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PRIMING 'SOLARSET' TOMATO SEEDS TO IMPROVE GERMINATION AT HIGH TEMPERATURE

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Abstract. **In Florida, the fall fresh market tomato (*Lycopersicon esculentum* Mill.) crop is planted by transplants which are sown in the greenhouse during July, Aug., and Sept. During this period, temperatures can exceed 35C in the greenhouse which will result in poor and nonuniform emergence. Methods which improve germination under stressful temperature were examined along with some of the physiological components of the seed which might contribute to thermoinhibition. Germination of nonprimed seeds of 'Solarset' and two lots of 'Sunny' produced in 1990 ('Sunny-90'), and in 1987 ('Sunny-87') was not affected until a temperature of 31C was reached. At 33C, germination was drastically reduced and at 36C germination was essentially completely inhibited. To overcome the reduction and inhibition of germination at high temperature, the seeds were primed in various osmotic solutions including KNO_3, K_3PO_4, $KNO_3 + K_3PO_4$, mannitol, and PEG 8000 (wp = −12 bars) at 25C in the dark for 6 days with continuous aeration. Generally, the KNO_3 or PEG 8000 solutions consistently improved germination of 'Solarset', 'Sunny-87', and 'Sunny-90' at 35C. After some refinement in the aeration procedure during priming, seeds primed in a PEG 8000 solution germinated better at 35C than seeds primed in KNO_3. Priming the seeds for 7 or 8 days produced the same result as priming for 6 days.**

Florida is the leading fresh market tomato producer in the United States. The income from tomato production accounts for over 42% of the total income derived from vegetable production in Florida (Florida Agricultural Statistics, 1993). The area planted to the tomato crop in the 1991-92 season was 21,000 ha with a total yearly income averaging about $729 million. About 73% of the acreage in 1990-91 was planted using 'Sunny' and 0.4% using 'Solarset'. In 1991-92, 52% was planted in 'Sunny' and 11% in 'Solarset' (Florida Agricultural Statistics, 1993).

Tomato crop production in Florida is largely from transplants raised in transplant houses. Seedling production of vegetable crops in Florida is a very specialized industry and is a year-round operation which supplies growers both in and outside the state.

'Sunny' is the dominant fresh market tomato cultivar production in Florida and yields well throughout the year except during the hot months of Aug., Sept., and early Oct. During these months, air and soil temperatures usually exceed 35C which can significantly reduce fruit set in 'Sunny'. 'Solarset', a cultivar bred to set fruit under conditions of high temperature stress, overcomes the poor fruit setting ability observed in 'Sunny' during late summer and early fall periods (Scott et al., 1989), thus, providing a cultivar with adequate yielding potential during these hottest months.

Germination of 'Solarset' seeds has been extremely poor and nonuniform during the months of July, August, and September where temperatures in the greenhouse can far exceed 35C. This problem potentially limited the large-scale use of 'Solarset' as a substitute for 'Sunny' during these months. Improving the germination potential of 'Solarset' seed might give Florida tomato growers a competitive edge in early fall production due to the potential of 'Solarset' to set fruit during this time.

Priming seeds has improved germination of many vegetable crops, particularly at stressful low temperatures (Bradford, 1986). Priming is a process of imbibing seeds in an osmotic solution that allows the seed to imbibe water and go through the first steps of germination but which does not permit radicle protrusion through the seed coat (Cantliffe, 1981). As a result, 'slow' and 'fast' germinating seeds of a single lot are brought to the same stage of germination readiness after priming (Cantliffe, 1989). Priming or osmoconditioning seeds prior to sowing has improved tomato seed germination at stressful high temperature (Odell and Cantliffe, 1986). Priming has increased germination rate, total germination, and seedling uniformity of many crops, especially under stressful environmental conditions (Cantliffe, 1981; Cantliffe et al., 1978).

The effect of seed priming on germination varies with species, cultivar, and seedlot (Ellis and Butcher, 1988). The causes of poor germination in tomato seed at high temperature are not clear, but large differences in germination among cultivars and seedlots could be reduced by refining some components of the priming procedure. To increase the degree of response to priming and to achieve a significant increase in germination rate or percentage, it is important to choose the best osmotic source and water potential in which to prime. In addition, the duration and temperature of the soak, optimum aeration of the seeds, the need for light upon priming, and the seed drying procedure after priming require close consideration (Cantliffe, 1981; Heydecker and Coolbear, 1977).

