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Germination and Seedling Emergence of Primed Tomato and Asparagus Seeds under Adverse Conditions

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Abstract. **Seeds of 'Ace 55' tomato *(Lycopersicon esculentum* Mill.) and 'Mary Washington' asparagus *(Asparagus officinalis* L.) were primed in -0.8 MPa (20C, 1 week, dark) polyethylene glycol 8000 (PEG), synthetic seawater (INO), or $NaNO_3$. Primed seeds of both species had a higher percentage of germination than untreated seeds only at 10C in nonsaline (– 0.05 MPa) medium, while in saline medium (– 0.6 MPa) priming increased the percentage of germination of tomato seeds at 10 and 30C, and of primed asparagus seeds at 10 and 20C. Sodium nitrate was superior to PEG or IN0 for priming tomato seeds since it resulted in fewer days to 50% germination and higher final germination percentage in saline media at all temperatures. IN0 was a satisfactory alternative to PEG or $NaNO_3$ for priming asparagus seeds since priming agent had little or no effect on germination. Seedling emergence from $NaNO_3$-primed seeds of both species sown in a seedbed provided saline (– 0.39 MPa) irrigation was faster than from untreated dry-sown seeds. In the saline seedbed, priming increased final emergence percentage (FEP) from asparagus seeds, provided they were not subsequently dried, but had no effect on the percentage emergence of tomato seeds. Fluid-drilling primed or germinated seeds of either species enhanced seedling establishment in the saline seedbed by reducing time to 50% emergence and/or increasing FEP relative to primed, dried-b&k or untreated seeds.**

Priming involves exposing seeds to an external water potential low enough to restrict germination and yet permit pregerminative physiological and biochemical activities (Bradford, 1986). Commonly used priming agents include inorganic salts such as $CaCl_2$, KNO_3, K_2HPO_4, or Na_2SO_4 and organic agents such as polyethylene glycol (PEG), mannitol, or sorbitol. As a priming agent, $NaNO_3$ was superior to PEG for tomato seeds while synthetic seawater was as effective as PEG for asparagus seeds (Frett et al., 1991). Primed seeds have improved vigor, particularly under adverse seedbed conditions such as low temperature (Pill and Finch-Savage, 1988; Szafirowska et al., 1981), matric stress (Frett and Pill, 1989), or salinity (Wiebe and Muhyaddin, 1987).

Seed treatments following priming, however, can affect subsequent germination responses. If primed seeds are transferred directly from the priming solution to the germination medium, germination is more rapid than that of primed seeds that have been dried before planting (Evans and Pill, 1988; Pill, 1986). Such seeds have been considered "pregerminated" (Bradford, 1986) and can be suspended in a protective hydrophilic carrier gel that then is delivered to the seedbed, the "fluid drilling" planting technique (Gray, 1984). Primed seeds of-asparagus (Evans and Pill, 1989), carrot, celery, and onion (Brocklehurst and Dearman, 1983) that had been dried before sowing germinated more slowly with at least some of the delay attributed to the increased time needed for seed re-imbibition.

The first experiment reported here was undertaken to determine the germination responses of tomato and asparagus seeds primed in PEG, synthetic seawater, or $NaNO_3$ when subjected to osmotic and temperature stresses. The purpose of our second study was to determine seedling emergence response in a saline seedbed from primed seeds subjected to varying levels of drying before planting.

Priming agents and germination conditions. Seeds of 'Ace 55' tomato and 'Mary Washington' asparagus were primed in -0.8 MPa polyethylene glycol 8000 (PEG), Instant Ocean (INO, synthetic seawater, Aquarium Systems, Mentor, Ohio), or $NaNO_3$ using methods described by Frett et al. (1991). The primed seeds were rinsed and transferred to 125 × 80 × 20-mm transparent polystyrene boxes containing germination paper moistened with 15 ml of nonsaline (– 0.05 MPa) or saline (– 0.6 MPa) solution for germination in the dark at 10, 20, or 30C (Table 1). The 4 (three priming agents and untreated seeds) × 2 (salinity levels) × 3 (temperatures) factorial was replicated five times (50 seeds per box) and arranged in completely randomized design. Germinated seeds (radicles visible) were counted and discarded each day. From the total number of seeds germinated, days to 50% germination (G_{50}) and final germination percentage (FGP) were calculated.

