Low-temperature Germination Response of su, se, and sh_2 Sweet Corn Cultivars

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SUMMARY. Early spring sweet corn (*Zea mays* var. *rugosa*) is usually planted in cold soils at sub-optimal temperatures for seed germination. It is important for growers to understand the relationships among temperature, germination, and vigor of sweet corn in order to plan the earliest planting dates that will not significantly reduce plant stand. The objectives of this research were 1) to determine the minimum temperatures to germinate to 75%, (the minimum germination percent for interstate commerce) for 27 new sweet corn su (sugary), se (sugar enhancer), and sh_2 (shrunken-2) cultivars; 2) to determine vigor differences among the phenotypes; and 3) to select the most promising se, su, and sh_2 cultivars for cold tolerance and vigor for early spring planting. Seeds of each cultivar were placed along a temperature gradient on a thermogradient table, Type 5001 (Seed Processing Holland, Enkhuizen, The Netherlands), and allowed to germinate over a 7-day period. The gradient treatments were [±2 °F (1.1 °C)] 52, 56, 60, 64, 68, 72, 76, 80, 84, and 86 °F (11.1, 13.3, 15.6, 17.8, 20.0, 22.2, 24.4, 26.7, 28.9, and 30.0 °C). Germination data from thermogradient testing were used to determine the minimum temperatures and time required for su, se, and sh_2 cultivars to germinate at ≥75%, defined as minimum acceptable germination percent (MAGP); and the minimum temperature to reach the maximum germination rate (MGR) for a cultivar, defined as the ability to germinate to MAGP at the same rate equally at low and high temperatures. Generally, su phenotypes germinated to MAGP within 4 days, with sh_2 requiring 6 days, but with se requiring 5 days. We found that within each phenotype, however, cultivars reacted uniquely to temperature. The most vigorous and cold tolerant su cultivars were 'NK 199' and 'Merit' which germinated to MAGP at 52 °F with 'NK 199' more vigorous than 'Merit'. The su cultivar 'Sweet G-90' was vigorous at warm temperatures, but the least cold tolerant and desirable for planting under cold conditions. Within the se cultivars, 'Precious Gem', 'July Gold', and 'Imaculata' germinated to MAGP at 52 °F with 'Precious Gem' requiring 6 days and 'July Gold' and 'Imaculata' requiring 7 days. 'Accord' was the least cold tolerant se cultivar, requiring at least 60 °F for MAGP with a slow MGR, even at warm temperatures. None of the sh_2 cultivars reached MAGP within 7 d at 52 °F, as was also observed for certain su and se cultivars.

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Sweet corn is a herbaceous, annual, warm-season monocot with an unknown place of origin (Rubatzky and Yamaguchi, 1997). Each undeveloped kernel is a single-seeded, dry indehiscent fruit composed of a small embryo and large endosperm (Copeland and McDonald, 2001). One of the features distinguishing sweet corn from field dent corn is the presence of the recessive form of the sugary gene su (Desai et al., 1997). Sweet corn requires temperatures of ≥50 °F (10 °C) for seed germination and proper seedling growth and development (Thompson and Kelly, 1959). In the early 1950s, optimal soil temperatures for sweet corn germination were established ranging from 60 to 95 °F (15.5 to 35 °C) with 95 °F considered optimal and 50 °F and 105 °F (40.5 °C) considered the minimum and maximum temperature extremes, respectively (Harrington and Minges, 1954). Since then, numerous hybrid cultivars have been released along with two additional genes which have been incorporated into commercial cultivars, shrunken-2 (sh_2) and sugary enhancer (se), with increased sugar levels and extended shelf life. Germination of these endosperm types can be more erratic and these seeds are difficult to plant using conventional equipment (Rubatzky and Yamaguchi, 1997). Although these higher sugar sweet corn phenotypes are favored among consumers, sweet corn growers have found that cold soils slow emergence, and reduce stands, earliness, and profitability. Four kernel properties thought to be associated with poor stands are 1) insufficient seedling energy reserves due to reduced starch concentration (Douglass et al., 1993); 2) membrane damage associated with high osmotic potential from elevated kernel sugar concentration; 3) excessively rapid influx of water during the germination process due to possible thin or cracked pericarp (Simon, 1978); and 4) susceptibility of the seeds to infection by fungal seed rot pathogens associated with delayed seed germination (Headrick et al., 1990). Seed companies have suggested that sh_2 and se phenotypes should be planted shallower and at soil temperatures higher [at least 10 °F (5.6 °C)] than required for the normal (su) phenotype (T. Natti, personal communication).