Currently, the cost of F_1 hybrid tomato seed is about $2,500/kg, a price that is expected to increase in the future. In addition, seedling production involves a high degree of mechanization. Therefore, germination of each 'Solarset' and 'Sunny' seed sown is needed to reduce production costs. By manipulating some components of the priming procedure, germination of 'Solarset' seed at high temperature might be improved to a level wherein total uniform emergence is achieved regardless of temperatures in the greenhouse.

The objective of the present experiments was to improve germination of 'Sunny' and 'Solarset' seeds at stressful high temperature (>33C) by establishing the most effective method for priming the seeds.

Materials and Methods

For priming, 100 tomato seeds of three seedlots 'Solarset' produced in 1990, 'Sunny-87' produced in 1987 and

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'Sunny-90' produced in 1990 were placed in a 50 ml test tube containing 35 ml of priming solution as noted. Aeration, during priming, was provided through a glass tube connected by a rubber hose to an aquarium pump. Priming was conducted in the dark at constant 25C in an incubator. Distilled water was added to the test tubes as needed to maintain constant volume, and therefore, constant water potential of the solution. After priming, the seeds were removed from the solution and rinsed with 200 ml of distilled water and surface-dried immediately. Seeds were then dried back to their original moisture content (6-8%) in a cold room at 10C and 45% relative humidity before they were used in germination tests. Germination tests, both on a thermogradient bar and in the incubators, were conducted at a constant temperature in the dark, unless otherwise specified.

The seeds (25 per replication per treatment) were imbibed on two layers of 9 cm diameter Whatman #3 filter paper moistened with 6 ml of distilled water. For temperatures above 30C on the thermogradient bar (Type DB 5000, Van Dok & De Boer Bv) the number of filter papers was increased to three and moistened with 8 ml of distilled water to reduce rapid redrying. Distilled water was added as needed to keep the filter paper moist. Germination was noted when a radicle visibly protruded through the seed coat. Germination counts were made daily for 14 consecutive days. Total percent germination and mean days to germination (MDG) were calculated as a measure of response to each replication. The formula of Gerson and Honma (1978) was used to calculate MDG:

$$MDG = \frac{N_1T_1 + N_2T_2 + N_3T_3 + \text{---} + N_xT_x}{\text{Total number of seeds germinated}}$$

where:

N = Number of seeds germinating within consecutive time interval;

T = Time (in days) from beginning of test to end of a particular interval.

Each replication for every treatment was primed separately. Data were analyzed by an analysis of variance (ANOVA) (Steel and Torrie, 1980) using SAS (Statistical Analysis System, 1988). Germination percentage was subjected to a square root arcsin transformation prior to ANOVA. Treatment means were separated by a Duncan's Multiple Range Test or LSD test (Little and Hills, 1978).

Experiment I. Germination Tests of Nonprimed and Primed Tomato Seeds at Different Temperatures

A standard germination test of nonprimed and primed seeds of the three seedlots were conducted on a thermogradient bar at nine different temperatures. The first attempt to improve germination was accomplished through priming and this test was planned to achieve a meaningful standard with which the results from the priming procedure could be evaluated. Priming was done for 6 days at 25C using aerated PEG 8000 solution (wp = –12 bars) in the dark. Descriptions of the thermogradient bar have been published by Fox and Thompson (1971) and Peters (1990). Seeds were sown along the length of the bar and temperature measurement on the bar at nine positions was recorded with calibrated thermistor beads and recorded every day until the experiment was completed. In addition, three thermometers with special foot-blocks were used to check the table temperature. The surface of the thermogradient bar was maintained in the dark by using five inspection plasti-coat wood covers.

An experiment consisting of 14, 16, 20, 23, 25, 28, 31, 33, and 36C treatments for nonprimed and primed seeds of 'Solarset', 'Sunny-90', and 'Sunny-87' was conducted in a split-block experimental design with temperatures as the main block and seedlots as the split block. Each seedlot was replicated three times.

