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RESEARCH ARTICLE

Genetic variability for early seed vigor traits for enhanced performance under sub-optimum temperatures in sweet corn (*Zea mays* Convar. saccharata L.)

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Abstract

High germination and seed vigor under sub-optimum temperature is desirable for successful stand establishment in Sweet Corn. An investigation was undertaken to assess the performance of *shrunken*2 based Sweet Corn hybrids; CMVL Sweet Corn-1 and Pusa Super Sweet Corn-2 and their parental lines; SWT16, SWT17, VSL16 and VSL4 for early seed vigor parameters under sub-optimum (15°C, 20°C) and optimum (25°C) temperature conditions. Among the genotypes, hybrids (CMVL Sweet Corn-1 and Pusa Super Sweet Corn-2) were superior than their parental lines for the seed vigor traits like seedling emergence, germination index, mean germination time (MGT), vigor indices, root growth parameters and field emergence under sub-optimum temperature. The inbred lines; SWT16 and SWT17 had better performance than VSL16 and VSL4 for seed vigor parameters under sub-optimum temperatures. Seedling root architecture affected seedling performance and establishment under sub-optimum conditions. In the study, under sub-optimum temperatures seedling root parameters i.e. the root length, surface area and root volume reduced whereas the root diameter increased in the sweet corn lines. Vigor index-II (0.87 and 0.78) and MGT (-0.87and -0.54) showed significant correlation with the field emergence of sweet corn genotypes under 15 and 20°C respectively and thus could be the selection indices for identifying sweet corn genotypes with optimum performance under sub-optimum temperature regimes.

Key words: Sweet corn, early seed vigor, sub-optimum temperature, seedling emergence, root growth.

Introduction

Maize is a nutri-rich cereal crop of India. It is cultivated in an area of 10.04 mha with an average production and productivity of 33.62 mt and 3.3 t/ha, respectively (DA and FW 2021-22). Maize genotypes with enhanced biological and economic value kernels are referred to as "specialty corn" or "high value maize". Sweet corn (*Zea mays* L. Convar. *saccharata*) is a specialty maize characterized by high sugar content in their kernels. Sweet corns are rich in fibre, mineral and vitamins (Chhabra et al. 2019) and are widely used for human consumption due to their eating quality (sweetness), kernel texture and aroma (Azanza et al. 1994; 1996; Evensen and Boyer 1986). In Sweet corn, among different endosperm mutants, namely, *shrunken*2 (*sh*2), *brittle*1 (*bt*1), *sugary*1 (*su*1) and *sugary enhancer*1 (*se*1), which enhance sugar in the kernel, *shrunken*2 (*sh*2) mutant has the highest kernel sucrose content (29.9%) accompanied with good keeping quality of fresh cobs, thus is frequently used in sweet corn breeding and improvement programmes (Hossain et al. 2013; Ko et al. 2016; Mehta et al. 2017). The commercial acceptance and widespread cultivation of *sh*2 based hybrids is limited due to their low seed germination and vigor which result in poor stand establishment under sub-optimum temperature regimes in the field (Styer and Cantliffe 1983; Douglass 1993). Sweet corn is predominantly grown in winter and early spring-summer (December-February) season when the seed germination, emergence, seedling growth and field

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stand is adversely affected under prevailing sub-optimum temperatures (10-15°C) (Parera et al. 1995; Guan et al. 2009). Sweet corn often suffer in the yield trials and seed production plots due to poor plant stand establishment in the winter season (Chauhan et al. 2022). The breeders, while selecting sweet corn inbreds for plant architecture and yield traits, generally ignore the seed vigor traits. Sweet corn hybrids also suffer from similar constraints in the farmers' field due to low-temperature intolerance. Early seedling vigor determines rapid, uniform emergence and the development of seedlings under a wide range of field conditions. Early seed vigor traits i.e., faster germination, early vigor, better seedling and root growth, are desirable for achieving optimum stand establishment in winter and early spring-summer season. Various morpho-physiological traits control early seed vigor, which is heritable (Cairns et al. 2009). This trait helps to select genotypes for direct seeded conditions and abiotic stresses (Singh et al. 2017). Understanding the relationship between temperature and early seed vigor in sweet corn genotypes and identifying parameters for screening sweet corn lines under sub-optimum temperatures for better performance. Additionally, the environment influences few early vigor traits, which are less reliable for screening lines for early vigor traits. The present investigation was undertaken to study the seed germination and early seed vigor traits in sweet corn's parental lines and hybrids and assess their performance under sub-optimum temperatures to identify parameters suitable for screening lines with better performance under low-temperature conditions.

