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Variation of Cold Tolerance among Open-pollinated Sweet Corn Cultivars

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Abstract. **Cold tolerance useful for sweet corn improvement may be present in open-pollinated (OP) cultivars. Cold tolerance in sweet corn is the ability to germinate, emerge, and grow under low temperatures. The cold tolerance of 35 open-pollinated sweet corn populations and controls was measured by growing the entries under 14 °C day/10 °C night in growth chambers. The same entries were grown under warm (24 ± 2 °C) conditions in a greenhouse. Traits measured included percent and time to emergence, seedling color, and seedling root and shoot dry mass. Respective repeatability estimates calculated from mean squares were 0.08, 0.33, 0.33, 0.50, and 0.60 for these traits. Entries were ranked separately in each environment based on their performance using a rank-summation index. Differences in cold tolerance existed among the entries. Emergence ranged from 75% to 100% among the entries, with a mean of 90.9%. Time to emergence ranged from 16.2 to 21.9 d, with a mean of 18.2 d. Root and shoot mass ranged from 0.07 to 0.27 g/plot and 0.07 to 0.24 g/plot, respectively. Correlations among the traits measured were favorable, permitting simultaneous improvement. The rankings between the warm and cold environments were significantly correlated ($r = 0.67^{***}$), indicating that some entries that performed well under low temperatures also performed well under warm conditions.**

Sweet corn grows poorly in cold, wet soils, which are common in the upper Midwest of the United States in early spring. The minimum temperature for germination, emergence, and growth of corn is ≈9 to 10 °C (Blacklow, 1972; Crevecoeur et al., 1983; Eagles and Hardacre, 1979).

Cold tolerance in corn, the ability to germinate, emerge, and grow under low temperatures, is a complex, quantitatively inherited trait (Grogan, 1970; Pesev, 1970; Pinnell, 1949). Numerous studies have been conducted to determine genetic variation for cold tolerance present in field corn (Brooking, 1990; Eagles and Brooking, 1981; Mock and McNeill, 1979; Mock and Skrdla, 1978). Mock and Skrdla (1978) tested 144 plant introductions for percent and time to emergence, and seedling dry mass under cold conditions. The plant introductions were chosen to represent a wide sample of ecological zones to determine if cold tolerance was present only in those genotypes adapted to colder climates. Indeed, they concluded that cold tolerance could be found in germplasm adapted to any latitude or climate. Mock and McNeill (1979) reported that out of 34 inbreds from various geographic locations in the United States examined for cold tolerance, the top nine were developed in the central latitudes of the U.S. Corn Belt.

Brooking (1990) reported that Mexican races adapted to 1800 m or higher emerged very rapidly under cool conditions. An earlier study (Eagles and Brooking, 1981) examined populations from areas where corn is grown in cool conditions in temperate and high altitude tropical zones. With one exception, the entries with the highest emergence percentage and time to emergence all possessed germplasm of highland Mexican origin.

The few studies that have examined cold tolerance in sweet corn studied germination under cold conditions and surveyed relatively few inbreds (Haskell, 1949; Haskell and Singleton, 1949; Mather and Haskell, 1949). Haskell examined germination of five sweet corn inbreds and one double cross field corn hybrid under cold conditions (10 and 5 °C). One entry, 'C4', germinated better under cold conditions than the other sweet corn inbreds or the field corn hybrid. Haskell (1949) concluded that genetic factors may be more important for cold tolerance than endosperm type. Likewise, Haskell and Singleton (1949) examined germination of kernels from ears segregating for *su1* in early spring field plantings. No difference in mean germination was observed between *su1* and *Su1* kernels. They concluded that sweet corn is not necessarily less cold tolerant than field corn.

Thus, little has been published regarding the cold tolerance of sweet corn germplasm. Cold tolerance useful for sweet corn improvement may be present in the few currently maintained, open-pollinated (OP) cultivars. Such germplasm must be evaluated for cold tolerance before it can be used. The objective of this work was to examine the cold tolerance of 35 sweet corn populations and four starchy cultivars in controlled environments.