The FGP and G_{50} of tomato and asparagus seeds were influenced by the interaction of seed treatment with temperature and salinity during germination (Table 2). The greatest increase in FGP as a result of priming tomato

Table 1. Seed and seedbed treatments for experiments with tomato and asparagus seed.

Expt. 1. Priming agents and germination conditions
Priming agent (– 0.8 MPa, 1 week, 20C, dark)
Polyethylene glycol 8000 (310.0 g·liter^{-1})
Instant Ocean (13.7 g·liter^{-1})
$NaNO_3$ (15.7 g·liter^{-1})
None (untreated seeds)
Germination environment
Temperature: 10, 20, or 30C
Salinity[z]: with or without – 0.6 MPa Instant Ocean in 0.5-fold Hoagland solution (Hoagland and Arnon, 1950).
Expt. 2. Seed moisture and planting method
Seeds
Primed[y]–surface-dried (20C, 50% RH, 2 h)
Primed[y]–dried-back (20C, 32.5% RH[x], 2 days)
Primed[y]–fluid-drilled[w] (sown without drying)
Germinated (100% with 1-3-mm-long radicles), fluid-drilled[w]
Untreated, fluid-drilled[w]
Untreated, dry-sown
Seedbed treatment
0 g (nonsaline) or 5.7 g (saline) Instant Ocean/liter in 50 mg N/liter from 20N-4.3P-8.8K fertilizer solution

[z]25.6%, 24.7%, or 23.8% (v/v) of full-strength Instant Ocean (38 g·liter^{-1}) at 10, 20, or 30C, respectively.
[y]Primed in – 0.8 MPa $NaNO_3$, 1 week, 20C, dark.
Stored over saturated $CaCl_2$ (Winston and Bates, 1960).
[w]Seeds mixed in 1.5% (w/v) hydroxyethyl cellulose (N-gel).

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Table 2. Final germination percentage [FGP and angular transformation (in brackets)] and days to 50% germination (G_{50}) of tomato and asparagus seeds at 10, 20, or 30C in saline or nonsaline media as influenced by seed treatments.

Seed treatment[z]	Germination environment: Temp (°C)	Germination environment: Salinity[y]	Tomato FGP (%)	Tomato G_{50} (days)	Asparagus FGP (%)	Asparagus G_{50} (days)
PEG	10	–	84 [67]	13.6	53 [47]	9.0
		+	18 [24]	18.8	19 [25]	12.9
	20	–	92 [74]	1.1	89 [71]	2.4
		+	88 [70]	3.4	82 [65]	3.5
	30	–	94 [76]	1.0	91 [73]	1.2
		+	70 [57]	8.4	90 [72]	2.5
Instant Ocean	10	–	68 [56]	14.5	50 [45]	9.4
		+	11 [18]	17.6	21 [27]	9.8
	20	–	93 [74]	1.4	92 [74]	2.2
		+	89 [71]	3.5	84 [67]	3.5
	30	–	91 [73]	0.8	90 [72]	1.0
		+	51 [45]	6.6	90 [72]	2.8
$NaNO_3$	10	–	74 [59]	0.8	56 [48]	7.4
		+	22 [27]	9.3	21 [27]	12.3
	20	–	90 [72]	0.7	91 [73]	1.9
		+	92 [76]	1.3	85 [68]	3.1
	30	–	90 [72]	0.5	93 [77]	1.0
		+	72 [58]	1.6	92 [73]	2.6
Untreated	10	–	3 [10]	16.3	6 [14]	21.8
		+	2 [8]	12.5	0 [0]	---[x]
	20	–	94 [76]	2.8	90 [72]	6.7
		+	78 [63]	7.6	73 [59]	10.4
	30	–	95 [78]	2.2	91 [74]	5.5
		+	48 [44]	9.4	92 [74]	7.9
$LSD_{0.05}$ (three-way interaction)			[8]	3.1	[6]	2.3
Significance						
Seed treatment (ST)			**	**	**	**
Salinity (S)			**	**	**	NS
Temperature (T)			**	**	**	**
ST × S			*	NS	NS	**
ST × T			**	**	**	**
S × T			**	NS	**	**
ST × S × T			**	**	**	**