Materials and methods

Freshly harvested seeds of sweet corn hybrids namely; CMVL Sweet Corn-1 (VSL16/ VSL4) and Pusa Super Sweet Corn-2 (SWT16/ SWT17) along with their parental lines; VSL16, VSL4, SWT16, SWT17 were procured from ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora and Maize section, Division of Genetics, ICAR-Indian Agricultural Research Institute, New Delhi respectively for the study. Early seed vigor traits were evaluated by seed germination and vigor assessment. The seeds were exposed to sub-optimum temperatures of 10, 15 and 20°C and compared with performance under 25°C (optimum temperature conditions). The seeds failed to germinate under 10°C, hence the early vigor parameters were assessed only under 15 and 20°C.

Seed germination and vigor assessment

25 seeds (4 replications) of each genotype were placed in plastic pots (5 inch) which were filled with sterilized sand and placed in growth chamber maintained at 15, 20 and 25°C in National Phytotron Facility, ICAR-IARI, New Delhi. Observations were recorded on seedling emergence up to 21 days (at 20 and 25°C) and 30 days (at 15°C) due to differential seedling growth under sub-optimum temperatures. The following parameters were computed based on seedling growth and emergence data.

- Germination percentage (GP): (No. of normal seedlings on final count / total seeds sown) ×100 (ISTA 2015)
- Germination index (GI): Kader (2005) $(N_1 \times t) + [N_2 \times (t-1)] + \ldots + (N_t \times 1)$ where $N_1, N_2 \ldots N_t$ are the no. of seedlings emerged on day 1, 2…t respectively
- Mean germination time (MGT): Ellis and Roberts (1978) $MGT = \Sigma(n.t)/\Sigma n$ (n is the no. of seedlings emerged on day t)
- Seed vigor indices: Abdul-Baki and Anderson (1973) Seed vigor index I (SVI-I): EP × seedling length (cm) Seed vigor index II (SVI-II): EP × seedling dry weight(g)

Root growth studies

Root growth of seedlings were measured after completion of emergence studies under sub-optimum (15, 20°C) and optimum (25°C) conditions. Seedlings were uprooted, washed and placed on root scanner for measurement of root growth parameters i.e., total root length, average diameter, surface area and volume by Winrhizo^R software in Epson root scanner (STD 4800 Scanner).

Seed vigor test

Electrical conductivity test

Seed membrane integrity was evaluated by measuring the conductivity of seed soak water (Vieira et al. 1999). Seeds 50 of each genotype were soaked separately in distilled water (250 ml) at 15, 20 and 25°C for 24 hours. The electrical conductance of seed leachate was measured using a digital electrical conductivity meter.

Electrical conductivity ($\mu S cm^{-1} g^{-1}$ of seed) = (Conductivity Reading-Background reading) /weight of seeds (g)

Cold test

The seeds of different genotypes were planted in plastic trays filled with moist field soil and exposed to 10^0C for 10 days, followed by exposure to optimum temperature (25^0C) for 7 days. The number of seedlings that emerged after the test period was counted for seed vigor estimation.

Field emergence studies

Four hundred seeds (100 per replication) of parental lines and hybrids were sown on 20 February 2020 in field under sub-optimum conditions (minimum temperature ranged from 9.4 to 18.1^0C from sowing to 21 days after sowing (DAS). Field emergence was observed up to 30 DAS. The number of seedlings that emerged in each row, were counted up to 30 DAS and field emergence was estimated as:

Field Emergence Percentage = Number of seedlings emerged/Number of seeds sown*100

Statistical analysis

The laboratory studies and field emergence experiment were laid in completely randomized design (CRD) and randomized block design (RBD), respectively. Germination values in percentage were arcsine converted before analysis. The statistical analysis for two-factor parameter was done using SPSS software. Based on the results of seed germination and vigor studies under optimum and sub-optimum conditions, the correlations were generated and the trait/s showing highest correlation with seed germination and vigor under sub-optimum conditions were identified.