Materials and Methods

Description of entries. The 35 OP sweet corn populations included 29 sweet corn cultivars and six sweet corn composites. The four OP starchy populations consisted of two starchy cultivars and two field corn synthetics. All the cultivars were obtained from the Seed Savers Exchange (Adelmann et al., 1993) or from the collection maintained by the Univ. of Wisconsin sweet corn breeding project. Three of the six composites, 'Maiz Dulce', 'Cacahuacintle Dulce', and 'WCDNTS', contain Mexican high-altitude germplasm. 'WCDNTS' was developed at the Univ. of Wisconsin–Madison and contains 50% 'Cacahuacintle Dulce' germplasm and 50% temperate sweet germplasm. The composite 'Pardo Dulce' contains Peruvian high-altitude germplasm and was developed by W. Compton at the Univ. of Nebraska. The remaining two composites, 'Minnesota 11' and 'Minnesota 14', were developed by D. Davis at the Univ. of Minnesota. 'Minnesota 11' contains field corn and sweet corn germplasm, while 'Minnesota 14' is a northern temperate sweet corn population. Two field corn synthetics, 'NSCT' and 'NSCT-FT', and the sweet corn hybrid 'Jubilee' were included as controls. The field corn synthetics were each cycle 12 from a recurrent selection program conducted by C. Gardner at the Univ. of Nebraska for seedling vigor under cold conditions. 'NSCT-FT' was developed from 'NSCT' for frost tolerance. 'Jubilee' is a popular sweet corn hybrid. All entries, except 'NSCT', 'NSCT-FT', 'Anasazi', and 'Tuscarora', were homozygous *su1*.

Seed production. Seed was produced for all populations in 1 year and in one location to minimize environmental effects on seed quality. All populations were grown on Plano silt loam (fine-silty, mixed, mesic Typic Argiudolls) at the West Madison Agricultural Research Station in the summer of 1993. Nursery rows were over-planted by machine and thinned to 15 plants per row. Rows were 5.3 m long with 0.76 m between rows. The number of rows planted of cultivars obtained from the Seed Savers Exchange (Adelmann et al., 1993) was determined by the quantity of seed supplied. Thirty rows were planted of cultivars maintained by the Univ. of Wisconsin sweet corn breeding project. Plants were sib-pollinated. All pollinated ears were harvested a minimum of 40 d after the date of pollination. Harvested ears were dried to ≈10% moisture in a forced air dryer at ≈35 °C and

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hand-shelled. Damaged kernels were discarded. Ears from populations maintained at the Univ. of Wisconsin were counted and a balanced bulk of kernels was made. Seed from cultivars originally supplied by the Seed Savers Exchange was bulked. All seed was stored at 12 °C.

Evaluations under cold conditions (ECC). A randomized complete-block design was used with eight replications. Two growth chambers (Percival Manufacturing Corp., Boone, Iowa) were used with four shelves per growth chamber. Each replication consisted of two plastic trays containing the 40 entries placed on one shelf. Plastic trays measured 27 × 54 cm and were filled with sterilized sand. The growth chambers were at 14 ± 1 °C and 10 ± 1 °C for 13-h days and 11-h nights, respectively. These temperatures were chosen because they were slightly higher than the minimum temperature for corn growth (Blacklow, 1972; Crevecoeur et al., 1983; Eagles and Hardacre, 1979) and allowed measurable growth on entries in a preliminary screening (data not shown). Fluorescent light was provided for 13 $h \cdot d^{-1}$.

Five kernels from each entry were weighed and planted per plot. To control seed-rotting pathogens, kernels were dusted with captan (*N*-[(trichloromethyl) thio]-4-cyclohexene-1,2-dicarboximide) before planting. Kernels were planted ≈2.5 cm deep. Trays were fertilized with 'Peter's' solution (20N–20P–20K) and covered with clear plastic tops to maintain moisture. To minimize effect of location within the growth chamber, the two trays comprising each replication were rearranged as a unit within chambers. Trays were moved daily during the first 14 d after planting, then every other day until the experiment was terminated.