[z]Seeds primed in -0.8 MPa PEG, Instant Ocean, or $NaNO_3$ (1 week, 20C, dark).
[y]Without (–) or with (+) – 0.6 MPa Instant Ocean in 0.5-fold Hoagland solution.
[x]Regarded as missing since FGP = 0%.
NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 3. Days to 50% emergence (E_{50}), final emergence percentage [FEP, and angular transformation (in brackets)] and shoot dry weight (SDW) of tomato and asparagus seedlings as influenced by seed treatments and exposure to salinity.

Seed treatment[z]	Salinity regime[y]	Tomato E_{50} (days)	Tomato FEP (%)	Tomato SDW (mg/plant)	Asparagus E_{50} (days)	Asparagus FEP (%)	Asparagus SDW (mg/plant)
Primed-sd	–	2.8	88 [70]	25.2	11.2	91 [75]	45.9
Primed-db	–	3.8	82 [65]	21.2	14.3	86 [68]	36.8
Primed-fd	–	1.8	92 [74]	30.0	10.8	95 [79]	43.0
Germinated-fd	–	2.6	98 [82]	28.5	11.7	86 [69]	39.3
Untreated-fd	–	6.1	93 [74]	13.0	15.4	84 [67]	42.7
Untreated-ds	–	6.4	87 [69]	13.4	15.7	79 [63]	40.5
Primed-sd	+	5.0	81 [65]	7.9	14.8	68 [56]	21.8
Primed-db	+	5.8	70 [57]	6.9	16.7	33 [34]	23.6
Primed-fd	+	1.8	84 [66]	9.9	13.3	78 [63]	24.5
Germinated-fd	+	2.6	96 [80]	11.3	11.7	85 [73]	29.3
Untreated-fd	+	10.7	61 [51]	3.9	19.0	34 [35]	22.0
Untreated-ds	+	9.6	80 [63]	4.1	18.7	41 [40]	21.3
$LSD_{0.05}$		0.7	[7]	3.7	1.9	[13]	3.2
Significance							
Seed treatment (ST)		**	**	**	**	**	NS
Salinity (S)		**	**	**	**	**	*
ST × S		**	**	**	NS	*	*

[z]Primed in $NaNO_3$ (-0.8MPa, 20C, 1 week, dark); germinated = 100% germinated seeds; sd = surface-dried (20C, 50% RH, 2 h); db = dried-back (20C, 32.5% RH, 2 days); fd = fluid-drilled; ds =dry-sown.
[y]Without (–) or with (+) –0.6 MPa Instant Ocean in 50 mg N/liter from 20N-4.3P-8.8K.
NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

and asparagus seeds occurred at 10C in both saline and nonsaline media. Seed priming is particularly beneficial at low temperatures (Pill and Finch-Savage, 1988; Szafirowska et al., 1981). The FGP of tomato or asparagus seeds in nonsaline media at 20C was not increased by priming, but in saline media at 20C the FGP of both species was increased by priming seeds in INO or $NaNO_3$ (Table 2). At 30C in saline media, the FGP of tomato seeds primed in PEG or $NaNO_3$ was higher than that of untreated seeds. Thus, salinity expanded the temperature range over which priming benefited tomato germination. The FGP of asparagus seeds at 30C in saline media was not increased by priming, revealing the greater salt tolerance of asparagus (Maas, 1986).

Since the G_{50} of tomato seeds primed in PEG or INO was lower than that of untreated seeds only at 20C in saline media (Table 2), the major effect of these two priming agents on tomato was that of increasing FGP. Sodium nitrate was superior to PEG or INO for priming tomato seeds since, relative to untreated seeds, G_{50} was decreased and FGP was increased under all conditions except 20 or 30C in nonsaline media. Faster germination from KNO_3-primed than from PEG-primed tomato seeds was associated with a higher seed moisture content and presumably a more advanced stage of development (Alvarado and Bradford, 1988). Primed asparagus seeds had lower G_{50} values than untreated seeds irrespective of germination environment and with priming agent exerting little or no effect (Table 2).