Results and discussion

Seed germination and vigor

Genotypic variability existed for seed vigor traits in sweet corn lines under study. Seed germination and vigor of sweet corn genotypes were significantly affected under sub-optimum temperatures. The seed germination percent, germination index and seed vigor indices were highest at 25°C followed by 20°C and least under 15°C. Among the genotypes and hybrids, CMVL Sweet Corn-1 and Pusa Super Sweet Corn-2 outperformed their parental lines both under optimum and sub-optimum conditions. Under 15 and 20°C temperatures, the inbreds, SWT 16 and SWT 17 were more sensitive than VSL4 and VSL16. The highest seedling emergence percentage and vigor was recorded in hybrids CMVL Sweet Corn-1 and Pusa Super Sweet Corn-2 and least in SWT 17 and SWT 16 under both the sub-optimum temperatures. The highest emergence percentage was recorded in CMVL Sweet Corn-1 (84.23%) and Pusa Super Sweet Corn-2 (82.69%) at 15°C, in CMVL Sweet Corn-1 (89.23%) at 20^{0}C and in CMVL Sweet Corn-1 (96.15%) and Pusa Super Sweet Corn-2 (96.15%) at 25°C (Table 1). Among the genotypes, highest germination index was observed in CMVL Sweet Corn-1 both under 15°C (249.50) and 20°C (295.00) and in Pusa Super Sweet Corn-2 (318.5) at 25°C (Table 1). Zaidi et al. (2010) and Wijewardana et al. (2015) reported genotypic variability for seedling vigor, root traits, biomass production and yield in maize.

The mean germination time depicted the time taken by the seed for emergence and was negatively correlated with the seed vigor. In the study, the parental lines of sweet corn took 1 to 2 days longer for emergence as compared to hybrids and the time lag between sowing to seedling emergence of the genotypes was longer under 15 than 20 and 25°C. The mean germination time of emergence was lowest in CMVL Sweet Corn-1 (9.4 days and 6.96 days) both under 15 and 20^{0}C and in Pusa Super Sweet Corn-2 (5.98 days) under 25°C. The maximum mean germination time taken for emergence was observed in SWT 17; 12.28 days, 8.32 days, 7.04 days respectively at 15, 20 and 25°C, reaffirming the slower germination and poor vigor of inbred lines under low temperature conditions (Table 1).

The vigor indices, which reflected the performance potential of seeds under stressful conditions were higher in hybrids under 25°C followed by 20 and 15°C. The highest seed vigor index I was observed in CMVL Sweet Corn-1 (3200.00) and Pusa Super Sweet Corn-2 (3252.56) at 15°C, in CMVL Sweet Corn-1 (3711.54) at 20°C and in Pusa Super Sweet Corn-2 (4611.54) at 25°C (Table 2). The highest seed vigor index II was observed in Pusa Super Sweet Corn-2 (2.21) at 15°C, in CMVL Sweet Corn-1 (3.68) and Pusa Super Sweet Corn-2 (3.74) which were at par under 20°C and in CMVL Sweet Corn-1 (4.44) at 25°C (Table 2). The hybrids performed better for seed germination parameters due to hybrid vigor and higher seed weight (3-4g higher 100 seed weight than the inbreds) favoring better availability of stored reserves than inbred lines. The present study reaffirmed sweet corns' low germination and vigor potential under sub-optimum temperatures. The inherently low vigor in sweet corns could be attributed to lower reserve mobilization accompanied with poor membrane integrity. Thomison (2002) also reported that kernel composition influences maize's seed germination, vigor and storage behavior. High lysine, high sugar and oil maize genotypes are reported to have lower vigor than normal maize genotypes, affecting their field establishment under sub-optimum conditions. Similar observations have also been reported in *shrunken*2 based sweet corn lines by Parera et al. (1995). Hassel et al. (2003) reported that sweet corn lines are more sensitive to emergence under low-temperature regimes as compared to other lines due to their lower test weight, poor membrane integrity and weaker cold tolerance.

