^{-2}$ pressure, and from 2.2 to 2.5 mm ($t = 5.6$, $P < 0.001$) by 50 $N \cdot m^{-2}$.

It does not appear possible to obtain effective height control with frames that apply <66 $N \cdot m^{-2}$. However, lower pressure did increase stem diameter when applied overnight. While not providing the height control needed for use with mechanical carousel transplanters, the lighter materials caused changes in plant morphology that may be advantageous for transplants that are to be set by hand.

Shorter daily treatment. Impedance treatment would be more economical if the apparatus could be used for short periods on several sets of plants each day. Even with the heavy frames (66 $N \cdot m^{-2}$), the height reduction with 0.5 h of treatment per day was insufficient (1.5 to 2 cm). An overnight treatment was necessary for a commercially useful height reduction of 3 to 4 cm (Table 3). In comparison, when brushing is used for mechanical stimulation, effective height control is obtained with only 15 to 30 s of treatment per day (Garner and Björkman, 1996). Impedance appears to be a considerably weaker mechanical stimulus than brushing.

Overnight impedance also increased adventitious root formation (Fig. 2, Table 3). This increase cannot be attributed to the permeability of the materials used, because film and screen frames increased adventitious root

Table 2. The effect of acrylic sheets and mylar-film-covered frames applied overnight on tomato transplant growth.

Treatment	Growth characteristic		
	Stem length ± SE (cm)	Stem diam (mm)	Shoot dry mass (mg)
Control	14.0 ± 0.7	2.24 ± 0.05	86 ± 6
Acrylic sheet	9.8 ± 0.3	2.67 ± 0.03	76 ± 1
Mylar film	10.1 ± 0.5	2.63 ± 0.06	72 ± 3
LSD[z]	0.9	0.15	NS
Orthogonal contrasts			
Treated vs. nontreated	***	***	*
Acrylic vs. mylar	NS	NS	NS

[z]Mean separation within columns by Fisher's protected LSD, $P = 0.05$.
NS, *, **, ***Contrasts nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Effect of altering the duration and permeability of material in impedance treatments on tomato transplant growth.

Treatment		Growth characteristic			
Duration (h)	Material[z]	Stem length (cm)	Stem diam (mm)	Shoot dry mass (mg)	Adventitious roots (% of plants)
0	None	13.2 ± 0.5	2.2 ± 0.02	81 ± 3	1 ± 1
0.5	Film	11.6 ± 0.3	2.4 ± 0.02	84 ± 3	4 ± 0
	Screen	11.3 ± 0.5	2.3 ± 0.03	74 ± 3	0 ± 0
15	Film	10.3 ± 0.2	2.6 ± 0.05	73 ± 3	70 ± 3
	Screen	9.8 ± 0.3	2.6 ± 0.10	72 ± 4	67 ± 6
LSD[y]		1.2	0.1	NS	8
Orthogonal contrasts					
Treated vs.nontreated		***	***	NS	***
0.5 vs. 15 h		**	***	NS	***
Film vs. screen		NS	NS	NS	NS

[z]Impermeable mylar film or permeable fiberglass screen.

[y]Mean separation within columns by Fisher's protected LSD, $P \leq 0.05$.

NS, *, **, ***Contrasts nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

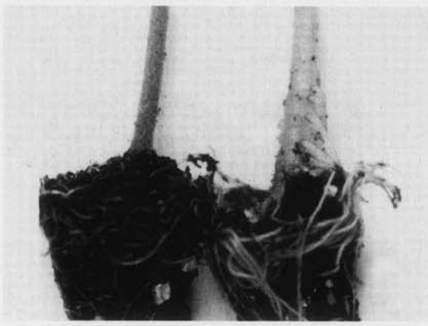

Fig. 2. Appearance of adventitious roots on impeded tomato transplants. (**left**) control; (**right**) impeded overnight with screen.

formation to the same extent. Significant adventitious root formation was absent in nontreated plants or with any other impedance or brushing treatment. This difference may have resulted from the denser canopy architecture that consistently accompanied overnight impedance treatments. As a result of the change in the leaf angle characteristic of impeded plants (Fig. 1) the soil surface was not visible from above. The differences in canopy architecture may result in persistent microclimatic changes (such as increased ethylene concentration or humidity) that in turn increase root initiation.

Other potential drawbacks to daytime impedance treatments should be considered. Photosynthesis is likely to be reduced while the treatment is applied, either through shading, or through CO_2 depletion under the solid material. Furthermore, substantial condensation occurred under the impermeable materials, which could result in reduced evaporative cooling of the upper leaves. The combination of high temperature and restricted CO_2 diffusion can damage the photosynthetic apparatus (Björkman, 1981). Nevertheless, no damage was observed with any of the materials in the plants treated for 30 min early in the day.

Other observations. For the first few days of treatment, the seedlings could not support the full weight of the frames. The stems were not crushed; rather, they leaned, then buckled. Supporting the frames below canopy height during the first 4 to 6 days applied the maximum pressure the stems could support without buckling. During this period, some of the stems became permanently curved (Fig. 1), which could be a disadvantage for use in a mechanical transplanter.

The reduction in plant height should be obtained with as little reduction in biomass as possible. The shoot-biomass reduction was similar to that obtained using brushing to achieve a similar height reduction (Table 1). The root biomass was not significantly affected by overnight impedance with the mylar-covered frame (23.4 vs. 24.1 mg in the control; $t = 0.65^{NS}$). Since the mylar-overnight treatment was the longest in duration and the most restrictive of air movement, the root biomass of other treatments was presumably also unaffected. These reductions in shoot biomass were, therefore, unlikely to have a significant effect on long-term growth because the reduction was small and not accompanied by a reduction in root mass.

When used to control excessive stem elongation in tomato transplant production, impedance has an advantage over brushing in that it increases the stem diameter and results in some adventitious root formation at the base of the stem. However, impedance is more laborious than brushing and requires more equipment to obtain satisfactory height control.

Literature Cited

Biro, R.I. and M.J. Jaffe. 1984. Thigmomorphogenesis: Ethylene evolution and its role in the changes observed in mechanically perturbed bean plants. Physiol. Plant. 62:289–296.

Björkman, O. 1981. Responses to different quantum flux densities, p. 57–107. In: O.L. Lange, P.S. Nobel, C.B. Osmond, and H. Ziegler (eds.). Encyclopedia of plant physiology. New ser., v. 12A. Springer, Berlin.

Garner, L.C. and T. Björkman. 1996. Mechanical conditioning for controlling excessive elongation in tomato transplants: Sensitivity to dose, frequency and timing of brushing. J. Amer. Soc. Hort. Sci. 121:894–900.

Latimer, J.G. and P.A. Thomas. 1991. Application of brushing for growth control of tomato transplants in a commercial setting. HortTechnology 1:109–110.

Pressman, E., M. Huberman, B. Aloni, and M.J. Jaffe. 1983. Thigmomorphogenesis: The effect of mechanical perturbation and ethrel on stem pithiness in tomato [*Lycopersicon esculentum* (Mill.)]. Ann. Bot 52:93–100.

Samimy, C. 1993. Physical impedance retards top growth of tomato transplants. HortScience 28:883–885.

Schaefer, R.L. and E. Farber. 1992. The student edition of MINITAB, Release 8. Addison-Wesley, New York.