It is important for sweet corn growers to understand the relationships among temperature, germination, and vigor to plan the schedule planting dates that will not significantly reduce plant stand and plant performance. Seed vigor is defined as those properties that determine the potential for rapid, uniform emergence, and the development of normal seedlings under a wide range of field conditions [Association of Official Seed Analysts (AOSA), 1983]. Seed companies are required by law to provide final germination percentages on seed containers, but they do not need to provide any indication of seed vigor. At present, a lot of sweet corn seed can only be sold in interstate commerce if it has a minimal final germination of 75% or greater (Maynard and Hochmuth, 1997). Therefore, in our study, we defined this minimum standard as our lowest level of acceptability for sweet corn germination in thermogradient testing.

AOSA (1998) has stated that sweet corn germination should be tested at 77 °F (25 °C) with first germination counts taken after 4 d and final counts taken on the 7^{th} d. AOSA also gives the lower and upper temperature limits for sweet corn germination from 68 °F to 86 °F; however, soil temperatures in early spring may be much lower than 68 °F. In order to rank germination of sweet corn seed lots at lower temperatures in early spring, more work is needed to determine if currently grown sweet corn cultivars behave differently from previously published standards. A thermogradient test could be used to predict final germination percentages and also seed vigor

Table 1. Seed specifications for 27 cultivars of sweet corn representing three kernel phenotypes.

Cultivar	Phenotype	Color	Lot no.	Source	Germination (%)[z]	Seeds (no./lb)[y]
Country Gentleman	su	White	113 (P2)	Southern States Cooperative (Richmond, Va.)	97	3314
Silver Queen	su	White	OC 5353 LF	Rupp Seeds, Inc. (Wauseon, Ohio)	95	2270
Trucker's Favorite	su	White	101 (P1)	Southern States Cooperative (Richmond, Va.)	95	1362
Bi-Queen	su	Bi-color	NC 4202 MR	Rupp Seeds, Inc. (Wauseon, Ohio)	90	2406
Butter and Sugar	su	Bi-color	69708 R	Rupp Seeds, Inc. (Wauseon, Ohio)	90	1816
Sweet G-90	su	Bi-color	68624 ELF	Jeffery's (Goldsboro, N.C.)	90	1498
Jubilee	su	Yellow	NC7103 LR	Rupp Seeds, Inc. (Wauseon, Ohio)	95	1861
Merit	su	Yellow	14007 MR	Rupp Seeds, Inc. (Wauseon, Ohio)	95	2542
NK 199	su	Yellow	30403804 TH	Rupp Seeds, Inc. (Wauseon, Ohio)	90	1725
Avalanche	se	White	19020 MR	Mesa Maize, Inc. (Olathe, Colo.)	92	3133
Imaculata	se	White	21028 ELR	Mesa Maize, Inc. (Olathe, Colo.)	90	2633
Sparkle	se	White	19056 ELF	Mesa Maize, Inc. (Olathe, Colo.)	95	2724
Accord	se	Bi-color	22053 LR	Mesa Maize, Inc. (Olathe, Colo.)	95	2452
Precious Gem	se	Bi-color	2207 ELF	Mesa Maize, Inc. (Olathe, Colo.)	92	3360
Yankee Gem	se	Bi-color	22031 ELR	Mesa Maize, Inc. (Olathe, Colo.)	95	2179
July Gold	se	Yellow	21034 ELF	Mesa Maize, Inc. (Olathe, Colo.)	92	2588
Merlin	se	Yellow	22023 LR	Mesa Maize, Inc. (Olathe, Colo.)	95	2588
Tuxedo	se	Yellow	21005 ELR	Mesa Maize, Inc. (Olathe, Colo.)	90	2724
Ice Queen	sh_2	White	133827019	Harris Moran Seed Co. (Modesto, Calif.)	95	4268
Silver Dollar	sh_2	White	141370009	Harris Moran Seed Co. (Modesto, Calif.)	95	2724
Snow White	sh_2	White	143460006	Harris Moran Seed Co. (Modesto, Calif.)	95	3632
SCH 55146	sh_2	Bi-color	40905	Harris Moran Seed Co. (Modesto, Calif.)	90	3541
Summer Sweet 8102	sh_2	Bi-color	69534 N	Abbott & Cobb (Feasterville, Pa.)	94	3087
Twin Star	sh_2	Bi-color	143124009	Harris Moran Seed Co. (Modesto, Calif.)	95	4449
Bandit	sh_2	Yellow	143141017	Harris Moran Seed Co. (Modesto, Calif.)	95	3632
Day Star	sh_2	Yellow	131805014	Harris Moran Seed Co. (Modesto, Calif.)	95	3268
Morning Star	sh_2	Yellow	133927032	Harris Moran Seed Co. (Modesto, Calif.)	95	3859