Performance in vigor test

In our study, hybrid CMVLSC-1 had the lowest conductance (398.46μScm^{-1}g^{-1}seed) at 15^{0}C whereas, inbred SWT 17 had the highest conductance (573.57 μScm^{-1}g^{-1} seed) at 25^{0}C (Table 2). Electrical conductivity was highest at 25^{0}C followed by 20^{0}C and least at 15^{0}C as at higher temperatures, the seeds are metabolically more active, and imbibition occurs at a higher rate, thus higher leachates and conductance values. The hybrids showed better membrane integrity as compared to their parental lines, which had less porous membranes exhibited by lower conductance values than inbred parents. Since sweet corn is vulnerable to leakage of electrolytes from the seed coat, this test gave a realistic prediction of seed vigor in sweet corn. Zhao and Wang (2005) also considered the electrical conductivity test as a potential method for seed vigor assessment in sweet corn.

Cold test is the most suitable test to measure the maize seed performance under sub-optimum conditions which mimics the exposure to low-temperature conditions in the field frequently encountered during early sowing. In the study, the cold test differentiated sweet corn lines for vigor potential, wherein hybrids outperformed parental lines under low-temperature stress. The results indicated highest emergence after cold test in CMVL Sweet Corn-1, which was statistically at par with Pusa Super Sweet Corn-2, indicating better vigor potential in hybrids. The male parent of Pusa Super Sweet Corn-2; SWT 17 had the lowest seedling emergence percentage after cold test among the parental lines exhibiting its lower vigor under low-temperature stress conditions among the parental lines under study.

Variability for seed quality characters

The early seed vigor traits are regulated by a cluster of genes influenced by the environment (Singh et al. 2017). The parameters with high heritability and lesser environmental effect are suitable for screening lines for low-temperature tolerance. Our study found a higher genotypic variance at sub-optimum temperature (15°C) for the seed germination and vigor traits. A higher GCV and broad sense heritability at 15°C was observed for emergence percentage, mean germination time and seedling vigor index II, whereas at 20°C for germination index and seedling vigor index I, which indicated higher genotypic variability for the respective traits (Table 3). Low ECV for the germination index, SV-I and SV-II at 15°C indicates lesser environmental influence at sub-optimum temperature. Hence, sub-optimum temperatures can be suitable for the selection of desirable genotype for better seedling emergence. In the current study, high genetic advance coupled with high heritability was recorded for emergence percentage, GI, MGT and SV-II which indicated that the heritability is due to additive gene effect and selection may be effective for these traits. Similar results on variability and heterosis for seed vigor traits have been reported in hybrid rice by Kumari et al. (2023).

Root growth studies

Seedling root provides anchorage to the young plant and is correlated with plant performance under stress wherein the root growth is more sensitive than shoot development in cold sensitive genotypes (Stamp 1984). In addition, nutrient absorption from soil is also limited by suppression of root growth (Hund et al. 2008). Under sub-optimum temperatures, metabolic and biochemical activities are affected during water uptake as the carbohydrate supply to shoot and nutrient supply for photosynthetic activities in crop plants are directly related to root synthesis (Hund et al. 2008). In our study, the root growth was least under the sub-optimum temperature of 15^{0}C, followed by 20^{0}C and highest under optimum temperature exposure i.e., 25^{0}C (Plate 1). Significant genotypic differences were observed for root growth traits i.e., root length, root surface area, root average diameter and root volume under all the temperature regimes. Hybrids had better root growth than their parental counterparts. The root growth measured with WINRHIZO^R showed that sub-optimum temperatures (15, and 20^{0}C) reduced root length, surface area and root volume in all the sweet corn lines but increased the root average diameter as compared to optimum temperature (Fig. 1). Root length and root surface area were significantly higher under 25^{0}C as compared to 15 and 20^{0}C. However, the root average diameter was higher under 15^{0}C as compared to 20 and 25^{0}C as the root length reduced and became thick and stubby. Correlation studies of field emergence and seed germination percentage with root traits parameters at different temperature regimes showed a positive correlation with all the root growth parameters at 15^{0}C with the highest values with seedling root length. However, under 20 and 25^{0}C highest values were obtained with seedling root length (r=0.845*) and root diameter (r=0.826*), respectively The greater stress tolerance and better root growth a cultivar was credited to the vigorous root architecture, as indicated by higher root biomass, root surface area, and root volume under low-temperature stress. The results indicated that seedling root length was critical for stand establishment in sweet corn genotypes. As root architecture played an important role in the seedling establishment under low-temperature regimes, the genotypes with better architecture, especially root length, are expected to perform better with good stand establishment under low temperature. Similar reports on influence of low temperature on root length, dry weight and growth has been reported by Imran et al. (2013) and Wijewardana et al. (2015)