Traits measured were: number of plants emerged (stand counts), seedling color, and seedling root and shoot dry mass. Stand counts were recorded every 2 d until 42 d after planting. These counts were used to calculate time to emergence (Smith and Millet, 1964):

$$\text{Time to emergence} = \frac{\Sigma(\text{number of plants emerged})(\text{number of days after planting})}{\text{Total number of plants emerged at 42 d after planting}}$$

Stand counts at 42 d after planting were used to calculate percent emergence. A seedling color score was obtained by matching the color of the seedling's first true leaf with the Royal Horticultural Society Colour Chart (Royal Horticultural Society, London). Color scores increased as the degree of yellowing increased. Seedlings were removed from trays on a per-plot basis, rinsed in water, separated into roots and shoots, bagged, and dried for 7 d at 120 °C before weighing.

Evaluations under warm conditions (EWC). The evaluation experimental procedure was the same as under cold conditions (CC) except the entries were grown in a greenhouse at ≈24 ± 2 °C. Stand counts were made every day until 12 d after planting. Percent and time to emergence, and root and shoot mass were obtained as described above. Seedling color was also determined and recorded, but variation was absent. Therefore, seedling color under warm conditions was only used as a standard for cold conditions. The evaluations at 24 °C were made to allow comparisons of the traits measured under cold conditions.

Statistical analysis. All analyses were done using Statistical Analysis System (SAS, 1989). All variables were checked for normality with Proc Univariate in SAS. Percent emergence and time to emergence were calculated on a per plot basis. Therefore, all variables were standardized to represent five seedlings per plot. Consequently, root and shoot dry mass were calculated as the total dry mass per plot in grams divided by the number of plants per plot and multiplied by five. This gave root and shoot dry mass on a per-plot basis and made values more manageable for analysis. Replications were considered random effects, while entries were considered fixed. Mean separations were based on Fisher's protected Least Significant Difference (LSD) at $P \le 0.05$. Phenotypic correlation coefficients for cold tolerance traits were calculated. Repeatability estimates were calculated on a per-replication basis using the mean squares from analysis of variance. The general formula of Vg/Vp was used as described by Falconer (1989).

Entries were ranked separately in each environment using a rank-summation index (Mock and Skrdla, 1978). Entries were ranked according to their performance on a 1 to 40 scale, allowing for ties, with a 1 representing the entry with the most desirable mean for that trait. This index was obtained by first ranking means of percent emergence, time to emergence, and root and shoot mass. Seedling color was also included for the cold environment. Second, the ranks of the traits were summed for each entry. A rank correlation coefficient of the ranked entries from the ECC and EWC was calculated.

Table 1. Levels of significance for percent emergence, time to emergence (TTE) (days), seedling root and shoot mass (g/plot), and seedling color for 35 OP sweet corn populations, one sweet corn hybrid, and four OP starchy populations.

		Variable				
				Dry mass		Seedling
Source	df	Emergence	TTE	Root	Shoot	color
Replication	7	**(***)[z]	***(***)	***(***)	***(***)	***
Entry	39	**(***)	***(***)	***(***)	***(***)	***
Error	273					
Total	319					
CV (%)		13.9 (13.3)	7.5 (6.5)	29.1 (34.1)	18.9 (17.0)	0.9

[z] Level of significance for trait grown under cold conditions (14/10 °C) followed by level of significance for trait grown under warm conditions (24 °C) (in parentheses).

,*Significant at $P \le 0.01$ and 0.001, respectively.

Results and Discussion

Kernel mass. A separate analysis of variance was performed for kernel mass for ECC and EWC. Entries were significant for kernel mass for both evaluations (data not shown). Kernel mass was analyzed separately since it was not a measure of cold tolerance.