[z]Percent germination given by the various seed sources given on the seed packet as required by law under the procedures outlined by the Association of Official Seed Analysts.
[y]1000 seeds/lb = 2204.6 seeds/kg.

under a wide range of temperatures (Hassell et al., 2001). These results could provide an indication of how new cultivars of se, sh_2 and su sweet corn phenotypes respond to varying temperatures, especially cooler temperatures, over a given time period and to provide growers with general scheduling tools for field planting in cold soils for acceptable seedling emergence.

The objectives of this research were 1) to determine the minimum temperatures to germinate to 75%, (the minimum germination percent for interstate commerce) for 27 new sweet corn su (sugary), se (sugar enhanced), and sh_2 (super sweet) cultivars; 2) to determine vigor differences among the phenotypes; and 3) to select the most promising se, su, and sh_2 cultivars within each phenotype for cold tolerance and vigor and possible use in early spring plantings in cold soils.

Materials and methods

A single seed lot of twenty-seven cultivars of three sweet corn phenotypes (se, sh_2 and su) were evaluated for differences in germination requirements (Table 1). All seeds were acquired from commercial seed sources which were pre-treated with the companies' own recommended fungicide treatment. Upon delivery, the seed packet information along with percent germination were recorded and then a 10-g (0.35 oz) seed sample was removed and counted to determine seed size using a Contador seed counter (Baumann Saatzuchtbedarf Co., Waldenburg, Germany). The remaining seeds were then placed in a seed storage facility at 57 ± 3.6 °F (13.8 ± 2 °C) and 50% relative humidity for three months. During that period samples were removed for each experiment.

For each experiment, five-hundred seeds of each cultivar were divided into ten groups of 50 seeds each. Then each group was placed into a transparent acrylic container, lined on the bottom with blue germination blotter (Hoffman Manufacturing Co., Albany, Ore.) and moistened with 14 mL (0.47 fl oz) of distilled water. Transparent acrylic lids covered the containers to prevent moisture loss. These containers were placed along a temperature gradient on a thermogradient table (Type 5001; Seed Processing Holland, Enkhuizen, The Netherlands), and allowed to germinate over a 7-d period. The gradient temperatures were (±2 °F) 52, 56, 60, 64, 68, 72, 76, 80, 84, and 86 °F. Temperatures were measured within the containers using a 12-channel scanning thermocouple thermometer (Barnant Co., Barrington, ILL.). Containers representing each cultivar were randomly arranged within temperature treatment locations on the thermogradient table.

