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Seedling Root Morphology and Shoot Growth after Seed Priming or Pregermination of Bell Pepper

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Abstract. **Primed, pregerminated, or nontreated seeds of bell pepper *(Capsicum annum* L.) 'Early California Wonder' were grown in controlled conditions for 14 days in glass tubes containing a gel medium. The number of basal roots (one per plant), lateral roots (one per plant), and taproot length (64 mm) did not differ between seed treatments 14 days after seeding. Roots of seedlings from nontreated seeds weighed more than seedlings from primed seeds, and the seedlings had smaller shoot : root ratios than those from pregerminated or primed seeds. Seedlings from pregerminated seeds had heavier and taller shoots than seedlings from nontreated or primed seeds. Taproot length from 1 to 6 days after radicle protrusion increased linearly for all seed treatments. Seedlings from pregerminated seeds initially had longer taproots but had slower linear taproot growth up to 6 days after seeding than seedlings from nontreated or primed seeds.**

Plug-mix (Hayslip, 1973), fluid drilling (Elliot, 1967), and gel-mix (Schultheis et al., 1988a) delivery systems have been developed as carriers of nontreated, primed, or pregerminated seeds for commercial field conditions. Seed priming has been used to improve germination percentage and rate, emergence, seedling growth and uniformity, and yields of several vegetable crops (Bradford, 1986). In bell pepper, priming of seeds in solutions of KNO_3 (Bradford et al., 1990; Sachs et al., 1980), or in polyethylene glycol (PEG) at -0.8 MPa (Yaklick and Orzolek, 1977) or - 1.15 MPa (Heydecker et al., 1975) enhanced the rate of germination. Sundstrom and Edwards (1989) reported an increased rate of germination when jalapeno *(Capsicum annuum)* and tabasco (C. *frutescens* L.) peppers were primed in a 3.0% or 2.75% KNO_3 solution, respectively. However, Ghate and Phatak (1982) reported a significant decrease in germination rate when pepper seeds were primed with K_2HPO_4 plus $(NH_4)_2HPO_4$ solution. Bradford (1986) cited several investigations reporting either no effect or beneficial responses of seed priming for several field and vegetable crops.

Ghate and Phatak (1982) reported faster germination and heavier seedlings with pregerminated bell pepper seeds. Pregerminated pepper seeds produced heavier seedlings, more uniform seedling emergence (Schultheis et al., 1988a), and earlier, more uniform anthesis (Schultheis et al., 1988b) than nontreated seeds.

Although the influences of bell pepper seed priming or pregermination on germination, emergence, seedling growth, or yields have been addressed, minimal information has been reported on root growth, morphology, or development subsequent to seed priming or pregermination. Stoffella et al. (1988a) have described the sequence of early root development in bell peppers as a rapid taproot elongation from radicle protrusion until cotyledons are fully developed, emergence of basal and lateral roots when cotyledons are fully developed, and an increase in lateral and basal root numbers, with a simultaneous reduction in taproot growth rate. The purpose of this investigation was to determine whether seed priming or pregermination results in a beneficial response on subsequent seedling root morphology and development.

A gel medium containing inorganic salts according to Linsmaier and Skoog (1965), and Gelrite gellan gum (Merck & Co., Rahway, N.J.) at 2.0 $g \cdot liter^{-1}$ was used as a substrate for seeding, germination, and subsequent seedling growth. The solution was adjusted to pH 5.7 with 0.02 N KOH. The medium was dispensed at 30 ml/tube (25 × 200 mm) and autoclaved at 121C and 0.1 MPa for 20 min.

Seeds of 'Early California Wonder' bell pepper were surface disinfected for 20 min in household bleach diluted to a 2% NaOC1 solution with distilled water. Seeds were rinsed three times in sterilized water, then either pregerminated or primed. Seeds were pregerminated by placing disinfected seeds into a petri dish containing filter paper and 3 ml of distilled water; the dishes then were placed in darkness at 25C for 5 days. Seeds with radicles 1 to 2 mm long were used in the pregerminated treatment. Seeds were primed by placing disinfected seeds in petri dishes containing - 0.5 MPa polyethylene glycol-6000 (PEG) that were held in darkness at 16C for 5 days.

A single disinfected (nontreated), primed, or pregerminated seed was placed in the center surface of the gelled medium. Tubes were fitted in a tube rack that was covered with black polyethylene film to minimize the light to the developing root system. Racks with glass tubes were placed in a growth room maintained at 25 ± 1C and a photoperiod of 16 h under cool-white fluorescent tubes (Philips TLM 40W/33RS and Osram Hell Wiss, 2:l ratio), with a photon flux rate (photosynthetically active radiation) of 65 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The nondestructive root study method was previously described by Stoffella et al. (1988a).

The design was a randomized complete block with each seed treatment replicated 44 times. A single seedling in a tube was considered an experimental unit.

Number of days to germination and number of days from radicle protrusion to fully expanded cotyledons were recorded. Taproot length was measured every 24 h during the first 10 days following radicle protrusion (nontreated and primed seeds) or seeding date (pregerminated seeds). Seedlings were removed from the tubes with forceps 14 days after seeding. Final taproot length, number of basal and lateral roots, and shoot height (base of hypocotyl to cotyledonary node) were measured just before removal of the plant. Roots were washed in distilled water to remove any adhering gel, surface-dried between sheets of filter paper, and severed from the stem. Fresh weights of roots and shoots were measured and shoot : root ratios were calculated for each seedling.

