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Tomato Transplant Morphology Affected by Handling and Storage

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Abstract. **Shoot and root growth changes in response to handling and storage time in 'Sunny' tomato *(Lycopersicon esculentum* Mill.) transplants were investigated. Transplants, 45 days old, were stored either in trays (nonpulled) or packed in boxes (pulled) for 0,2,4,6, or 8 days at 5 and 15C. Also, 35-day-old nonpulled and pulled transplants were kept in darkness at 20/28C for 0, 1, 2, or 3 days. At SC, pulled transplants had longer and heavier stems, a higher shoot : root ratio, higher ethylene evolution, and lower root dry weight than nonpulled transplants. At 15C, pulled transplants had more shoot growth than nonpulled transplants. Nonpulled, initially 35-day-old transplants had heavier shoots and roots and higher (7.0 $t \cdot ha^{-1}$) yields of extra-large fruit than pulled transplants (4.1 $t \cdot ha^{-1}$), but there were no differences in the total yields of marketable fruits.**

Containerized transplants are used extensively in tomato production regions (Risse et al., 1979; Weston and Zandstra, 1986). In Florida, transplants still in the trays used for transplant production are generally shipped directly to growers. Field establishment generally occurs 1 to 3 days after plant arrival. Transplants shipped out of Florida are hand-pulled from the tray, packed at high densities in waxed fiberboard boxes, and transported at 14C in closed containers. Planting into the field may be delayed from 1 to 7 days, depending on weather conditions and distance to market.

Transplant age at shipping is determined by regional preference. Growers in the northern United States prefer tall (12 to 16 cm) transplants that are at least 6 weeks old. Growers in Florida prefer short (10 cm) transplants that are 5 weeks old.

Studies on shipping containers, storage time, and temperature have been reported for bare-root tomato transplants (Risse and Moffit, 1984) and for transplants grown in Speedling trays (Risse et al., 1979). Storage between 10 and 13C for less than 10 days is generally recommended for tomato plants (Hardenburg et al., 1986). Plant survival and fruit yield reductions were reported for bare-root transplants packed at high density, 1250 plants per wooden crate compared to 1000 plants per crate (Risse et al., 1985). However, those studies did not consider transplant growth during storage. Knowledge of these growth changes will be useful to optimize transplant handling and storage before transplanting them to the field.

The objectives of this study were to determine the effects of a) transplant handling on shoot and root growth changes during extended low-temperature storage and b) transplant handling following reduced-temperature storage, on early growth and fruit yields.

Prolonged storage at low temperature (Expt. 1). 'Sunny' tomato plants were grown

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Table 1. Root and shoot components in response to tomato transplant handling and storage time at 5, 15, and 20/28C.

Handling method (HM)	Stem		Leaf area	Dry wt (mg)			Shoot : root ratio
	Diam (mm)	Length (cm)	(cm^2)	Leaf	Stem	Root	
			Storage at 5C[z]				
Nonpulled	2.6	13.2	33.3	158	110	47	5.9
Pulled	2.6	15.0	39.7	161	126	41	7.2
	NS	**	**	NS	**	*	**
HM × time	NS	NS	NS	NS	NS	NS	NS
			Storage at 15C[z]				
Nonpulled	2.6	13.5	34.2	153	117	48	5.7
Pulled	2.8	15.3	40.4	161	131	48	6.3
	NS	**	**	NS	*	NS	*
HM × time	NS	NS	NS	NS	NS	**	NS
			Storage at 20/28C[y]				
Nonpulled	3.1	8.0	29	116	72	49	4.0
Pulled	3.1	7.5	26	104	64	42	3.9
	NS	**	*	*	**	**	NS
HM × time	NS	NS	NS	NS	NS	NS	**

[z]Means were pooled across all storage times (2, 4, 6, and 8 days). Tomato transplants were 45 days old at time = 0. Before storage (0 day), measurements were 2.1 mm (stem diameter), 13.1 cm (stem length), 35.8 cm^2 (leaf area), 169 mg (leaf dry weight), 108 mg (stem dry weight), 43 mg (root dry weight), and 6.7 (shoot : root ratio).

[y]Means were pooled across all storage times (1, 2, and 3 days). Tomato transplants were 35 days old at time = 0. Before storage (0 day), measurements were 3.2 mm (stem diameter), 8.6 cm (stem length), 29 cm^2 (leaf area), 132 mg (leaf dry weight), 83 mg (stem dry weight), 49 mg (root dry weight), and 4.3 (shoot : root ratio).