The experiment was repeated on three different occasions over a nine-week period with each repetition considered a replication using the same seed lots. Germination counts were made at the same time daily for 7 days, the recommended termination of seed testing (AOSA, 1998). A seed was considered germinated, upon the appearance of a 0.1- to 0.2-inch-long (3- to 5-mm) radicle through the seed coat (Copeland and McDonald, 2001). After seeds germinated, they were removed from the dish and the germination counts recorded. Germination data from thermogradient testing were used to

Table 2. Number of days required for seed of sh_2, se, and su sweet corn phenotypes to germinate to a minimum 75%.

Phenotype[z]	Days to 75% germination
su 3.6 a[y]	
se 3.9 b	
sh_2 4.4 c	
Temperature [°F (°C)][x]	
52 (11.1)	6.0 a
56 (13.3)	6.0 a
60 (15.6)	5.7 b
64 (17.8)	4.8 c
68 (20.0)	4.2 d
72 (22.2)	3.6 e
76 (24.4)	3.2 f
80 (26.7)	3.0 f
84 (28.9)	3.0 f
86 (30.0)	3.0 f
Source of variation[w]	
Replication	0
Phenotype	5^{**}
Temperature	61^{**}
Phenotype × temperature	1
Error	33

[z]Each phenotype is an average of nine cultivars.
[y]Means within column and factor separated by least significant difference at $P = 0.05$.
[x]Temperature varied on thermogradient table as a standard deviation of about +2 °F (1.1 °C).
[w]The sum of the squares from the analysis of variance for each factor converted to a percentage of the total sum of squares.
**F test significant at the $P = 0.01$ level.

Table 3. Sources of variation[z] in the analysis of variance (ANOVA) for cultivars of three sweet corn phenotypes in the number of days required to germinate to minimum 75% at various temperatures on a thermogradient table.

Source of variation	Percent of total sums of square[z] — Phenotype sh_2	se	su
Replication	0	0	0
Cultivar	22^{**}	25^{**}	14^{**}
Temperature	68^{**}	67^{**}	67^{**}
Cultivar × temperature	5^{**}	4^{**}	14^{**}
Error	5	8	5

[z]The sum of the squares from the ANOVA for each factor converted to a percentage of the total sum of squares.
**F value significant at $P = 0.01$.

determine the minimum temperatures and earliest day for su, se, and sh_2 types to germinate to ≥75%, defined as minimum acceptable germination percent (MAGP) in this study. The best candidates for early spring planting in cold soils reached MAGP at 52 °F within 7 d. Additionally, another important characteristic indicating greater vigor was to germinate to MAGP at the lowest temperatures and for the maximum germination rate (MGR) at low temperature to be equal to the MGR at high temperatures. Additionally, we felt that achieving MGR at the lowest temperatures was an indication of greater cold tolerance.

This experiment was considered a factorial combination of phenotype, temperature and time, however, cultivars within each endosperm phenotype (su, se, sh_2) confounded a clear understanding of how individuals within each phenotype actually reacted to temperature. It was expected that cultivars could widely vary within a phenotype and the effect of cultivar could not be ignored. Cultivars within a phenotype did not share any commonality to cultivars in other phenotypes and therefore, a cultivar factor could not be added as an additional factor with phenotype, temperature and time. Therefore, the analysis required two steps. In the first step, we were interested in determining if there were any general temperature preferences existed among the three phenotypes. In the first analysis, the data was analyzed as a randomized complete block experiment with factorial combination of phenotype, temperature and day of germination counts. In the second step, we were interested if cultivars within a phenotype differed uniquely from each other in response to temperature. To answer the second question, each phenotype was analyzed separately as a factorial experiment of the three factors: cultivar, temperature, and time.