Variability for root growth

A higher heritability for root length, root surface area and root volume was found at 15°C whereas a higher genotypic variance at sub-optimum temperature (15°C) was observed for the root surface area and root volume indicating higher genotypic variability for the respective traits (Table 5). Low ECV for the root growth characters at 15°C indicated lesser environmental influence at sub-optimum temperature. Hence, sub-optimum temperatures can be utilised to differentiate the genotypes for early seedling growth and a better and effective selection can be made at sub-optimum temperatures. In the present study, high genetic advance

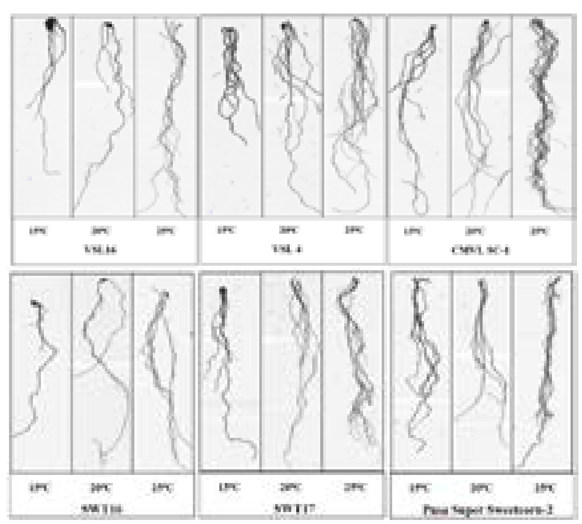


Plate 1. Seedling root growth under different temperatures in sweet corn genotypes

Table 1. Effect of temperature on seed germination parameters of sweet corn genotypes

Genotype/ Trait	Emergence per cent*			Mean	GI			Mean	MGT (Days)			Mean
Temperature	15°C	20°C	25°C		15°C	20°C	25°C		15°C	20°C	25°C	
VSL16	76.76 (50.14)	80.38 (53.49)	94.23 (70.44)	83.79 (58.02)	213.0	257.0	284.5	251.5	10.31	7.97	6.66	8.31
VSL4	79.38 (52.54)	82.23 (55.32)	94.23 (70.44)	85.28 (59.43)	215.5	264.0	289.2	256.2	10.22	7.82	6.86	8.3
CMVL SC-1	84.23 (57.38)	89.23 (63.16)	96.15 (74.05)	89.87 (64.86)	249.5	295.0	304.5	283.0	9.4	6.96	6.57	7.64
SWT 16	65.38 (40.83)	71.15 (45.36)	88.84 (62.67)	75.12 (49.62)	164.0	176.0	290.5	210.1	10.99	7.41	6.38	8.26
SWT 17	55.07 (33.42)	75.38 (48.92)	89.15 (63.06)	73.20 (48.46)	154.0	181.5	302.5	212.6	12.28	8.32	7.04	9.21
Pusa Super SC-2	82.69 (55.78)	84.23 (57.38)	96.15 (74.05)	87.69 (62.40)	229.5	269.0	318.5	272.3	9.75	7.16	5.98	7.63
Mean	73.91 (48.36)	80.43 (53.99)	93.12 (69.52)		204.2	240.4	298.2	247.6	10.49	7.60	6.58	8.16
		C.D. (p≥0.05)	SE(m)			**C.D.** (p≥0.05)	SE(m)			**C.D.**	SE(m)	
	T	(2.21)	(0.77)		T	4.36	1.51		T	0.15	0.05	
	G	(3.13)	(1.08)		G	6.17	2.14		G	0.21	0.07	
	(T×G)	(5.43)	(1.88)		(T×G)	10.7	3.71		(T×G)	0.36	0.13	