Experiment II. The Effect of Priming Solutions on Tomato Seed Germination

To examine the effect of osmoticum on priming effectiveness, seeds of the three seedlots were primed for 6 days in the dark at 25C in several different osmotic sources (wp = –12 bars): KNO_3 (3%), K_3PO_4 (5.1%), KNO_3 (1.56%) + K_3PO_4 (2.36%), mannitol (8.84%), or PEG 8000 (31%). To investigate any side effects of the osmotic solutions on germination, the seeds were also primed in aerated distilled water for 36 hours. Nonprimed seeds were used as a control. Germination tests were conducted in the dark at constant temperatures of 15, 25, or 35C in incubators. For each temperature, a randomized complete block experiment design was used with seedlot and seed treatment combinations replicated three times.

Experiment III. The Effect of Varying Duration of Priming on Tomato Seed Germination

Seeds of the three seedlots were primed in KNO_3 (3%) and PEG 8000 (31%) solutions (wp = –12 bars each) for 0, 4, 5, 6, 7 and 8 days at 25C in the dark to measure changes in germination as compared to the standard 6-day priming duration used in Experiment II. KNO_3 and PEG 8000 solutions were selected based on the observed improvement in germination of seeds of the three seedlots at 15, 25, and 35C. For germination tests, 25 seeds per replicate were imbibed in 9 cm Petri dishes with one layer of blue germination blotter paper (Anchor Paper Co., St. Paul, MN) moistened with 6 ml of distilled water in the dark at a constant 25 and 35C. A randomized complete block experimental design with seedlot, kind of osmoticum, and priming duration treatment combinations were replicated four times in each temperature.

In another experiment, seeds of the three seedlots were primed in 31% PEG 8000 solution (wp = –12 bars) for 0, 4, 5, 6, 7 and 8 days at 25C in the dark. This portion of the experiment was repeated as a result of some refinement in aeration procedure developed during priming over a period of time. Germination was conducted at 25 and 35C in incubators with a photoperiod of 12 hours of light (–15 μmol m^{-2} s^{-1}) and 12 hours of dark. A randomized complete block experimental design with seedlot and priming duration treatment combination was replicated four in each temperature.

Results

Experiment I. Germination Tests of Nonprimed and Primed Tomato Seeds at Different Temperatures

Total germination of nonprimed tomato seeds was significantly reduced at 33C and germination was essentially totally inhibited at 36C on the thermo-gradient bar (Table 1). Germination rate and mean days to germination (MDG) of nonprimed tomato seeds was significantly delayed at 36C as compared to seeds germinated at 25C. At 33C, the reduction in percent germination was greater in 'Sunny-87' seeds than 'Solarset' seeds which generally had lower germination values at lower temperatures. 'Sunny-87' seeds had a significantly slower rate of germination at 36C than 'Sunny-90' and 'Solarset' seeds.

Generally, priming seeds in PEG 8000 enhanced total germination at 33 and 36C, temperatures at which thermoinhibition was evident in nonprimed seeds (Table 2). Primed 'Sunny-90' seeds generally had the greatest germination percentages.

Germination of primed seeds at 14 and 36C was delayed compared to that at the 20 to 33C range. At 14C, 'Sunny-87' germinated more slowly than 'Solarset', but at 36C 'Solarset' germinated more slowly than 'Sunny-87'.

Experiment II. The Effect of Priming Solutions on Tomato Seed Germination

Promising results were observed at 33C and higher by priming tomato seeds in the previous experiment. Therefore, the three seedlots were primed in various solutions to identify the most effective osmoticum.

Total germination for 'Sunny-90' seeds was unaffected by priming solution at 15C (Table 3). Nonprimed 'Solarset' seeds had less total germination compared to primed 'Solarset' or nonprimed 'Sunny-90' and 'Sunny-87' seeds. Fewer 'Sunny-87' seeds germinated at 15C when primed in K_3PO_4 and KNO_3 + K_3PO_4 solutions compared to 'Solarset' and 'Sunny-90' seeds primed in the same solutions, or when any seedlot was primed in KNO_3, mannitol or PEG 8000. 'Sunny-90' seeds primed in KNO_3, K_3PO_4, KNO_3 + K_3PO_4, PEG or mannitol had more rapid germination compared to nonprimed seeds. Germination rate (MDG) of 'Sunny-87' seeds was greatest when they were primed in KNO_3 or KNO_3 + K_3PO_4 compared to water or not priming the seeds.