All germination data were transformed by ARCSIN of square root then analyzed. All data were subjected to analysis of variance and means were compared by least significant difference at $P = 0.05$, if the F test was significant.

Results and discussion

The most desired commercial cultivar for early spring planting should be able to germinate at MAGP of ≥75% at the low temperatures. In addition, the most desirable cultivar should germinate to MAGP at low temperatures at a constant MGR in a minimum amount of time. Furthermore, even as temperatures increase within the optimal range for germination, the MGR should remain constant and stable. If a cultivar meets both criteria, we considered that cultivar highly vigorous and among the best candidates for early spring planting.

Our first approach was to determine if phenotypes (pooled response of all cultivars within each phenotype) generally differed in germination response. Most variation in the days to reach MAGP was assigned to temperature with much less, but significant contributions were assigned to phenotype without any interactions (Table 2). In general, we found some slight and minor vigor differences among se, su, and sh_2 phenotypes with su phenotypes germinating to MAGP within 4 d, sh_2 requiring >4 d, and se requiring intermediate time. The phenotypes behaved similarly to temperature gradient ranges from cold to warm. In general, at least 6 d were needed for all phenotypes to germinate to MAGP at 52 °F with progressive decreases in MGR as temperature increased to 76 °F. From 76 to 86 °F, MGR became constant and stable, requiring 3 d to germinate to MAGP at all temperatures within that range.

Analysis and conclusions possible concerning phenotypic responses are confounded by variation suspected among cultivars. The cultivar effect within each phenotype was examined and found to indeed contain additional variation affecting the germination response (Table 3). Although both the main effects of cultivar and temperature were significant in separate analysis of each phenotype, the interaction between cultivar and temperature within a phenotype proved that cultivars react uniquely to temperature. Therefore, generalizations on the pooled response of all cultivars within a phenotype mute true specific differences.

SU CULTIVARS. The su phenotype tended to be more tolerant of cold temperatures than se and sh_2 pheno-

Table 4. Number of days required for su sweet corn cultivars to germinate to minimum 75% at various temperatures on a thermogradient table.

		Days to reach 75% germination (no.)									
	Release	Temp (°F)[z]									
Cultivar	year[y]	52	56	60	64	68	72	76	80	84	86
Sweet G-90	1979	---	---	---	7.0 a[x]	6.0 bcd	4.7 fgh	3.0 klm	2.7 lmn	2.7 lmn	2.7 lmn
Bi-Queen	1975	---	7.0 a	6.7 ab	4.3 ghi	4.0 hij	2.3 mn	2.0 n	2.0 n	2.0n	2.0 n
Merit	1961	7.0 a	5.7 cde	4.3 ghi	4.0 hij	3.3 jkl	3.0 klm	3.0 klm	3.0 klm	3.0 klm	3.0 klm
Silver Queen	1960	---	6.0 bcd	6.3 abc	4.3 ghi	4.0 hij	3.3 jkl	3.0 klm	3.0 klm	3.0 jkl	3.0 jkl
Jubilee	1959	---	6.0 bcd	4.3 ghi	4.0 hij	3.3 jkl	3.0 klm	3.0 klm	2.7 lmn	2.7 lmn	2.7 lmn
NK 199	1954	5.3 def	4.0 hij	3.7 ijk	2.3 mn	2.0 n	2.0 n	2.0 n	2.0 n	2.0 n	2.0 n
Butter & Sugar	1954	---	7.0 a	6.3 abc	5.0 efg	4.0 hij	3.7 ijk	3.0 klm	3.0 klm	3.0 klm	2.3 mn
Trucker's Favorite	1899	---	7.0 a	6.0 bcd	4.7 fgh	4.3 ghi	3.3 jkl	3.0 klm	2.0 n	2.0 n	2.0 n
Country Gentleman Country	1890	---	7.0 a	6.3 abc	5.3 def	4.7 fgh	4.0 hij	2.7 lmn	2.0 n	2.0 n	2.0 n

[z]Temperature varied on thermogradient table with a standard deviation of about + 2 °F; °C = 5/9(°F – 32).
[y]A. Burgoon, personal communication.
[x]Separation of cultivar × temperature interaction means by least significant difference (P = 0.05) = 0.7. Data are means of three replications.