*Values in parenthesis are Arcsine converted values

Table 2. Effect of temperature on seed vigor indices of sweet corn genotypes

Genotype/ Trait	SV-I			Mean	SVI-II			Mean	EC (μScm^{-1}g^{-1}seed)			Mean
Temperature	15°C	20°C	25°C		15°C	20°C	25°C		15°C	20°C	25°C	
VSL16	2844.23	3269.87	4003.85	3372.65	1.98	2.93	3.52	2.81	431.54	465.54	546.38	481.15
VSL4	2194.23	3564.10	4121.80	3293.37	1.70	2.85	3.55	2.70	416.16	452.46	527.59	465.40
CMVLSC-1	3200.00	3711.54	4270.51	3727.35	2.11	3.68	4.44	3.41	398.46	437.45	494.41	443.44
SWT 16	2267.31	3002.56	4233.97	3167.94	1.73	2.98	3.55	2.75	445.45	474.45	557.03	492.31
SWT 17	1332.05	3178.85	4151.28	2887.39	1.70	2.33	3.12	2.38	459.45	496.45	573.57	509.82
Pusa Super SC-2	3252.56	3631.41	4611.54	3831.83	2.21	3.74	4.12	3.35	405.53	438.14	508.91	450.86
Mean	2515.06	3393.05	4232.15	3380.08	1.90	3.08	3.71	2.89	426.10	460.75	534.65	
		C.D. (p≥0.05)	SE(m)			**C.D.** (p≥0.05)	SE(m)			**C.D.** (p≥0.05)	SE(m)	
	T	58.36	20.26		T	0.05	0.02		T	16.513	5.49	
	G	82.53	28.66		G	0.08	0.03		G	23.353	7.764	
	(T×G)	142.95	49.64		(T×G)	0.13	0.05		(T×G)	NS	13.447	

SV-I : Seedling Vigor Index-I ; SVI-II: Seedling Vigor Index-II; EC: Electrical Conductivity

Table 3. Variability of seed quality characters at optimum and sub-optimum temperatures (ºC) in parental lines and hybrids of sweet corn

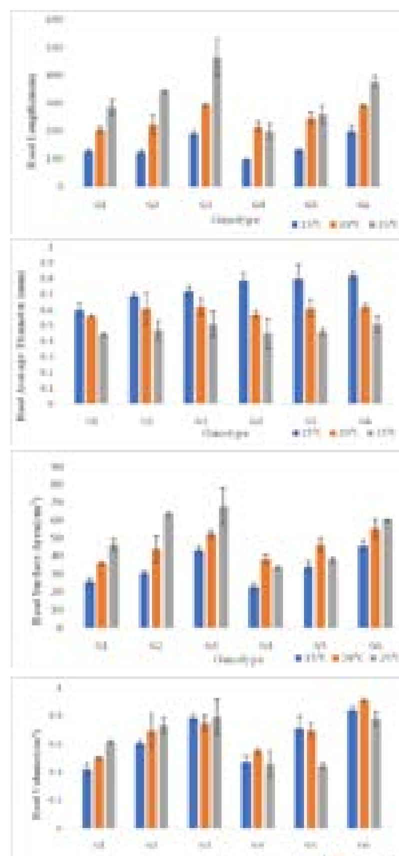
Parameters	Emergence percent			GI			MGT (Days)			SVI-I			SVI-II		
	15	20	25	15	20	25	15	20	25	15	20	25	15	20	25
Mean	73.91	80.43	93.12	204.25	240.41	298.28	10.49	7.60	6.41	1.90	3.08	3.71	2515.06	3393.05	4232.15
Environmental Variance	6.18	5.23	4.69	6.09	91.09	110.11	0.08	0.02	0.02	0.001	0.004	0.006	2165.77	7787.94	14288.51
Genotypic Variance	127.80	39.60	3.29	1404.64	2419.27	122.93	1.02	0.25	0.11	0.05	0.28	0.22	536323.38	77613.39	38487.06
Phenotypic Variance	133.98	44.84	4.03	1410.74	2510.37	233.05	1.11	0.28	0.13	0.05	0.29	0.23	538489.16	85401.33	52775.58
ECV	3.36	2.84	2.32	1.20	3.96	3.51	2.84	2.26	2.28	2.03	2.11	2.13	1.85	2.60	2.82
GCV	15.29	7.82	3.29	18.34	20.45	3.71	9.67	6.68	5.29	11.80	17.37	12.76	29.11	8.21	4.63
PCV	15.65	8.32	4.03	18.38	20.84	5.11	10.07	7.05	5.76	11.98	17.50	12.94	29.17	8.61	5.42
Heritability (BS)	0.953	0.88	0.66	0.995	0.96	0.52	0.92	0.89	0.84	0.97	0.98	0.97	0.99	0.90	0.72
Genetic Advance (%)	30.77	15.14	5.54	37.71	41.37	5.56	19.11	13.04	10.02	23.97	35.53	25.93	59.86	16.12	8.15