Evaluation under cold conditions. Replications and entries were significant for all traits (Table 1). Repeatability estimates calculated from mean squares in the analysis of variance were 0.08, 0.33, 0.33, 0.50, and 0.60 for emergence percentage, time to emergence, seedling color, and root and shoot mass, respectively. These estimates represent upper limits of heritability (Falconer, 1989) and provide information on environmental variation within the cold evaluation. Briefly, repeatability partitions the environmental variance and all of the genetic variance. Therefore, there should be sufficient genetic variation for cold tolerance within this sample of sweet corn cultivars, composites, and starchy populations for all traits, except emergence percentage. As measures of environmental variation within the evaluation, they indicate percent emergence was the most affected, while shoot mass was affected the least.

Based on the rank-summation index for the ECC, the top 25% of the entries consisted of five sweet corn cultivars, four sweet corn composites, and one starchy cultivar (Table 2). Three of the four sweet corn composites contain Mexican high-altitude germplasm. These were 'Maiz Dulce', 'WCDNTS', and 'Cacahuacintle Dulce'. 'Howling Mob' and 'Howling Mob' (GD) were two of the five sweet corn cultivars within the top 25% of the entries. Although these entries were obtained from different sources, no differences were found between them (Table 2). Revilla and Tracy (1995a, 1995b) reported these two accessions grouped together based upon Roger's distance and principal components from isozyme allele frequencies and morphological data.

Emergence ranged from 100% to 75% (Table 2). Mean emergence for all entries and the mean for emergence under warm conditions were >90% (Table 2). Earlier research (Tatum and Zuber, 1942) indicated that when pericarp injuries were present, seed-rotting microorganisms may invade the seed, severely reducing germination. The similarity between means for the two evaluations suggests that when soil pathogens are controlled, as attempted in these studies, percent emergence may not be a good indicator of cold tolerance.

Under cold conditions, percent emergence was significantly correlated with time to emergence, root and shoot mass, and kernel mass (Table 3). Although significant, these correlations were small, explaining less than 20% of the variation of each trait.

A negative correlation has been reported by numerous researchers for percent emergence and time to emergence (Eagles and

Hardacre, 1979; Menkir and Larter, 1985; Mock and McNeill, 1979; Mock and Skrdla, 1978). A negative relationship implies that as the ability to germinate and emerge under cold conditions increases, time to emergence decreases.

The time to emergence in cold conditions ranged from 16.2 for 'Tuscarora' to 21.9 d for 'Orchard Baby' (Table 2). 'Orchard Baby' had a significantly slower rate than any other entry and ranked 30th for cold tolerance performance (Table 2). Only 'Tuscarora' had a significantly shorter time to emergence than 'NSCT' and 'NSCT-FT', which were selected for seedling vigor under cold conditions. However, seven populations were not significantly slower than 'Tuscarora', including 'Howling Mob', 'Malcomb's,' and 'Cacahuacintle Dulce' (Table 2). Thirty-one entries out of 40 did not have time to emergence values significantly different from 'NSCT' or 'NSCT-FT'. Twenty-three out of 39 populations had significantly shorter time to emergence values than 'Jubilee'.

'NSCT-FT' was selected from 'NSCT' for its frost tolerance ability (Gardner et. al., 1987). Although selected for seedling vigor under cold conditions, overall cold tolerance performance of these entries, as scored by the rank-summation index, was inconsistent, suggesting other mechanisms of cold tolerance may be playing a role in these populations.

The correlation between time to emergence and shoot mass was significant and negative ($r = -0.58^{***}$) (Table 3). This correlation could be useful for selection of improved time to emergence and overall cold tolerance. Compared to shoot mass, collecting and calculating time to emergence values is time consuming. Once emergence begins, stand counts must be taken consecutively every 2 d up to 21 d. Shoot mass, however, can be determined easily by harvesting the seedling at soil level, drying, and weighing.