Table 5. Number of days required for se sweet corn cultivars to germinate to minimum 75% at various temperatures on a thermogradient table.

		Days to reach 75% germination (no.)									
	Release	Temp (°F)[z]									
Cultivar	year[y]	52	56	60	64	68	72	76	80	84	86
Accord	2001	---	---	7.0 a[x]	6.3 bc	5.7 de	4.7 gh	4.0 ij	4.0 ij	4.0 ij	4.0 ij
July Gold	1995	7.0 a	6.0 cd	5.0 fg	4.0 ij	4.0 ij	3.0 lm	3.0 lm	3.0 lm	3.0 lm	3.0 lm
Sparkle	1995	---	6.5 ab	5.0 fg	4.3 hi	3.8 jk	3.0 lm	3.0 lm	3.0 lm	3.0 lm	3.0 lm
Yankee Gem	1995	---	6.0 cd	5.0 fg	4.3 hi	3.7 jk	3.0 lm	3.0 lm	2.0 n	2.0 n	2.0 n
Precious Gem	1994	6.0 cd	5.0 fg	4.0 ij	3.0 lm	3.0 lm	3.0 lm	2.0 n	2.0 n	2.0 n	2.0 n
Imaculata	1994	7.0 a	5.3 ef	4.0 ij	4.0 ij	3.3 kl	3.0 lm	3.0 lm	3.0 lm	3.0 lm	3.0 lm
Avalanche	1992	---	6.7 ab	5.3 ef	4.0 ij	4.0 ij	3.0 lm	3.0 lm	3.0 lm	3.0 lm	3.0 lm
Tuxedo	1990	---	7.0 a	6.0 cd	5.3 ef	4.3 hi	4.0 ij	4.0 ij	3.3 kl	3.3 kl	3.3 kl
Merlin	1985	---	7.0 a	7.0 a	6.0 cd	5.3 ef	4.0 ij	4.0 ij	3.7 jk	3.7 jk	3.7 jk

[z]Temperature varied on thermogradient table with a standard deviation of about + 2 °F; C = 5/9(°F – 32).
[y]A. Burgoon, personal communication.
[x]Separation of cultivar × temperature interaction means by least significant difference (P = 0.05) = 0.5. Data are means of three replications.

Table 6. Number of days required for sh_2 sweet corn cultivars required to germinate to minimum 75% at various temperatures on a thermogradient table. USDA livestock and seed variety database.

		Days to reach 75% germination (no.)									
	Release	Temp (°F)[z]									
Cultivar	year[y]	52	56	60	64	68	72	76	80	84	86
Twin Star	2000	---	7.0 a[x]	5.0 fg	5.0 fg	4.0 ij	3.7 jk	3.0 l	3.0 l	3.0 l	3.0 l
SCH 55146	2000	---	---	7.0 a	6.0 cd	5.0 fg	4.3 hi	4.0 ij	4.0 ij	4.0 ij	4.0 ij
Morning Star	1998	---	5.5 def	5.3 ef	4.0 ij	3.7 jk	3.3 kl	3.0 l	3.0 l	3.0 l	3.0 l
Bandit	1997	---	---	6.7 ab	6.0 cd	5.0 fg	4.3 hi	3.7 jk	3.3 kl	3.0 l	3.0 l
Ice Queen	1997	---	7.0 a	6.0 cd	5.0 fg	4.3 hi	4.0 ij	4.0 ij	3.7 jk	3.3 kl	3.3 kl
Silver Dollar	1996	---	---	7.0 a	6.7 ab	5.7 de	5.0 fg	5.0 fg	5.0 fg	5.0 fg	5.0 fg
Day Star	1994	---	6.5 abc	5.7 de	4.7 gh	4.0 ij	3.7 jk	3.0 l	3.0 l	3.0 l	3.0 l
Summer Sweet 8102	1992	---	7.0 a	6.7 ab	4.3 hi	4.0 ij	3.3 kl	3.3 kl	3.0 l	3.0 l	3.0 l
Snow White	1990	---	---	6.3 bc	5.3 ef	5.0 fg	4.7 gh	4.0 ij	4.0 ij	4.0 ij	4.0 ij