GI = Germination Index; MGT = Mean germination time; SVI-I = Seedling Vigor Index-I; SVI-II = Seedling Vigor Index-II
ECV = Environmental Coefficient of Variance; GCV = Genotypic Coefficient of Variance; PCV = Phenotypic Coefficient of Variance; *Significant at p=0.05

Table 4. Emergence and vigor traits of sweet corn genotypes under field conditions

Genotype/ Trait	Emergence percent*	GI	MGT (Days)	SV I	SV II
VSL16	69.00 (43.63)	363.50	8.95	1977.00	2.78
VSL4	68.00 (42.84)	350.00	8.89	1964.00	2.72
CMVL SC-1	79.00 (52.19)	399.50	7.83	2188.00	3.68
SWT 16	74.00 (47.73)	385.50	8.94	2555.00	3.90
SWT 17	70.00 (44.43)	374.20	8.98	2524.00	3.79
Pusa Super SC-2	81.00 (54.10)	428.00	7.42	2979.67	4.29
Mean	73.44 (47.26)	383.45	8.50	2364.61	3.53
C.D.	4.03 (3.81)	16.95	0.49	93.56	0.17
SE(m)	1.26 (1.19)	5.31	0.16	29.31	0.05

*Values in parenthesis are Arcsine converted values



G1 = VSL16; G2 = VSL4; G3 = CMVL Sweet Corn-1; G4 = SWT 16; G5 = SWT 17 and G6 = Pusa Super Sweet Corn-2

Fig. 1. Root growth parameters under different temperatures in sweet corn

Table 5. Variability for root growth at optimum and sub-optimum temperatures in the parental lines and hybrids of sweet corn

Parameters	RL			RSA			RAD			RV		
	15	20	25	15	20	25	15	20	25	15	20	25
Mean	142.46	241.53	337.94	33.61	45.40	51.55	0.75	0.59	0.50	0.63	0.68	0.63
Environmental Variance	251.47	1405.35	2152.44	12.99	37.44	67.59	0.0008	0.0011	0.0004	0.0056	0.008	0.0142
Genotypic Variance	1782.18	467.17	10299.16	81.34	39.73	170.04	0.0049	0.0012	0.0027	0.026	0.0178	0.017
Phenotypic Variance	2033.65	1872.52	12451.60	94.33	77.18	237.64	0.0057	0.0023	0.0031	0.031	0.0258	0.031
ECV	11.13	15.52	13.72	10.72	13.47	15.94	3.81	5.64	3.84	11.73	13.12	18.77
GCV	29.63	8.94	30.02	26.82	13.88	25.29	9.21	5.78	10.19	25.47	19.51	20.70
PCV	31.65	17.91	33.01	28.89	19.34	29.90	9.93	8.00	10.92	28.06	23.49	27.94
Heritability (BS)	0.87	0.2495	0.8271	0.86	0.5148	0.7156	0.85	0.5217	0.8710	0.82	0.6899	0.5492
Genetic Advance (%)	57.14	9.20	56.26	51.31	20.51	44.07	17.59	8.59	19.60	47.65	33.39	31.61

RL = Root Length; RSA = Root Surface Area; RAD = Root Avg. Diameter; RV = Root Volume
ECV: Environmental Coefficient of Variance; GCV = Genotypic Coefficient of Variance; PCV = Phenotypic Coefficient of Variance; *Significant at p=0.05

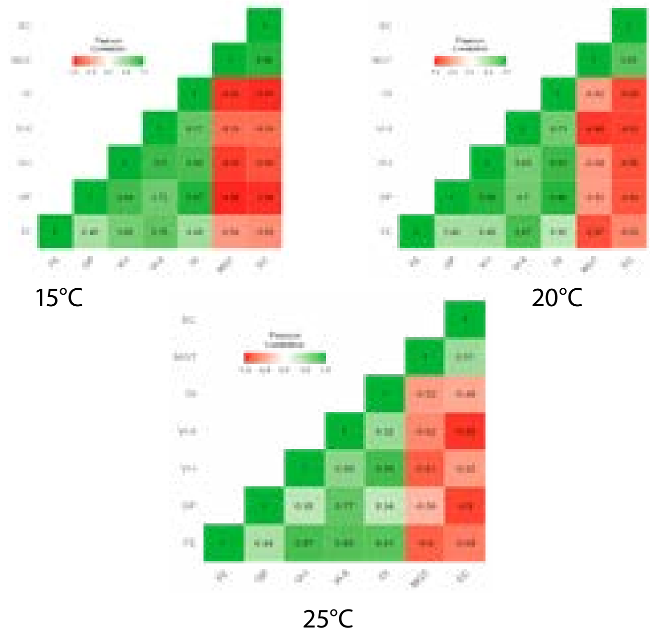


Fig. 2. Correlation of field emergence with seed germination and vigor traits under 15°C, 20°C and 25°C in sweet corn genotypes