Root and shoot dry mass ranged from 0.07 to 0.27 g and 0.07 to 0.24 g, respectively (Table 2). The maximum values in these ranges represent a 385% increase over the minimum value for root mass and a 343% increase over the minimum value for shoot mass. Clearly, this represents a wide range of variation under cold conditions. Root and shoot mass were significantly correlated ($r = 0.60^{***}$) (Table 3).

The populations containing Mexican high-altitude germplasm, 'Maiz Dulce', 'Cacahuacintle Dulce', and 'WCDNTS', had root and shoot mass within the top ten entries (Table 2). Other researchers (Brooking, 1990; Eagles and Brooking, 1981) have reported similar results with populations containing Mexican high-altitude germplasm. 'Golden Bantam' had the highest shoot mass of all entries and was significantly different from all entries

Table 2. Seed source and population type, rank-summation index values[z,y] and mean percent emergence, time to emergence (TTE), seedling root and shoot mass, and five kernel weights for 35 OP sweet corn populations, one sweet corn hybrid, and four OP starchy populations.

	Entry characteristic						
					Dry mass (g/plot)		
Cultivar	Source and type[x]	Index value	Emergence (%)	TTE (d)	Root	Shoot	Kernel mass (g)
Anasazi	SS, OPC	98.5 (72)	90.0 (92.5)	17.8 (6.0)	0.14 (0.22)	0.14 (0.27)	1.09 (1.01)
Aunt Mary's	SS, OPC	118 (97.5)	90.0 (82.5)	18.8 (6.4)	0.14 (0.23)	0.11 (0.27)	1.22 (1.28)
Bantam Evergreen	SS, OPC	106 (58.5)	90.0 (95.0)	17.9 (6.3)	0.16 (0.26)	0.17 (0.29)	1.19 (1.24)
Black Aztec	SS, OPC	97 (30.5)	92.5 (100.0)	18.3 (6.1)	0.13 (0.26)	0.21 (0.33)	1.30 (1.24)
Cacahuacintle Dulce	UW,Com	62.5 (41.5)	87.5 (95.0)	16.7 (6.2)	0.27 (0.28)	0.21 (0.33)	1.54 (1.52)
Campbell	SS, OPC	99.5 (68)	95.0 (97.5)	18.7 (6.5)	0.18 (0.27)	0.19 (0.27)	1.05 (1.15)
Clem Bennett	SS, OPC	42.5 (57)	95.0 (92.5)	17.5 (6.5)	0.24 (0.30)	0.19 (0.34)	1.30 (1.30)
Country Gentleman	UW, OPC	150 (124)	75.0 (80.0)	19.0 (6.2)	0.09 (0.16)	0.12 (0.20)	0.68 (0.78)
Dorinny	SS, OPC	129 (106.5)	87.5 (82.5)	18.2 (6.7)	0.13 (0.26)	0.18 (0.26)	1.06 (1.22)
Golden Bantam	UW, OPC	75.5 (37.5)	87.5 (97.5)	17.8 (6.3)	0.19 (0.29)	0.24 (0.33)	1.21 (1.22)
Golden Early Market	UW, OPC	86.5 (68.5)	85.0 (90.0)	17.3 (6.3)	0.17 (0.28)	0.22 (0.29)	1.19 (1.08)
Golden Sunshine	SS, OPC	83.5 (136.5)	90.0 (77.5)	17.8 (6.6)	0.15 (0.19)	0.17 (0.23)	1.22 (1.21)
Haye's White	SS, OPC	102 (93.5)	92.5 (95.0)	17.1 (6.2)	0.13 (0.17)	0.16 (0.23)	0.80 (0.75)
Hidatsa	SS, OPC	153 (129)	82.5 (90.0)	20.5 (7.3)	0.11 (0.21)	0.13 (0.21)	0.93 (0.93)