[z]Temperature varied on thermogradient table with a standard deviation of about + 2 °F; C = 5/9(°F – 32).
[y]A. Burgoon, personal communication.
[x]Separation of cultivar × temperature interaction means by least significant difference (P = 0.05) = 0.6. Data are means of three replications.

type, but within the su phenotype, we detected that some cultivars tolerated cold temperatures better than others, yet other cultivars required warmer temperatures for more acceptable germination (Table 4). The most vigorous and cold tolerant su cultivars were 'NK 199' and 'Merit' germinating to MAGP at 52 °F with 'NK 199' more vigorous than the latter. 'NK 199' germinated to MAGP after only 5 d at 52 °F with 'Merit' requiring 7 d. 'NK199's' germination rate reached MGR at 64 °F requiring only 2 d to reach MAGP. 'Merit' germinated to MAGP in 7 d with germination rate reaching MGR at ≥68 °F, requiring no less than 3 d to reach MAGP even with temperatures increasing to 86 °F. All other cultivars, except 'Sweet G-90', were able to germinate to MAGP within 7 d at 56 °F. Some of these cultivars, however, required warmer temperatures before MGR plateaued. 'Trucker's Favorite' required the highest temperature to reach MGR, which stabilized at ≥80 °F, but 'Country Gentleman', 'Sweet G-90', and 'Butter & Sugar' cultivars stabilized at ≥76 °F, with 'Silver Queen' and 'Bi-Queen' reaching MGR at ≥72 °F. Although 'Jubilee' did not reach MAGP within 7 d at 52 °F, 'Jubilee' tolerated cold temperatures well, reaching MAGP within 6 d at 56 °F and MGR plateaued at ≥68 °F. Of all su cultivars, 'Sweet G-90' was the least cold tolerant since it was the slowest to reach MAGP requiring ≥64 °F with MGR plateauing at ≥76 °F. Of all the su phenotypes evaluated, 'NK 199' is the most vigorous and desirable for earliest planting in cold soils. Conversely, 'Sweet G-90' is vigorous at warm temperatures, but of all nine su cultivars, this cultivar is the least cold tolerant and desirable for planting under cold conditions.

SE CULTIVARS. 'Precious Gem', 'July Gold', and 'Imaculata' germinated to MAGP at 52 °F with 'Precious Gem' tending to be more vigorous than the latter (Table 5). 'Precious Gem' germinated to MAGP in 6 d at 52 °F with 'July Gold' and 'Imaculata' requiring 7 d. 'Precious Gem' reached MGR at ≥76 °F requiring only 2 d to reach MAGP without further increases in MGR with increase in temperature to 86 °F. 'July Gold' and 'Immaculata' reached MGR at ≥72 °F and 68 °F, respectively, but required no less than 3 d to reach MGR without any changes in MGR, even with temperatures increasing to 86 °F. The remaining cultivars, including Sparkle, Merlin, and Avalanche, but not Accord, germinated to MAGP within 6 to 7 d at 56 °F. 'Accord' required the higher temperature of 60 °F to reach MAGP and reached a stable MGR at ≥76 °F requiring no less than 4 d without further increases with higher temperatures. The MAGP of 'Sparkle', 'Merlin', and 'Avalanche' stabilized at ≥72 °F requiring no less than 3 d at these temperatures. Of all se cultivars, Yankee Gem and Tuxedo required the warmest temperatures to reach MGR, germinating to MAGP in 2 d at ≥80 °F. Precious Gem is considered the most desirable se cultivar evaluated for planting in cold soil because of its ability to germinate to MAGP in 6 d at 52 °F and also have a more rapid MGR. 'Accord' is the least cold tolerant and desirable for planting under cold conditions because it required at least 60 °F for MAGP and had a slow MGR even at warm temperatures.