Priming did not improve total germination of 'Solarset' and 'Sunny-90' seeds at 25C when compared with nonprimed seeds (Table 4). Priming 'Solarset' seeds in KNO_3 + K_3PO_4 reduced germination as compared to 'Solarset' seeds primed in mannitol or distilled water. Priming 'Sunny-87' seeds in K_3PO_4 and KNO_3 + K_3PO_4 solutions had an adverse effect on percent germination. 'Sunny-87' seeds primed in KNO_3, mannitol, PEG 8000, and water had a similar percent germination as nonprimed seeds. Primed 'Sunny-87' seeds germinated less at 25C than seeds of 'Solarset' and 'Sunny-90' primed in any of the osmotica evaluated.

'Solarset' seeds primed in solutions other than water germinated more rapidly than nonprimed seeds or seeds primed in distilled water for 36 hours (Table 4). Nonprimed 'Solarset' seeds averaged 5.6 MDG whereas seeds

Table 1. Germination percent and mean days to germination (MDG) of nonprimed tomato seeds at different temperatures after one year of storage.

Temperature (C)	Seedlots: SolarSet % Germ.[z]	SolarSet MDG	Sunny-90 % Germ.	Sunny-90 MDG	Sunny-87 % Germ.	Sunny-87 MDG
14	84	4.8	97	4.5	83	5.3
16	78	4.2	97	3.7	92	4.6
20	88	3.9	99	3.0	91	4.2
23	83	3.1	100	2.6	92	3.1
25	80	2.5	97	2.3	91	3.2
28	81	2.8	96	2.3	93	3.4
31	81	2.9	95	2.6	93	4.0
33	60	4.2	72	4.2	39	6.1
36	5	6.4	2	10.2	1	14.0

[z]$LSD_{(0.05)}$ for seedlot × temperature interaction for percentage germination = 11 and MDG = 2.3.

Table 2. Germination percentage and mean days to germination (MDG) of tomato seeds primed in aerated PEG 8000 solution (for 6 days at 25C) at different temperatures.

Temperature (C)	Seedlots: SolarSet % Germ.[z]	SolarSet MDG[y]	Sunny-90 % Germ.	Sunny-90 MDG	Sunny-87 % Germ.	Sunny-87 MDG	% Germ. Mean
14	71	3.6	99	3.9	84	4.6	84c[y]
16	87	2.2	95	2.6	87	3.3	89bc
20	83	1.9	100	2.0	93	2.3	92ab
23	84	1.5	97	1.5	95	1.8	92abc
25	84	1.6	97	1.6	99	2.1	93a
28	87	1.5	97	1.2	93	1.5	92abc
31	88	1.4	100	1.2	91	1.6	93ab
33	85	2.1	100	1.8	91	2.1	92ab
36	49	3.8	75	2.5	65	2.9	63d
Mean	80c		96a		89b		

[z]Mean separation for percentage germination by Duncan Multiple Range Test, 0.05, Temperature × seedlot interactions were not significant.
[y]$LSD_{(0.05)}$ for MDG 0.6.

Table 3. The effect of osmoticum in the priming solutions on percentage germination and mean days to germination (MDG) at 15C of seeds of three tomato seedlots.

Priming solution	Seedlots: SolarSet % Germ.[z]	SolarSet MDG	Sunny-90 % Germ.	Sunny-90 MDG	Sunny-87 % Germ.	Sunny-87 MDG
KNO_3	92	6.9	98	5.5	82	3.8
K_3PO_4	93	5.2	95	4.2	37	6.4
$KNO_3 + K_3PO_4$	93	5.2	98	3.4	58	3.9
Mannitol	95	7.2	99	6.7	79	5.5
PEG 8000	97	6.8	95	7.4	84	5.6
Primed in water	89	9.3	88	6.9	78	7.3
Nonprimed seeds	48	11.3	82	8.8	70	7.3

[z]$LSD_{(0.05)}$ for solution × seedlot interaction for percent germination = 19 and MDG = 2.0.

