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Germination and Seedling Growth Characteristics of Three Tomato Species Affected by Water Deficits[1]

A. G. Taylor,[2] J. E. Motes, and M. B. Kirkham[3]
Department of Horticulture, Oklahoma State University, Stillwater, OK 74078

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Abstract. **Two species of tomato, *Lycopersicon chilense* Dun. and *Solanum pennellii* Corr., which have drought-resistant characteristics, were compared to the commercial tomato, *Lycopersicon esculentum* Mill. cv. Campbell 1327, to evaluate the effects of water deficits on germination and early seedling growth at 25, 30, and 35°C. Five levels or water stress (0, −2, −4, −6, and −8 bars) were maintained by solutions of polyethylene glycol (PEG) 6000. Germination of dry seed was inhibited more by water stress than by growth of the germinated seedlings of each species. Germinated seed of all species were able to continue growth at 35° plus water stress at all levels, while germination under the same conditions was totally suppressed. The water-sensitive phase of germination occurred just prior to radicle emergence. Emergence was not affected by sowing germinated seed in a drying soil; but sowing dry seed under the same conditions resulted in a decrease in emergence. Germination and seedling growth of *L. chilense* and *S. pennellii* were more sensitive to water stress than *L. esculentum* at 25°. At 30 and 35°, *L chilense, S. pennellii* and *L. esculentum* had similar rates of germination and similar amounts of early seedling growth.**

Germination and seedling-emergence problems are extensive in semi-arid and arid regions. In these areas, the rate of evaporation is high, soil crusting can occur, and soil salinity may result. High soil temperatures generally accompany dry soils. Although soil moisture may be adequate for growth of established plants, the surface layer of soil often may dry rapidly and prevent seed germination and seedling establishment. Sowing germinated seed is a possibility for assuring an adequate plant stand under such conditions.

A method for sowing germinated seed in a fluid gel has been reported (5). The seed are first germinated in controlled conditions and then suspended in a fluid gel which is extruded behind the furrow opener of a conventional planter. The major advantages of sowing germinated seed, compared to dry seed, are earlier and more uniform emergence (3). Another major advantage is the capacity of a germinated seed to continue growth at environmental conditions suboptimal for normal germination to occur. When lettuce (*Lactuca sativa* L.) cultivars, which have thermal dormancy and light requirements for germination, are first germinated in ideal conditions at optimal termperatures and in red light, the seed will continue growth at elevated soil temperatures (6).

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[2]Present address: Department of Seed and Vegetable Sciences, New York Agricultural Expt. Station, Geneva, NY 14456.
[3]Present address: Evapotranspiration Laboratory, Kansas State University, Manhattan, KS 66506.

The maximum cardinal temperature for germination of tomato is about 35°C (11). Cultivar differences in germination ability, however, have been shown to exist at high temperatures (1). The minimum cardinal temperature for tomato seed germination is approximately 10 to 12° (2). Growth will continue if tomato seed are first germinated in ideal conditions and then sown at low temperatures (2). Price et al. (15) found that the time to 50% emergence for tomato was reduced from 28.8 days for dry seed to 6.6 days for germinated seed at 12.5°.

Radicle growth of calabrese (*Brassica oleracea* var. *italica* Plenck.) and cress (*Lepidium sativum* L.) is less sensitive to water deficits than earlier stages of germination (7). A similar response to water stress has been observed in 7 different families of vegetables consisting of 13 species (17). Data for tomato was reported; however, the experiment was performed at 20°C. The purpose of this study was to evaluate the effects of water deficits on germination and growth of germinated seed of tomato. The water-sensitive phase of germination was examined and performance of germinated and dry seed was studied in drying soil. Two wild species of tomato, *Lycopersicon chilense* and *Solanum pennellii*, which have drought-resistant characteristics, were compared to *Lycopersicon esculentum*, the commercial tomato. *S. pennellii* is both drought tolerant and salt tolerant (4). The leaves of *S. pennellii* have a high capacity to absorb and retain atmospheric water (16). *L. chilense* is a drought avoider and develops an extensive root system (16).

Materials and Methods

In this paper, the term "germinated seed" will refer to a seed with the radicle emerged from the seed coat.