coupled with high heritability was recorded for root length, root surface area and root volume which indicates that the heritability is due to additive gene effect for these traits. Similar results have been reported by Li et al. (2015). It is suggested that the selection for the desired root traits may be effective under sub-optimum temperature (15°C) conditions.

Field emergence

Rapid and uniform field emergence is much critical for stand establishment under sub-optimum conditions. Low temperature stress has been recognized as an important environmental factor that restricted plant growth and agricultural production (Mauch-Mani and Mauch 2005). Guan et al. (2009) also reported that chilling temperature was an important constraint affecting maize during seed germination and early seedling growth. In the study, the field emergence was highest in CMVL Sweet Corn-1 and Pusa Super Sweet Corn-2 (which were at par) (79.00 and 81.00% respectively). The germination index, a seed vigor assessment index was also highest in Pusa Super Sweet Corn-2 (428.00) followed by CMVL Sweet Corn-1 (399.50) (Table 4). The mean germination time (MGT) ranged from 7 to 8 days in hybrids and from 8 to 9 days in the parental lines indicating marginally slower emergence under sub optimum field conditions. The lowest mean germination time was observed in CMVL Sweet Corn-1 (7.83 days) and Pusa Super Sweet Corn-2 (7.42 days) which were at par. The highest seed vigor index I was observed in Pusa Super Sweet Corn-2 (2979.67) followed by SWT 16 (2555.00) and SWT 17 (2524.00). Highest seed vigor index II was also recorded in Pusa Super Sweet Corn-2 (4.29) followed by SWT 16 (3.90) and SWT 17 (3.79) which were at par. Environmental conditions control all growth stages of maize but seedling emergence, establishment and early vegetative growth are most influenced among them. Ploschuk et al. (2014) also reported short and low seedlings' biomass under cold stress due to inhibited root growth, resulting in short and weaker seedlings.

Correlation studies

Correlation studies of field emergence with seed vigor parameters showed high values both under optimum (25^{0}C) and sub-optimum (15^{0}C, 20^{0}C) conditions (Fig. 2) Matthews and Hosseini (2006), Noli et al. (2008) and Matthews et al. (2011) reported high correlation of seedling emergence with MGT and vigor indices. Both MGT and single counts were significantly correlated to the rate and emergence percentage in a field condition, In the present study, under 15^{0}C temperature, field emergence was highly correlated with vigor index- II, and negatively correlated with the electrical conductivity of seeds. While under 20^{0}C, field emergence showed high correlation values with vigor index-II, and negatively correlated with MGT. At the lower temperatures, the lines showed slower and less synchronous germination and, took longer time to germinate and emerged slowly as compared to the lines with the faster and synchronous germination i.e., hybrids that had lower MGT. Under optimum temperature (25^{0}C), field emergence was positively correlated with vigor indices (VI-I and II), germination index, and mean MGT. The highest correlation value of field emergence was under 20^{0}Cand 15^{0}C with vigor index- II (0.87 and 0.78) and with MGT (-0.87and -0.54), respectively, indicating that these two tests could be conducted at 20^{0}C for best representation of field emergence under the given environmental conditions (Fig 2). Matthews and Hosseini (2006) also reported that the mean just germination rate (MJGT) had a significant correlation with emergence in maize. The study concluded that early seed vigor parameters; vigor index-II and MGT could be used as the selection indices for screening sweet corn lines with low-temperature tolerance for better performance in winter and early spring-summer season.

Authors contribution

Conceptualization of research work (SB, FH); Designing of experiments (SB, FH, MJ); Contribution of experimental material (FH); Execution of field and lab experiments (NP, SB, SK, MA), Analysis of data and interpretation (NP, SB), Preparation of manuscript (NP, SB)

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