Hooker's Sweet Indian	SS, OPC	139.5 (117)	90.0 (85.0)	18.4 (6.3)	0.10 (0.20)	0.14 (0.21)	0.86 (0.76)
Howling Mob	PI231298	38 (53.5)	95.0 (90.0)	16.9 (6.4)	0.21 (0.40)	0.22 (0.37)	1.40 (1.37)
Howling Mob (GD)	SS, OPC	52.5 (24)	100.0 (97.5)	17.6 (6.0)	0.18 (0.35)	0.21 (0.31)	1.16 (1.12)
Jubilee	RB, Hyb	117 (81.5)	92.5 (100.0)	19.5 (5.6)	0.13 (0.15)	0.07 (0.18)	0.97 (0.93)
Kennedy's White Midget	SS, OPC	144.5 (77)	90.0 (95.0)	18.2 (6.1)	0.09 (0.21)	0.12 (0.25)	0.81 (0.89)
Lindsey Meyer Blue	UW, OPC	87 (72)	97.5 (97.5)	17.2 (6.4)	0.12 (0.22)	0.18 (0.28)	1.09 (1.02)
Luther Hill	SS, OPC	128.5 (110)	92.5 (95.0)	18.1 (6.3)	0.07 (0.14)	0.13 (0.21)	0.77 (0.74)
Maiz Dulce	UW, Com	46 (51.5)	97.5 (92.5)	17.5 (6.2)	0.25 (0.26)	0.19 (0.34)	1.26 (1.23)
Malcomb's	SS, OPC	56 (124)	97.5 (90.0)	17.3 (6.4)	0.18 (0.16)	0.14 (0.21)	0.99 (0.88)
Mandan Red	SS, OPC	115.5 (75)	95.0 (92.5)	18.2 (6.1)	0.11 (0.20)	0.17 (0.29)	0.99 (0.91)
Midnight Blue	SS, OPC	112 (82)	90.0 (95.0)	20.1 (6.6)	0.15 (0.24)	0.17 (0.28)	1.09 (1.07)
Midnight Snack	SS, OPC	95 (65.5)	92.5 (97.5)	18.3 (6.4)	0.16 (0.24)	0.19 (0.28)	1.07 (1.12)
Minn11 C2	UW, Com	62.5 (43)	92.5 (92.5)	17.9 (6.1)	0.20 (0.35)	0.18 (0.30)	1.34 (1.33)
Minn14 C3	UW, Com	125.5 (130)	90.0 (80.0)	18.0 (6.8)	0.12 (0.21)	0.12 (0.23)	1.28 (1.24)
No Name	SS, OPC	134 (82)	85.0 (92.5)	19.4 (6.5)	0.13 (0.31)	0.12 (0.24)	1.10 (1.12)
NSCT	UN, Syn	135 (70)	90.0 (100.0)	17.9 (6.1)	0.09 (0.20)	0.14 (0.25)	1.17 (1.09)
NSCT-FT	Un, Syn	85 (24.5)	100.0 (97.5)	17.8 (5.7)	0.12 (0.28)	0.16 (0.30)	1.36 (1.31)
Orchard Baby	SS, OPC	127.5 (138)	87.5 (85.0)	21.9 (6.7)	0.16 (0.20)	0.10 (0.19)	0.62 (0.60)
Pardo Dulce	UW, Com	109 (122.5)	87.5 (77.5)	18.5 (6.7)	0.17 (0.22)	0.14 (0.26)	1.09 (1.25)
Pease Crosby	PI255893	103.5 (48.5)	90.0 (100.0)	17.3 (6.0)	0.11 (0.24)	0.16 (0.26)	0.82 (0.83)
Queen Anne	SS, OPC	161.5 (100)	75.0 (87.5)	18.6 (6.5)	0.11 (0.22)	0.15 (0.28)	1.04 (1.03)
Stowell's Evergreen	UW, OPC	126.5 (137.5)	90.0 (75.0)	19.6 (7.1)	0.13 (0.21)	0.12 (0.23)	1.11 (1.01)
Sweet Baby Blue	SS, OPC	180 (143)	82.5 (77.5)	18.7 (6.6)	0.09 (0.14)	0.12 (0.22)	0.62 (0.66)
Tucscarora	SS, OPC	67.5 (62.5)	100.0 (92.5)	16.2 (5.9)	0.15 (0.24)	0.20 (0.27)	1.64 (1.62)
WCDNTS	UW, Com	60 (64.5)	95.0 (92.5)	17.9 (6.2)	0.21 (0.24)	0.18 (0.30)	1.44 (1.32)
Whipple's Yellow	SS, OPC	84.5 (55)	100.0 (100.0)	18.8 (6.6)	0.18 (0.26)	0.21 (0.32)	1.20 (1.15)
Mean	---	---	90.9 (91.1)	18.2 (6.3)	0.15 (0.24)	0.16 (0.27)	1.10 (1.09)
LSD ($P = 0.05$)	---	---	12.0 (12.0)	1.3 (0.4)	0.04 (0.08)	0.03 (0.05)	0.10 (0.12)