Seed germination and water stress. Seed of *Lycopersicon esculentum* cv. Campbell 1327, *Lycopersicon chilense*, and *Solanum pennellii* were germinated in an aerated glass column (39.5 cm length; 4.5 cm diameter) filled with distilled water. A constant-temperature water bath contained the columns and maintained a 30°C germination temperature. Water in the columns was changed daily. Seed remained in the columns until the average radicle length was 2 to 3 mm. This required 52, 40, and 36 hr for *L. chilense*, *L. esculentum*, and *S. pennellii*, respectively. The germination of *L. chilense* and *S. pennellii* was normal, as determined by standard germination testing.

Water stress was maintained in all laboratory experiments with polyethylene glycol (PEG) 6000. The equation derived by Michel and Kaufmann (13) was used to obtain the desired osmotic potential of the solution. The equation is:

$$\Psi s = -(1.18 \times 10^{-2})C - (1.18 \times 10^{-4})C^2 + (2.67 \times 10^{-4})\,CT + (8.39 \times 10^{-7})\,C^2T$$

where:

Ψs = osmotic potential

C = concentration of PEG 6000 in g/kg water

T = temperature in °C

Dry and germinated seed of each species were transferred to 25 × 60 mm Petri dishes fitted with two pieces of #2 filter paper. Three ml of PEG 6000 solution were placed in each dish. Water deficits ranged from 0 to −8 bars in 2-bar increments. There were 20 seeds per Petri dish with 4 replications per treatment. A completely randomized design was used.

In preliminary experiments, necrosis of the radicle was observed if the water potential of the medium was −10 bars or less. Phytotoxicity has been reported due to use of PEG as an osmoticum (10).

The experiment was conducted for 6 days in darkness. Three continuous temperatures were evaluated as separate experiments: 25, 30, and 35°C. Temperature was maintained by a General Electric Model 806 incubator. Percent germination and total seedling length were measured for the dry-seed treatment at the end of the 6-day period. Maximum percent germination was calculated. Water stresses at which germination was reduced 50 and 100% were determined. The water stress at which growth of dry and germinated seed was reduced 50% was also calculated. Values were derived by regression analysis of the raw data.

Water sensitive phase of germination. Two experiments were performed to determine which stage of germination is most sensitive to water deficit. Fifty seeds of each species were placed in aerated water as described previously. At 0, 6, 12, 18, and 24 hr prior to radicle emergence, 50 seeds were transferred to 15 × 100 mm Petri dishes. Each Petri dish was fitted with one piece of #3 filter paper and was moistened with 6 ml of −7.0 bar PEG 6000 solution. From earlier studies, this water stress was found to totally inhibit germination of all 3 species. Temperature was maintained at 25°C. Percent seeds with radicles continuing to elongate 48 hr after transfer to the water stress was determined.

A second experiment consisted of priming the seed. Fifty seeds of each species were placed in Petri dishes containing −7.0 bar PEG 6000 solution at 25°C. Seed remained in this solution for 96 hr and percent germination was calculated. Seeds were then transferred to Petri dishes containing water for 24 hr. Once again, percent germination was calculated. Seeds were then transferred to the −7.0 bar PEG 6000 solution and percent seed with radicles continuing to elongate was determined. A completely randomized design was used for the laboratory experiments with four replications per treatment.

Seedling emergence. A Percival (Percival Co., Bone, Iowa) walk-in incubator maintained predetermined environmental conditions for the emergence test. Photoperiod was 12 hr with 30°C day and 25° night. The growing medium consisted of 2 parts sand: 1 part vermiculite (v/v) in 50 × 36 × 7-cm flats. Because seedling emergence was the only desired measurement, light intensity was not determined, and nutrients were not added to the growing medium.

Screen-cage psychrometers (J.R.D. Merrill Co., Logan, Utah) and an HR-33T dew-point microvoltmeter (Wescor Inc., Logan, Utah) were used to measure soil water potential and temperature. Measurements were determined at 1.5- and 5.0-cm depths. Flats were initially watered to field capacity (drainage occurred) and then allowed to dry over the course of the experiment (14 days). Seed treatments were sown 2 (normal) and 5 (stressed) days after watering.

Treatments consisted of sowing 50 dry seeds, 50 dry seeds in gel, and 50 germinated seeds in gel at a 1.5-cm depth. Laponite 508 (Laporte Inc., Hackensack, N.J.) at 15 g/liter was used as the gel. A Waring blender at low speed dispersed the laponite in water to form the viscous gel. The gel extrusion rate was 15 ml/m.

Daily emergence data were taken over a 2-week period. The time in days for 50% of the seedlings to emerge and the time in days for 10 to 90% of the seedlings to emerge were calculated (18). The time for 10 to 90% emergence is a measure of the uniformity of emergence. A seedling was considered emerged when the cotyledons were fully expanded.