Table 4. The effect of osmoticum in the priming solution on germination percent and mean days to germination (MDG) at 25C of three tomato seedlots.

Priming solution	Seedlots: SolarSet % Germ.[z]	SolarSet MDG	Sunny-90 % Germ.	Sunny-90 MDG	Sunny-87 % Germ.	Sunny-87 MDG
KNO_3	93	2.4	98	1.7	81	1.7
K_3PO_4	93	2.0	96	1.9	35	2.9
$KNO_3 + K_3PO_4$	85	2.1	95	1.2	49	2.2
Mannitol	95	2.5	96	2.0	84	1.9
PEG 8000	93	2.8	99	2.4	88	2.1
Primed in water	95	3.5	96	2.9	82	3.4
Nonprimed seeds	92	5.6	90	3.5	82	3.6

[z]$LSD_{(0.05)}$ for percent germination solution × seedlot interaction = 9, and MDG = 0.6.

primed in osmotic solutions averaged 2.5 MDG. This general germination rate enhancement was observed in each of the seedlots when primed using an osmotic solution.

Percent germination of 'Solarset' and 'Sunny-90' seeds at 35C was enhanced by priming regardless of osmoticum (Table 5). K_3PO_4 was an effective osmotic when 'Solarset' seeds were primed, but was less effective when 'Sunny-87' or 'Sunny-90' were primed. There were few differences in percent germination at 35C between 'Solarset' and 'Sunny-87' seeds primed in any of the osmotic solutions.

Priming tomato seeds significantly increased MDG at 35C compared to not priming the seeds (Table 5). The osmoticum treatments were generally more effective at 35C than priming in distilled water. 'Sunny-87' seeds primed in K_3PO_4 germinated slower than seeds primed in KNO_3, KNO_3 + K_3PO_4 and PEG 8000. 'Solarset' seeds primed in K_3PO_4 germinated more rapidly than 'Sunny-87' seeds. Nonprimed 'Solarset' seeds did not germinate over 14 days.

Experiment III. The Effect of Varying Duration of Priming on Tomato Seed Germination

Percent germination at 25C was similar regardless of the duration of priming in either KNO_3 or PEG 8000 (Table 6). Priming seeds in PEG 8000 resulted in more germination compared to seeds primed in KNO_3. Primed 'Sunny-90' seeds had a greater percent germination than 'Sunny-87' while 'Solarset' had the lowest germination at 25C of the three seedlots. 'Sunny-87' seeds primed in KNO_3 germinated slower than 'Sunny-90' seeds primed in KNO_3 solution. Germination rate in PEG was generally the same as in KNO_3.

Germination of 'Solarset' seeds, at 35C, after 4, 5 or 6 days of priming was less than seeds primed for 7 or 8 days (Table 7). Priming 'Sunny-90' seeds for 8 days improved percent germination over 4 days. There was no difference in percent germination in 'Sunny-87' seeds. 'Sunny-90' seeds had a greater percent germination than 'Solarset' and

Table 5. The effect of osmoticum in the priming solution on germination percent and MDG at 35C of three tomato seedlots.

Priming solution	Seedlots: SolarSet % Germ.[z]	SolarSet MDG	Sunny-90 % Germ.	Sunny-90 MDG	Sunny-87 % Germ.	Sunny-87 MDG
KNO_3	55	2.4	75	3.0	65	2.3
K_3PO_4	64	3.0	57	4.6	19	6.5
$KNO_3 + K_3PO_4$	29	2.3	81	2.8	14	2.7
Mannitol	54	3.3	81	4.0	45	4.7
PEG 8000	51	5.0	75	5.3	56	2.7
Primed in water	36	7.8	53	7.7	35	7.2
Nonprimed seeds	0	14.0	12	8.4	7	11.0

[z]$LSD_{(0.05)}$ for percent germination solution × seedlot interaction = 22, and MDG = 2.8.