SH_2 CULTIVARS. All sh_2 cultivars generally required slightly higher temperatures for a minimal germination response than se and su cultivars, since none of the sh_2 cultivars reached MAGP within 7 d at 52 °F as did certain su and se cultivars (Table 6). At 56 °F, 'Ice Queen', 'Day Star', 'Twin Star', 'Summer Sweet' and 'Morning Star' reached MAGP in <7 d, with 'Morning Star', in contrast, requiring about 6 d. Of these more cold tolerant cultivars, Summer Sweet and Morning Star's MGR plateaued at 72 °F requiring 3 d to reach MGR. 'Day Star' and 'Twin Star' required 76 °F before MGR plateaued without further increases at warmer temperatures. Ice Queen required at least 80 °F for MGR to plateau suggesting this cultivar is better suited planting under warmer soil conditions. The last group of sh_2 cultivars required at least 60 °F to reach MAGP including Bandit, Snow White, Silver Dollar, and SCH 55146. Of these, both Silver Dollar and SCH 55146 reached MGR at 72 °F, the lowest temperature that the MGR plateaued of any sh_2 cultivars. Some of these cultivars, however, required warmer temperatures before MGR plateaued, with Snow White requiring 76 °F, but Bandit required 80 °F to reach MGR. Morning Star was considered the best sh_2 cultivar evaluated for planting in cold soil, with Silver Dollar and SCH 55146 considered the least cold tolerant cultivars since both required 7 d to achieve MAGP and still required 4 to 5 d, respectively, for MGR even at 86 °F.

Harrington and Minges (1954) stated that sweet corn germination occurs from as low as 50 °F and as high as 95 °F and we questioned whether new cultivars of sweet corn, in particular, the super sweet phenotypes, would have different temperature requirements for germination, especially in cold soils. Our work indicates that their recommendation is too general for all sweet corn phenotypes. We found that phenotypes and cultivars within phenotypes have different responses to temperature and this earlier recommendation of temperature is inappropriate for optimal response at cold temperatures and even detrimental to germination at the high end of the range given. We questioned whether the newer and sweeter su, sh_2 and se cultivar releases produced over the years may have different high temperature requirements than older releases, but we did not find any strong trend that this was the case with any of the phenotypes. Although there may be germination and vigor differences among sweet corn phenotypes, these differences are dominated strongly by cultivar differences. Another important factor not investigated in this study, but felt to potentially have a strong influence, is the potential for variation among different lots within a cultivar. Only one seed lot was evaluated in our work and it is possible that the vigor of seed can be affected by mother plant status and the production factors at the time of seed production such as differences in field fertility, climate, growing location, rate of seed drying, post harvest handling, storage conditions, etc (Borowski et al., 1991; Parera et al., 1996). It is unknown if the relationships defined in this work will hold true for other seed lots of the same genotype in repetitions of the same work. However, we feel that the value of this research is that there are general germination temperature differences inherent among the three sweet corn phenotypes and that broad generalities about the response of phenotypes to temperature are incomplete since cultivars with phenotypes can differ widely in response to temperature.

Differences in cultivar response to cold temperatures will continue to go unnoticed if the final germination percent from the standard germination test is the only data provided to the grower by seed companies. Vigor differences among some cultivars could be detected if the 4-d germination counts were also provided. However, providing a thermogradient temperature range along with daily germination counts would give the grower very useful information needed to make wise decisions about choice of a planting time under cold soil temperatures to achieve acceptable germination and uniform plant stands.

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