After the initial 2-week emergence period, the flats were rewatered and percent emergence was again determined. There were 4 replications per treatment. The experimental design was a randomized complete block with a 3 × 2 factorial arrangement of treatments.

Table 1. Effects of water stress on growth of dry and germinated seed of 3 tomato species at 25, 30, and 35°C.

Species	Maximum germination (%)	Dry seed: 50% reduction in germination (bars)	Dry seed: 100% reduction in germination (bars)	Dry seed: 50% reduction in growth (bars)	Germinated seed: 50% reduction in growth (bars)	Germinated seed: Growth rate (mm/day)
			25°C			
L. chilense	82.5a[z]	-2.4 a	-4.9a	-2.6a	-4.0a	6.4a
L. esculentum	90.0a	-3.7b	-6.9b	-3.2a	-5.9b	11.8b
S. pennellii	90.0a	-2.8a	-5.2a	-2.8a	-4.8a	7.4a
			30°C			
L. chilense	65.0a	-1.5a	-3.0a	-1.4b	-4.9a	8.6a
L. esculentum	77.5ab	-2.9b	-5.5b	-2.7a	-5.1a	12.4b
S. pennellii	90.0b	-2.2ab	-4.2a	-2.3ab	-4.8a	8.6a
			35°C			
L. chilense	5.0a	-0.5a	-1.0a	-0.5a	-6.0a	3.8a
L. esculentum	7.5a	-0.7a	-1.5a	-0.7a	-7.9b	6.5b
S. pennellii	47.5b	-1.0a	-2.0a	-1.0a	-6.3a	5.7ab

[z]Mean separation within each column within each temperature by LSD, 1% level.

Results and Discussion

Seed germination and water stress. At 0 bars, germination of the *Lycopersicon* genus was more sensitive to elevated temperatures than *S. pennellii* (Table 1). Water stresses at which germination was reduced 50 and 100%, and the water stress at which growth of the germinated seed was reduced 50%, were more negative for *L. esculentum* than for *L. chilense* and *S. pennellii* at 25 °C (Table 1). Therefore, germination of *L. esculentum* appeared less sensitive to water deficits than did the two wild species. The drought-resistant mechanisms of *L. chilense* and *S. pennellii* were not observed during germination or early germinated seed growth. In sorghum (*Sorghum bicolor* L. monench.), cultivars require different seed moisture contents before germination can occur (12). Differences may be related to seed size or seed composition, which ultimately affect the amount of water imbibed. Similarly, in this experiment, differences in germination among the 3 species might have been due, in part, to seed size. The weight per seed in mg for *L. chilense*, *L. esculentum*, and *S. pennellii* were 0.72, 3.30, and 0.52, respectively.

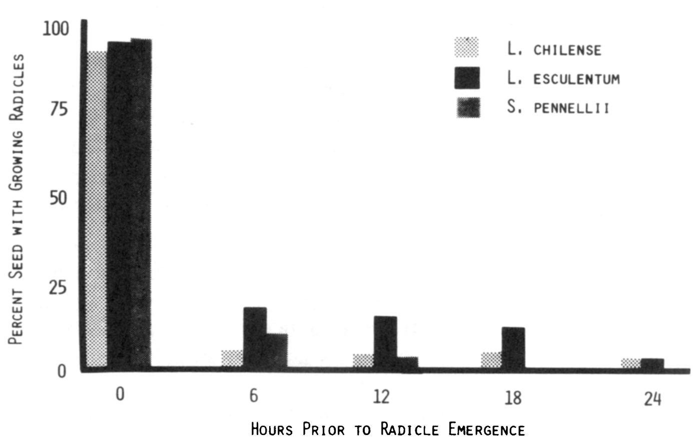

Fig. 1. Effect of transferring 3 species of tomato seed to −7 bars at various times prior to radicle emergence on continued seedling growth.

No differences were observed in dry seed at 35°C (Table 1). This is due to the fact that germination was low at 0 bars and completely inhibited at −2 bars. Germinated seed continued growth at 35° with water stress. Thus it appeared that once a seed was germinated, it could continue growth at suboptimal environmental conditions, under which normal germination cannot occur.

For each species and at each temperature, the water stress at which growth of germinated seed was reduced 50% was more negative than the water stress at which growth of dry seed that germinated was reduced 50% (Table 1). This supported other research (7) which showed that germination is more sensitive to water stress than is growth of a germinated seed. The growth rates of germinated *L. esculentum* seed were greater than those of the two wild species (Table 1), which might have been due to differences in seed size and vigor.