Table 6. Mean days to germination (MDG) of three tomato seedlots at 25C after priming in KNO_3 or PEG 8000 solution (at 25C for 4-8 days).

	Priming solution				
	KNO_3		PEG 8000		
Seedlot	Solution mean % germinated	MDG[z]	Solution mean % germinated	MDG	Seedlot mean % germination[y]
Solarset		1.5		1.4	85c
Sunny-90		1.2		1.4	98a
Sunny-87		2.4		2.3	92b
Mean	90b		94a		
Interactions			% Germination	MDG	
Seedlot * solution			ns	**	
Seedlot * days			ns	ns	
Solution * days			ns	ns	
Seedlot * solution * days			ns	ns	

[z]$LSD_{(0.05)}$ value for MDG for seedlot × solution interaction = 1.0.
[y]Mean separation by Duncan's Multiple Range Test, 5% level.

Table 7. Interaction of germination percent of three tomato seedlots at 35C after priming in KNO_3 or PEG 8000 solution (at 25C for 4-8 days in the dark), and main effect of mean days to germination (MDG).

Priming days	Seedlot			
	SolarSet	Sunny-90	Sunny-87	Seedlot mean[x]
		% germination[z]		MDG
4	45	76	23	4.2a
5	38	79	27	4.1a
6	34	81	24	3.4b
7	56	84	24	2.9b
8	56	92	25	3.0b
Interaction				Solarset = 3.0a
Seedlot × solution		ns		Sunny-90 = 3.6a
Solution × days		ns		Sunny-87 = 3.7a
Seedlot × days[x]		*		
Seedlot × solution × days		ns		Solution Mean
				KNO_3 = 3.3a
				PEG 8000 = 3.7b

[z]Nonprimed seeds common to evaluate percent germination at 35C for both KNO_3 and PEG 8000 solutions; 'Solarset' = 0; 'Sunny-90' = 12; 'Sunny-87' = 1. Solution means for % germination: KNO_3 = 43b, PEG 8000 = 58a. Data pooled over priming solutions. $LSD_{(0.05)}$ for seedlot × days interaction = 15.
[x]Seedlot × solution, seedlot × days, solution × days, and seedlot × solution × days interactions were nonsignificant at $P \leq 0.05$. MDG for nonprimed seeds: Solarset = 14.0; Sunny-90 = 8.1; Sunny-87 = 11.0. Treatment means (main effect means including seedlot mean) followed by the same letter are not statistically different from each other at $P \leq 0.05$. Mean separation by $LSD_{(0.05)}$.

'Sunny-87' seeds regardless of the priming duration. Without priming, the tomato seeds did not germinate at 35C.

Priming seeds of the three seedlots for 6-8 days in KNO_3 or PEG 8000 increased germination rate (MDG) at 35C compared to priming for 4-5 days (Table 8). There was no difference in MDG among the seedlots at 35C. Tomato seeds primed in KNO_3 germinated more rapidly than those primed in PEG 8000 solution.

Priming in PEG 8000 solution

Slight modifications were made in the aeration process during priming and seeds of the three seedlots were again primed in PEG 8000 solution for 4-8 days at 25C in the dark. Percent germination of primed seeds at 25C was similar regardless of priming duration (Table 8). 'Sunny-90' seeds had a greater germination percentage than 'Sunny-87' and 'Solarset' seeds at 25 and 35C. Fewer 'Solarset' seeds germinated at 25 and 35C than 'Sunny-87' seeds. Priming tomato seeds for 8 days in PEG 8000 at 25C improved total germination at 35C compared to nonprimed seeds or seeds

Table 8. Germination percent of three tomato seedlots at 25 and 35C after priming in PEG 8000 solution (for 4-8 days at 25C)[z].

Priming days	Mean	Mean[y]
	25C	
0	92a	Solarset = 85c
4	89a	Sunny-90 = 97a
5	93a	Sunny-87 = 92b
6	93a	
7	89a	
8	91a	
	35C	
0	23c	Solarset = 59c
4	80b	Sunny-90 = 87a
5	82ab	Sunny-87 = 75b
6	84ab	
7	85ab	
8	87a	

[z]Seedlot × day interaction for percent germination at either temperature was not significant at $P \leq 0.05$.
[y]Main effect means at each temperature followed by the same letter are not significantly different at $P \leq 0.05$. Mean separation by $LSD_{(0.05)}$.

primed for 4 days. Percent germination of primed seeds observed at 35C were similar among the 5- to 8-day treatments regardless of cultivar.