NS,*,**Nonsignificant or significant F test at P = 0.05 or 0.01, respectively.

Table 2. Mean shoot and root temperatures (°C) for pulled and nonpulled 'Sunny' tomato transplants held at 5C.

Transplant type	Time in storage (h)			
	0	8	16	24
Shoots				
Pulled	13.2	8.6	7.6	6.8
Nonpulled	10.4	5.2	5.2	5.0
Roots				
Pulled	15.0	10.3	8.0	6.8
Nonpulled	15.4	6.0	5.0	5.2

for 45 days at Speedling, Inc., Bushnell, Fla. in polystyrene trays with 200 (18 cm^3) inverted pyramid cells. Greenhouse transplant production practices were standard proprietary procedures of the supplier (Beirenger and Bostdorff, 1989). Handling treatments were transplants that were a) kept in trays (nonpulled) and packed in waxed fiberboard boxes and b) hand-pulled (pulled) from trays and packed upright in waxed fiberboard boxes at a density of 850 plants per box. Boxes were 22 × 45 × 52 cm (height × width × length). Plants from each treatment were kept in dark rooms at 5 or 15C for 0, 2, 4, 6, or 8 days. Air temperature at the leaf and root-media levels were recorded hourly using a Grant Squirrel meter/logger (Science Electronics, Dayton, Ohio), with 16 thermistor probes placed on each of the pulled and nonpulled transplant boxes, at 5 and 15C. Stem diameter was measured with a digital caliper below the cotyledonary node. Stem length (SL) was measured from the shoot apex down to the base. (lower hypocotyl level). Leaf area (LA) was measured with a LI-3100 leaf area meter (LI-COR, Lincoln, Neb.). After roots were washed, they were blotted and root fresh weight (RFW) was determined. Plant material was oven-dried at 65C for 3 days, and dry weights of leaves (LDW), stems (STDW), and roots (RDW) were recorded and shoot : root (S : R) ratios were calculated. Measurements were taken just before storing the plants (0 day) and after 2, 4, 6, and 8 days of storage.

Ethylene evolution after 8 days of storage was determined at 1, 2, 3, and 5 h for four transplants from each handling treatment and storage temperature. Individual transplants were cut at the hypocotyl base, weighed, and placed in a 35-ml test tube. Test tubes were then sealed with a serum cap and kept in the light at 23C. The test tubes selected had minimal void volume, thus facilitating ethylene detection. Seedlings were not damaged during sample preparation, and samples were withdrawn hourly for 5 h. Ethylene was measured with a gas chromatograph (HP Model 5710A; Hewlett-Packard, Orlando, Fla.) equipped with a flame-ionization detector and activated alumina column.

A randomized complete block design with 10 replications (one plant per rep) per handling treatment was used at each storage time. Data for each storage temperature were tested separately by analysis of variance (ANOVA). Treatment effects were partitioned into orthogonal contrasts.

Brief storage at high temperature (Expt. 2). 'Sunny' tomato plants were grown for 35 days, as previously described, in polystyrene trays with 128 (30.7 cm^3) inverted pyramid cells. Treatments were the same as Expt. 1 (nonpulled and pulled), except pulled transplants were packed at a density of 550 plants/box. At 35 days after seeding, plants from each transplant group were kept in a closed container at 20/28C (night/day) for 0, 1, 2, or 3 days. Shoot and root measurements were taken as described for Expt. 1. Transplants were planted in the field on 17 Aug. 1989 at Parrish, Fla. Raised beds, 0.2 m high, were spaced 1.8 m apart, with each bed 0.8 m wide. Plants were spaced 0.50 m within the bed. Standard cultural practices, fertilization, and pesticides were used (Hochmuth, 1988). Fruits were harvested at the mature-green stage from 10 plants at 75,93, and 115 days after transplanting and graded by size (U.S. Dept. Agr., 1976).

A randomized complete block design with treatments replicated four times was used, and data were analyzed by ANOVA.