Water sensitive phase of germination. When seed of each species with emerged radicles were transferred to −7 bars, 91 to 95% continued growth (Fig. 1). If germinating seed were transferred 6 hr or more prior to radicle emergence, few seed continued growth (Fig. 1). These data indicate that the water-sensitive phase of germination occurred just prior to radicle emergence. Leaching of inhibitors from the seed coat can promote germination of certain desert species (19); however, soaking tomato seed in water or leaching the seed was not adequate to allow continued growth under water stress (Fig. 1).

Seed first primed for 4 days at −7 bars, resulted in little or no germination (Table 2). Imbibed seeds of each species were then able to germinate when exposed to water for a 24-hr period. Because *L. chilense* normally requires a longer period to germinate than the other species tested, it received a 36-hr water treatment. This resulted in increased germination (57 to 94.5%) (Table 2). These seeds, when transferred back to −7 bars, continued radicle elongation. Calabrese and cress respond similarly (9), in that once seed had radicles emerged, they could continue growth at water deficits that would normally inhibit germination.

According to Obroucheva (14), initiation of cell elongation of roots is under different metabolic control than elongation itself. This hypothesis has been used to describe the water-sensitive phase of germination (7). Thus it appears that a less negative critical water potential exists for the initiation of radicle growth than for growth itself.

Seedling emergence. Soil water potential during emergence did not decrease below −2 bars for the normal condition. Soil water potential gradually decreased to about −20 bars at 1.5-cm depth during emergence in the stressed condition. At the end of emergence, soil water potential was approximately −3 bars at 5-cm depth.

The gel used to extrude the germinated seeds was 98.5% water. A treatment of sowing dry seed in gel was evaluated to determine

Table 2. Growth of 3 tomato species at 25°C after the following sequence: (1) 4 day imbibition at -7 bars, (2) 24 hr in water, (3) transfer of seed back to -7 bar solution.

Species	Germination after 4 days at -7 bars (%)	Germination after 24 hr in water (%)	Radicles growing after transfer to -7 bars (%)
L. chilense	0.0a[y]	57.0a	59.0a
L. esculentum	5.0a	92.5b	92.0b
S. pennellii	0.0a	95.0b	95.5b
L. chilense[z]	0.0a	94.5b	94.0b

[z]*L. chilense* received 36 hr in aerated water.
[y]Mean separation within columns by LSD, 1% level.

Table 3. Emergence characteristics of dry seed, dry seed in gel, and germinated seed of cv. Campbell 1327 sown in stressed and non-stressed soil.

Treatment	Emergence (%)		50% emergence of seedlings (days)		10-90% emergence of seedlings (days)		Emergence after rewatering (%)	
	Normal	Stressed	Normal	Stressed	Normal	Stressed	Normal	Stressed
Dry seed	76.5	43.0	5.4	5.8	4.9	5.5	90.5	68.0
Dry seed in gel	79.5	49.0	5.6	5.9	5.2	5.5	89.0	76.0
Germinated seed in gel	98.5	97.5	3.0	2.7	3.0	2.2	98.5	97.5
Trt x stress LSD 5%	14.6		0.3		0.7		8.5	

the effect of the additional moisture on emergence. Percent emergence of dry-sown treatments was less than 50% when sown in the stressed soil (Table 3). Emergence of germinated seed was unaffected by soil water status.

Time for 50% of the seedlings to emerge, and time for 10 to 90% of the seedlings to emerge, were less for the germinated-sown seed than for the dry-sown seed (Table 3). Other work showed that emergence from germinated seed was earlier and more uniform than that from dry-sown seed (3). For the germinated treatment, times for 50% emergence and 10 to 90% emergence of seedlings were lower in the stressed than in the normal conditions. This can be attributed partially to the differences in soil temperatures during emergence. Due to evaporation, temperature of the growing medium was about 4°C lower in the normal than in the stressed treatments.

Rewatering the flats resulted in an increase in emergence of the dry-sown seeds of about 15 and 25% for the normal and stressed conditions, respectively (Table 3). Sowing the dry seed in gel did not increase emergence. Thus it can be concluded that the benefit of sowing germinated seed in a marginally stressed soil may be that seedling establishment can occur. Even though the top 2 to 3 cm of the soil may dry, root growth of the germinated seeds can continue and thus soil moisture below the top layer could be exploited.

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