[z] Rank-summation index values based on ranks of percent emergence, rate of emergence, and seedling root and shoot weight. A smaller index value indicates better performance. Seedling color was also included for the cold environment (14/10 °C).

[y] Value for cultivar grown under cold conditions followed by value of cultivar grown under warm conditions (24 °C), (in parentheses).

[x] Seed source and population type abbreviations, SS, Seed Savers; OPC, open-pollinated cultivar; UW, Univ. of Wisconsin–Madison Sweet Corn Breeding Project; Com, composite; PI, open-pollinated cultivars obtained from the North Central Plant Introduction Center, Ames, Iowa; RB, Rogers Brothers Seed Company; Hyb, hybrid; UN, Univ. of Nebraska; Syn, synthetic.

Table 3. Phenotypic correlation coefficients (N = 40) for percent emergence, time to emergence (TTE), seedling leaf color, seedling root and shoot dry mass, and five kernel mass for 35 sweet corn OP populations, one sweet corn hybrid, and four starchy OP populations grown under cold conditions (14/10 °C) above diagonal and warm conditions (24 °C) below diagonal.

	Entry characteristic					
Variable	Emergence	TTE	Seedling color	Root mass	Shoot mass	Kernel mass
Emergence	---	–0.41**	–0.07	0.36*	0.38*	0.44**
TTE	–0.59***	---	–0.15	–0.28	–0.58***	–0.51***
Seedling color	---	---	---	–0.21	0.13	0.20
Root mass	0.29	–0.10	---	---	0.60***	0.61***
Shoot mass	0.39*	–0.19	---	0.79***	---	0.59***
Kernel mass	0.13	–0.14	---	0.65***	0.68***	---

*,**,***Significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

except ‘Howling Mob’ and ‘Golden Early Market’. ‘Golden Bantam’ is a historically important sweet corn cultivar and is the source of many sweet corn inbreds and cultivars (Gerdes and Tracy, 1994).

Seedling color ranged from 144 to 152 (data not shown). The mean (±SD) for the ECC was 145 (±1.4). With the exception of ‘Sweet Baby Blue’, all entries had color scores below 148, suggesting that the range of color was narrow for the entries. ‘Sweet Baby Blue’ had a color score of 152 and ranked last out of the 40 entries. As color scores increase, the degree of yellowing increases. No significant correlations were observed with seedling color (Table 3). This, and the narrow range of color scores, suggests that seedling color, as measured here, was not an effective indicator of cold tolerance.

Kernel mass ranged from 0.62 to 1.64 g (Table 2). Kernel mass was significantly correlated with percent emergence ($r = 0.44^{**}$), time to emergence ($r = -0.51^{***}$), and root ($r = 0.61^{***}$) and shoot ($r = 0.59^{***}$) mass (Table 3). These correlations suggest that percent emergence and root and shoot mass under cold conditions may be improved by selecting for large kernel size. Narrow, deep kernels, such as in ‘Jubilee’, are desirable in sweet corn (Tracy, 1994).