Priming seeds of 'Solarset' and 'Sunny-87' seeds at 25C for 6-8 days increased germination rate compared with nonprimed seeds or seeds primed 4 or 5 days (Table 9). Germination rate of 'Solarset', 'Sunny-90' and 'Sunny-87' was not affected at 35C by prime duration. At either germination temperature, nonprimed seeds of the three seedlots germinated more slowly than primed seeds.

Discussion

Germination of nonprimed 'Solarset' and 'Sunny' seeds was reduced above 31C, as reported for tomato seeds by other investigators (Berry, 1969; Jarowski and Valli, 1965; Thompson, 1974; Wagenvoort and Bierhuizen, 1977). Germination of nonprimed seeds of both cultivars was completely inhibited at 35C during the 14-day period. Priming the seeds in PEG 8000 solution for 6 days partially alleviated thermo-inhibition at 35C increasing 'Solarset', 'Sunny-90', and 'Sunny-87' germination from 0 to 49, 75, and 65%, respectively, as compared to nonprimed seeds.

The response of the three seedlots to priming was variable at 35C when PEG was initially used to prime the seeds (Table 5). Differential germination response among cultivars and seedlots after priming is not uncommon (Ellis and Butcher, 1988). Refinement of components of the priming procedure, such as osmoticum and water potential, soak duration, temperature of the soak, aeration, and duration of priming have been reported to influence germination response after priming (Cantliffe, 1981; Heydecker and Coolbear, 1977). Factors that may influence germination of primed seeds were considered in order to improve the results achieved from priming during subsequent imbibition at 35C.

Priming tomato seeds in salt solutions of KNO_3, K_3PO_4, a mixture of $KNO_3 + K_3PO_4$, PEG 8000, or mannitol have previously been reported to improve germination (Ells, 1963; Odell and Cantliffe, 1986; Heydecker and Coolbear, 1977; Thanos and Georghiou, 1982). In the present experiments, KNO_3 and PEG 8000 consistently improved germination percentage and rate of the three tomato seedlots at 35C as compared to mannitol, K_3PO_4 and $KNO_3 + K_3PO_4$. A priming solution of $KNO_3 + K_3PO_4$ was reported to improve tomato seed germination at high temperature (Odell and Cantliffe, 1986), but in the present experiment the salt combination or K_3PO_4 used alone only improved germination at 35C of either 'Sunny-90' or 'Solarset', respectively, compared to the control. Mannitol used as the osmoticum improved germination of 'Solarset' and 'Sunny-90' seeds, but had a minimal effect on 'Sunny-87'. Therefore, PEG 8000 or KNO_3 were considered an acceptable osmoticum, since, no other osmoticum evaluated was superior.

Effectiveness of priming may be altered by the duration of the soak. Priming the seedlots for 6, 7, or 8 days resulted in similar germination when KNO_3 or PEG 8000 were used as the osmoticum. Priming seeds for 4 or 5 days was not as efficient as 6, 7, or 8 days in improving both total germination or germination rate.

'Solarset' and 'Sunny' seeds primed in either PEG 8000 or KNO_3 had the same total germination, however, viscosity and oxygen diffusivity problems with PEG 8000 required greater attention (Greenway et al., 1968; Mexal et al., 1975). Reducing air bubble size in the solution and allowing more air to consistently pass through the solution by tying fine nylon mesh on the glass tube at the point of air release in to PEG 8000 priming solution led to increased germination at 35C of 'Solarset' seeds. The increase was from 49% (without the new procedure) to 70% at 35C with the new procedure. Germination of 'Sunny-90' and 'Sunny-87' seeds was also improved by altering aeration techniques, from 75 to 95% and 65 to 88%, respectively, at 35C. These results suggested that germination in 'Sunny-90' and 'Sunny-87' seeds at 35C could reach a level of germination observed at optimum temperature. However, optimizing all the conditions of the priming procedure did not result in a complete germination of 'Solarset' at 35C.