Seed moisture and planting method. Seeds of tomato and asparagus primed only in – 0.8 MPa $NaNO_3$ were surface-dried (sd), dried-back (db), or fluid-drilled (fd) (Table 1). In addition, untreated seeds or germinated seeds (radicles 1 to 3 mm long) were mixed in hydroxyethyl cellulose gel (N-gel, Aqualon Co., Wilmington, Del.) for fluid drilling. Fifty seeds were mixed in 15 ml of the gel contained within a 125-ml plastic bag so that extrusion through a cut corner would be 25 $ml \cdot m^{-1}$ of row. Seeds were sown dry or fluid-drilled at 50 seeds per 17 × 12 × 6-cm plastic flat in five 1-cm-deep × 12-cm-long furrows. The growth medium was a commercial peat-lite (ProMix BX, Premier Brands, Stanford, Conn.). The flats were irrigated daily with 50 mg N/liter from 20NA-3P-8.8K (Peters 20-10-20, W.R. Grace, Fogelsville, Pa.). On alternate days, half of the flats received the fertilizer solution that contained 5.7 g INO/liter to provide osmotic stress (Table 1).

The 2 (salinity) × 6 (seed treatment) factorial was arranged in a randomized block design with four replications. The experiment was conducted under natural light (Oct.-Nov. 1989) in a glasshouse with a day/night temperature range of 23 to 27C/14 to 17C.

Days to 50% emergence (E_{50}) and final emergence percentage (FEP) were calculated from daily seedling emergence counts (epicotyl or hypocotyl first visible). Shoots of tomato and asparagus seedlings were cut at the growth medium surface 17 and 36 days after sowing, respectively, and the dry weight (mg/shoot) determined.

Tomato. FEP, E_{50}, and shoot dry weights were influenced by the interaction of seed treatment and salinity (Table 3). Only germinated-fd seeds had a higher FEP than dry-sown, untreated seeds irrespective of salinity regime (Table 3). Primed-fd seeds had higher FEP than primed-db seeds regardless of salinity regime, suggesting that FEP was associated with the moisture content of primed seeds at the time of seed sowing.

Salinity increased the E_{50} of seedlings from all treatments, except primed-sd seeds or germinated-fd seeds (Table 3). Slower seedling emergence from most seed treatments may reflect osmotically restricted water availability. The INO plus fertilizer solution yielded -0.39 MPa at 20C (6.9 $dS \cdot m^{-1}$), while the fertilizer solution alone yielded -0.04 MPa at 20C (0.59 $dS \cdot m^{-1}$). Irrespective of salinity, primed-db seeds had higher E_{50} than primed-fd or primed-sd seeds, a response noted elsewhere (Evans and Pill, 1989; Frett and Pill, 1989; Pill, 1986) that, at least in part, may reflect the increased time required for re-imbibition. Seedling shoot dry weights generally were related inversely to E_{50} values (Table 3) as noted in asparagus (Evans and Pill, 1989) and parsley (Pill, 1986). Priming and pregermination increased shoot weight in nonsaline media regardless of seed drying treatment. In saline media, seedling shoot weights from primed-db seeds were the same as those from untreated seeds, while other primed or pregerminated seeds resulted in higher shoot weights (Table 3).

Asparagus. The FEP and seedling shoot dry weights were influenced by the interaction of salinity and seed treatment, while E_{50} was influenced only by these main effects (Table 3). Salinity reduced FEP from all seed treatments except from germinated-fd seeds (Table 3). In nonsaline conditions, only primed-fd seeds had a higher FEP than untreated seeds, but in saline conditions, primed-fd, primed-sd, and germinated-fd seeds had higher FEP than untreated seeds. Thus, sowing seeds of high moisture content, such as surface-drying primed seeds or fluid-drilling primed or germinated seeds, is an effective strategy to improve FEP in saline conditions. Francois (1987) noted that germination percentage of ‘UC 157’ asparagus seeds was not affected with up to 4.2 $dS \cdot m^{-1}$ of conductance induced by salt (equal weights of NaCl and $CaCl_2$), but above this threshold, germination was decreased by 1.5% with each unit increase in salinity up to 7.2 $dS \cdot m^{-1}$. While the growth medium soluion would approach the 6.9 $dS \cdot m^{-1}$ of the INO-fertilizer solution immediately after irrigation, values would increase between irrigations as water was lost by evapotranspiration. Thus, the low (40%) FEP of untreated seeds in saline media (Table 3) would be expected.