Evaluation under warm conditions. Replications and entries were significant factors for all traits (Table 1). The top 10 (25%) entries based on the rank-summation index for the EWC include six sweet corn cultivars, three sweet corn composites, and one field corn synthetic (Table 2). There was no variation for seedling color among these entries under warm conditions. The color score was 141.

Percent emergence was significantly correlated with time to emergence and shoot mass ($r = 0.39^{*}$) (Table 3). Root and shoot mass were significantly correlated and each was significantly correlated with kernel mass.

Comparisons under cold and warm conditions. Ranks in the ECC and EWC were tested for similarity using a rank correlation procedure. The rank correlation was significant ($r = 0.67^{***}$) meaning that entries ranked similarly.

Sixteen of the 40 entries had positive changes in rank between EWC and ECC. Two entries occupied the same rank and 22 had negative changes in rank. A negative change in rank is considered to represent sensitivity to low temperatures, while a positive change in rank represents tolerance to low temperatures. The magnitude of the change is expressed in size of the value. For example, a negative change of two would be less sensitive to cold than a negative change of 10.

The most consistent entries between environments are those that occupy the same ranks, ‘Aunt Mary’s’ and ‘Sweet Baby Blue’. However, they rank low in both environments, with ranks of 27 and 40, respectively. The entry with the largest negative change in rank between the warm and cold environment was ‘NSCT’. It dropped from 18 in the warm environment to 34 in the cold. Three entries, ‘Black Aztec’, ‘Pease Crosby’, and ‘Kennedy’s White Midget’ were tied for the second largest negative change in rank between the two environments, at 14. This result suggests that ‘NSCT’, ‘Black Aztec’, ‘Pease Crosby’, and ‘Kennedy’s White Midget’ are the most sensitive entries to low temperatures as measured in this experiment.

‘Malcomb’s’ and ‘Golden Sunshine’ had the largest (+28) and second largest (+26) positive changes in rank, respectively. ‘Malcomb’s’ was ranked fifth in the cold environment, while ‘Golden Sunshine’ was ranked 11th. These positive changes in rank suggest that these entries may possess characters that are important for tolerance to low temperatures.

The assumption that breeders interested in cold tolerance would select those entries that consistently rank high in either environment seems reasonable. Six entries were among the top 10 in ECC and EWC (Table 2); these were ‘Howling Mob’, ‘Howling Mob (GD)’, ‘Golden Bantam’, ‘Minnesota 11 C2’, ‘Cacahuacintle Dulce’, and ‘Maiz Dulce’ and had change in ranks of +8, –3, –6, –2, –2, and +5. The small changes in rank mean that the overall performance of these entries was consistent in ECC and EWC, as judged by the rank-summation index.

Significant correlations were not consistent between the ECC and EWC. Kernel mass was significantly correlated with percent emergence and time to emergence in the ECC but not in the EWC (Table 3). This result means that, under cold conditions, kernel mass was a more important factor for emergence and time to emergence than under warm conditions. Rate of emergence and shoot mass were significantly correlated ($r = -0.58^{***}$) in cold but not in warm conditions ($r = -0.19$, $P > 0.20$), suggesting that time to emergence may be an important indicator of cold tolerance.

Other traits were significantly correlated at both conditions. Percent emergence and time to emergence correlations were significant in both evaluations (Table 3). Root and shoot mass correlations for ECC and EWC were both significant (Table 3).

Correlations between the cold tolerance traits measured in this experiment were favorable, suggesting that simultaneous improvement of these traits should be possible. Rate of emergence and root and shoot mass appear to be important indicators of cold tolerance.

Entries that ranked high in cold and warm conditions may be valuable sources of cold tolerance. Likewise, entries with Mexican high-altitude germplasm also appear to be important sources of cold tolerance. In addition to supplying genes for cold tolerance, the use of the Mexican entries would broaden the genetic base of modern sweet corn.

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