Continued research is necessary to determine why some 'Solarset' seeds remain thermoinhibited after priming. In tomato seed, the endosperm layer in front of the radicle tip has to be dissolved for germination to proceed normally (Groot and Karssen, 1987). In pepper seed germinated at low temperature, endosperm weakening was observed before germination occurred (Watkins and Cantliffe, 1983a; 1983b). In gibberellin-deficient mutants of tomato, weakening of the endosperm did not occur and germination was inhibited. In both tomato and pepper seeds, the addition of gibberellin increased the rate of endosperm weakening, and therefore, germination. The occurrence of thermoinhibition in 'Solarset' seeds after priming and its association with the seed coat and endosperm restraint requires further investigation.

Table 9. Mean days to germination (MDG) of three tomato seedlots at 25 and 35C after priming in PEG 8000 solution (for 4-8 days).

Priming days	Seedlots		
	Solarset	Sunny-90	Sunny-87
	MDG		
	25C		
0	2.6	2.2	2.3
4	1.5	1.3	1.7
5	1.5	1.2	1.7
6	1.3	1.1	1.2
7	1.2	1.1	1.2
8	1.3	1.0	1.4
Seedlot × day interaction[z]			*
	35C		
0	7.1	7.4	3.9
4	1.9	1.3	2.1
5	1.5	1.4	2.1
6	1.3	1.2	1.4
7	1.3	1.3	1.4
8	1.2	1.1	1.5
Seedlot × day interaction			***

*, ***Significant F-test at $P = 0.05$ or 0.001, respectively.
[z]$LSD_{(0.05)}$ for MDG at 25C = 0.18; for MDG at 35C = 1.2.

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EVALUATION OF CONTROLLED-RELEASE UREA FOR FRESH MARKET TOMATO

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Abstract. **Tomato, *Lycopersicon esculentum* Mill. cv. Sunny, was grown in the winter-spring 1991 with 4 N and K rates as main plots and 4 soluble N and controlled-release urea (CRU) combinations as sub-plots. Nitrogen and K rates were 1x, 2x, 3x and 4x where the 1x N and K rate was equivalent to 87 N and 145 K lb/acre. The CRU rates were 0, 50, 75 and 100% of the total N applied. Tomatoes were grown on raised beds with full-bed polyethylene mulch and a fully enclosed subirrigation system. Increasing proportions of CRU reduced plant heights ($P \leq 0.05$). Fresh weight of plants was lower with 1x and 2x than with 3x and 4x N and K rates ($P \leq 0.05$). Total yields of extra large fruit were similar with 2x, 3x and 4x N and K rates, but declined as the percentage of CRU-N increased ($P \leq 0.05$). Total marketable yields were maximized at 3x N and K rate ($P \leq 0.01$) and decreased with the percentage of N from CRU ($P \leq 0.01$). Residual soil NO_3^- and NH_4^+ concentrations were similar with all 4 SN:CRU treatments. Residual NO_3^- and K+ concentrations increased with increasing N and K rates. CRU percentages had no significant effect on N, K, Ca, and Mg concentrations in shoots, but P concentrations increased with increasing CRU applications.**

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Nitrogen loss from sandy soils in Florida is a major problem in vegetable production when soluble N-fertilizers (SN) are applied. Full-bed polyethylene mulch reduces N-loss due to leaching, but denitrification and volatilization losses still reduce N-utilization efficiency (Hauck and Koshino, 1971). Excessive soil moisture due to high rainfall within a short period or to overirrigation, may also contribute to N-leaching. Application of controlled release N-fertilizers (CRN) from which the release of N is a function of soil temperature rather than soil moisture, may reduce rapid N loss due to leaching (Gandeza et al., 1991; Hauck and Koshino, 1971; Prasad et al., 1971). Several CRN fertilizers have been studied for their effect on tomatoes. In earlier experiments tomato yields with CRN sources were similar or slightly higher than with a 100% SN source. On light sandy soil in the fall (Aug-Dec), early yields of fresh-market