Analysis of variance was performed on each measured and calculated variable, and seed treatment means were separated by Duncan's multiple range test, at $P = 0.05$, using the Statistical Analysis System (SAS Institute, Inc., 1988) software program. For each seed treatment, taproot lengths were subjected to linear regression analyses: $y = b_0 + b_1x$, where y = taproot length, and x = days after radicle protrusion or seeding (pregermination treatment). A *t* test, at $P = 0.05$, was used to compare regression slopes (b_1) between seed treatments.

Primed seed germinated ≈2 days earlier than nontreated seeds (Table 1). Similar im-

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Table 1. Mean shoot and root characteristics as influenced by seed treatments.[z]

Seed treatment	Germination[y] (days)	Emergence[x] (days)	Taproot length (mm)	Basal root (no.)	Lateral root (no.)	Shoot ht (mm)	Shoot wt (mg)	Root wt (mg)	Shoot : root ratio
Nontreated	4.4	5.5	65.8	0.9	0.7	37.2 b[w]	57.3 b	13.7 a	4.4 b
Primed	2.6	5.8	64.0	0.7	0.8	38.9 b	62.3 b	11.5 b	5.7 a
Pregerminated	---	5.3	63.4	0.7	1.0	41.2 a	68.5 a	12.1 ab	6.2 a
F test	**								

[z]Root and shoot traits were measured 14 days after seeding.
[y]Days from seeding to radicle protrusion.
[x]Days from radicle protrusion to fully expanded cotyledons.
[w]Mean separation within columns by Duncan's multiple range test, $P = 0.05$.
**Significant at $P = 0.01$.

Table 2. Regression equations describing taproot growth from 1 to 6 days after radicle protrusion.

Seed treatment	Regression equation[z,y]	R^2
Nontreated	$y = -11.07 + 11.9x$	0.89
Primed	$y = -11.00 + 11.1x$	0.84
Pregerminated	$y = -1.66 + 9.9x$	0.69

[z]y = taproot length (mm), and x = days (1–6) after radicle protrusion (nontreated and primed) or seeding date (pregerminated).
[y]Linear slopes (b_1) are significantly different between nontreated or primed seeds as compared with pregerminated seeds according to *t* tests, $P = 0.05$.

provements in rate of germination by priming pepper seeds were reported (Bradford et al., 1990; Heydecker et al., 1975; Sachs et al., 1980; Stoffella et al., 1988b; Yaklick and Orzolek, 1977). However, the number of days between radicle protrusion and full expansion of cotyledons was similar for the seed treatments (Table 1). Cotyledons were fully expanded ≈5.5 days after radicle protrusion for each seed treatment (Table l), and the first basal and lateral roots were initiated ≈ 1 day later (data not presented).

Basal and lateral root counts 14 days after seeding averaged about one per plant for all seed treatments (Table l), consistent with Stoffella et al. (1988a).

Pregerminated seeds had produced significantly taller and heavier shoots by 14 days after seeding than primed or nontreated seeds (Table 1). Seedlings from nontreated seeds had higher root weights 14 days after seeding than seedlings from primed seeds. Nontreated seeds had a smaller shoot : root ratio than primed or pregerminated seeds. This response suggests that a greater portion of photosynthates is distributed to the roots than the shoots in seedlings developing from nontreated seeds as compared with seedlings developing from primed or pregerminated seeds. Heavier seedlings from pregerminated pepper seeds as compared with nontreated seeds have also been reported by Ghate and Phatak (1982) and Schultheis et al. (1988a).

Preliminary regression analyses of taproot length data indicated that growth rates decreased after day 6 for all seed treatments (data not presented). Taproot growth rate reduction after day 6 may reflect the competitive "sinks" between shoots, basal roots, and lateral roots or a depletion of oxygen in the lower depths of the medium. Therefore, regression equations describing taproot growth from days l-6 were calculated for each seed treatment (Table 2). The regression equations indicate that taproots initially were longer but that they grew more slowly from 1 to 6 days after seeding in pregerminated ($b_1 = 9.9$) than in nontreated ($b_1 = 11.9$) or primed ($b_1 = 11.1$) seeds (Table 2). According to the equations, taproots were ≈58 mm long for all treatments by day 6; also, taproot lengths were similar (64 mm) for all treatments by day 14 (Table 1). Similarly, Stoffella et al. (1988b) reported a linear increase in taproot length from 1 to 7 days after radicle protrusion for nontreated, primed, or pregerminated seeds of 'Early California Wonder' grown at 15, 25, or 35C. Furthermore, Sundstrom and Edwards (1989) reported that radicle lengths 7 and 14 days after seeding were similar for primed and water-soaked jalapeno and tabasco seeds, except for a longer radicle for primed jalapeno seeds 7 days after seeding. Thus, neither priming nor pregermination provided a significant advantage in terms of taproot growth rate by 6 days after radicle protrusion (priming) or seeding (pregermination).

Pregerminated seeds resulted in minimal differences in subsequent seedling root morphology as compared with nontreated or primed seeds. Priming seeds resulted in similar taproot growth rates and a smaller root mass than nontreated seeds. Pregerminating or priming seeds caused no beneficial or deleterious effect in seedling root morphology.

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