Saline irrigation increased E_{50} of seeds from all treatments, except from germinated-fd seeds (Table 3). As with tomato seeds, the E_{50} of primed-db asparagus seeds was higher than from primed-fd or primed-sd seeds. Under saline conditions, germinated-fd seeds and primed-fd seeds gave E_{50} values lower by 7.0 and 5.4 days, respectively, than the 18.7-day E_{50} value of untreated seeds.

Salinity decreased shoot dry weights of asparagus (Table 3) by an average of 42%, but of tomato by an average of 67%, as would be expected given the greater salt tolerance of asparagus (Maas, 1986). Compared with the untreated seeds, only primed-sd seeds had heavier shoots in nonsaline media, and only germinated-fd seeds had higher shoot weights in saline media.

We have shown that $NaNO_3$ was superior to PEG or INO for priming tomato seeds, but that priming agent had little or no effect on the germination of asparagus seeds. When exposed to saline irrigation, primed seeds of both species regardless of drying treatment had lower E_{50} values than dry-sown untreated seeds. In this stressful seedbed, priming did not increase FEP from tomato seeds but increased FEP from asparagus seeds, provided they were not dried-back. Fluid-drilling primed or germinated seeds enhanced the establishment of both species in a saline seedbed relative to dry-sowing primed-db or untreated seeds.

Literature Cited

Alvarado, A.D. and K.J. Bradford. 1988. Priming and storage of tomato *(Lycopersicon esculentum)* seeds. I. Effects of storage temperature on germination rate and viability. Seed Sci. & Technol. 16:601-612.

Bradford, K.J. 1986. Manipulation of seed water relations via osmotic priming to improve germination under stress conditions. HortScience 21:1105-1112.

Brocklehurst, P.A. and J. Dearman. 1983. Interactions between seed priming treatments and nine seed lots of carrot, celery, and onion. I. Laboratory germination. Ann. Applied Biol. 102:577-584.

Evans, T.A. and W.G. Pill. 1989. Emergence and seedling growth from osmotically primed or pregerminated seeds of asparagus *(Asparagus officinalis* L.). J. Hort. Sci. 64:275-282.

Francois, L.E. 1987. Salinity effects on asparagus yield and vegetative growth. J. Amer. Soc. Hort. Sci. 112:432-436.

Frett, J.J. and W.G. Pill. 1989. Germination characteristics of osmotically primed and stored impatiens seeds. Scientia Hort. 40:171-179.

Frett, J.J., W.G. Pill, and D.C. Morneau. 1991. A comparison of priming agents for tomato and asparagus seeds. HortScience 26:1158-1159.

Gray, D. 1984. The role of fluid drilling in plant establishment. Aspects Applied Biol. 7:153-172.

Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. Calif. Agr. Expt. Sta. Circ. 347.

Maas, E.V. 1986. Salt tolerance of plants. Applied Agr. Res. 1:12-26.

Pill, W.G. 1986. Parsley emergence and seedling growth from raw, osmoconditioned, and pregerminated seeds. HortScience 21:1134-1136.

Pill, W.G. and W.E. Finch-Savage. 1988. Effects of combining priming and plant growth regulator treatments on the synchronization of carrot seed germination. Ann. Applied Biol. 113:383-389.

Szafirowska, A., A.A. Khan, and N.H. Peck. 1981. Osmoconditioning of carrot seeds to improve seedling establishment and yield in cold soil. Agron. J. 73:845-848.

Weibe, H.J. and T. Muhyaddin. 1987. Improvement of emergence by osmotic treatment in soil of high salinity. Acta Hort. 198:91-100.

Winston, P.W. and D.H. Bates. 1960. Saturated solutions for the control of humidity in biological research. Ecology 41:232-237.