Experiment 1. Pulled transplants stored at 5C had a 13% longer SL, 14% more STDW, 22% higher S : R ratio, and smaller RFW and RDW than nonpulled transplants (Table 1). During the first 24 h of storage, pulled transplants cooled more slowly than those not pulled (Table 2). After 1 day of storage, pulled-transplant shoot and root temperatures were ≈ 1.5C higher than nonpulled transplants. Shoot growth promotion in pulled transplants possibly was a response to a higher air temperature in the shoot and root environment than in nonpulled transplants and due to high respiration heat generated by the high packing density (Risse et al., 1985). Conversely, the root growth limitation in pulled transplants could have been due to the excess moisture around the roots, reducing oxygen diffusion rates (Miller, 1986). Temperatures between 10 to 13C were reported to suppress root growth (Hardenburg et al., 1986). Data from this experiment indicate that shoot and root growth continued even at lower temperatures.

At 15C, shoots of pulled transplants grew more than those of nonpulled transplants (Table 1). Leaf and stem growth increased from 0 to 4 days, with a decrease after 6 days (data not shown) when lower leaves began to turn yellow. The partitioning of the significant handling method × time interaction for RDW (Table 1) indicated that RDW for pulled transplants increased to 56 mg at 4 days, declining to 43 mg after 6 days. Conversely, nonpulled transplants maintained root growth (57 mg) up to 6 days, declining (43 mg) at 8 days. The root growth decline on pulled transplants may have resulted from the combined effect of pulling and packing compaction and high moisture levels. After 6 days, transplant separation was difficult as a result of roots growing into adjoining root cells.

Ethylene evolution ($nl\cdot g^{-1}\cdot h^{-1}$) measured after 1 h of incubation was 2.5 (SE± 0.3) at 5C and 2.2 ± 0.2 at 15C for nonpulled transplants and 5.3 ± 0.3 at 5C and 2.1 ± 0.2 at 15C for pulled transplants. Similar trends were observed after 2, 3, and 5 h of incubation. Increased ethylene production of pulled transplants kept at 5C was probably due to the additive effects of excess moisture, chilling temperature, and physical stress (Abeles, 1973). In tomato seedlings, anaerobic environment in the root zone due to water logging increases ethylene synthesis in the shoot (Bradford and Dilley, 1978). Under these conditions, ethylene has been suggested to control root growth (Jackson, 1985), and in our experiment, roots of pulled transplants grew less (lower fresh and dry weights) than nonpulled transplants kept at 5C, but RDW for the two groups was the same at 15C (Table 1).

Experiment 2. Pulled transplants stored at 20/28C (night/day) had shorter SL, lower LA, LDW, STDW, and RDW than nonpulled transplants (Table 1). The significant handling method x time interaction for S : R ratio (Table 1) indicated that nonpulled transplants had higher S : R ratios (4.0 and 4.3 at 1 and 2 days) than pulled transplants (3.8 and 3.7 at 1 and 2 days). The shoot and root growth decreases in pulled plants could have been due to the interaction of high air temperature, darkness, and the physical effects of pulling and packing. Plant survival was 100% and, therefore, not affected by transplant handling or storage time. Reduced plant survival was reported for field-grown transplants packed at high density [1250 plants per crate (Risse et al., 1985)] and for containerized transplants stored for 10 or 15 days at either 4.4, 12.8, or 21.1C (Risse et al., 1979).

In the first and second harvest, nonpulled transplants yielded more (3.7 and 3.2 $t \cdot ha^{-1}$) extra-large fruits than pulled transplants (2.2 and 1.9 $t \cdot ha^{-1}$). Similarly, nonpulled plants produced more total extra-large fruits than pulled transplants. Extra-large fruits accounted for 12% (7.0 $t \cdot ha^{-1}$) and 7% (4.1 $t \cdot ha^{-1}$) of the total marketable fruits for nonpulled and pulled transplants, respectively, with $P = 0.01$ for F test. Differences in yield for medium and large fruit and for total yield were nonsignificant (data not shown).

The results of these experiments indicate that transplant maturity and handling affected transplant growth after 4 days of storage at either 5 or 15C. Nonpulled 45-day-old transplants maintained better shoot and root characteristics than pulled transplants. Considerations should be given to minimize the effects of pulling and packing young transplants. Transplant storage temperatures should be selected to avoid the possibility of chilling injury or fruit disorders, such as catfacing, present in transplants conditioned at 10 to 18C before transplanting (Wien, 1990). However, this response may differ among varieties and physiological age of seedlings (Lyons, 1977). If planting is delayed beyond 2 days, storage at lower (i.e., 8 to 9C) than ambient temperatures would be desirable to retard shoot growth and early flower development.

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