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Analyzing the role of sowing and harvest time as factors for selecting super sweet (-*sh2sh2*) corn hybrids

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Abstract

Providing suitable environment for high-kernel sweetness and yield is important for successful commercialization of sweet corn hybrids. Twenty five super sweet corn genotypes were evaluated at three-sowing and -harvest dates. Genotype, sowing- and harvest- time had significant influence on kernel sweetness accounting 33.8%, 9.1% and 3.9% of total variation, respectively. Genotype × sowing time, genotype × harvest time and genotype × sowing time × harvest time interactions contributed 13.8%, 8.2% and 18.9% of total variation, respectively. Kernel brix across genotypes ranged from 16.1-25.5%. Sixty eight per cent of the hybrids attained highest brix in third sowing compared to 12% and 16% in first and second sowing, respectively. Sixty four per cent of the genotypes attained peak in brix at 24-DAP (days after pollination), while 24% and 12% genotypes had highest brix at 20-DAP and 28-DAP, respectively. Genotypes with stable brix across sowing- and harvest-time have been identified. Sowing time also had significant influence on anthesis, cob- and fodder-yield. Late sowing favoured kernel sweetness and cob yield. Cob- and fodder- yield possessed positive correlation, but did not show any association with kernel sweetness. The information generated here holds immense significance in the genetic improvement of sweet corn.

Key words: Brix, harvest time, *shrunken2*, sowing time, super sweet corn

Introduction

Of the various specialty corns, sweet corn (*Z. mays* ssp. *mays* var. saccharata) holds significant share in both domestic- and international- market (Lertrat and Pulam 2007; Hossain et al. 2013). It is harvested at immature stages of endosperm development (generally 20-24 days after fertilization), and used as both fresh and processed vegetable, besides serving as an important source of fibre, minerals, and vitamins (Khanduri et al. 2010, 2011). Fresh sweet corn products like sweet corn milk and soups are gaining popularity in many countries, while sweet corn ears are eaten green as highly prized fresh product. Further, after the harvest of sweet corn cobs, green plants serve as a source of large quantities of fodder to the cattle, and therefore provide extra sources of income to farmers (Bian et al. 2015). Global import of frozen sweet corn was valued US $393 million, while the same for preserved sweet corn was estimated as US $968 million during 2011 (FAOSTAT 2014). Countries like France, Hungary, Thailand and US are the leading exporters of sweet corn based products. Global export of sweet corn was estimated as US $1256 million; and countries *viz.*, Japan, UK, Germany, Belgium, China, Russian Federation and Spain have emerged as leading importers. The demand of sweet corn has increased tremendously in the last few years primarily due to urbanization, increased consumption and availability of organized food processing industries (Lertrat and Pulam 2007).

Commercial sweet corn is based on one or more homozygous recessive genes, of these *shrunken2* (*sh2*) has been abundantly used for enhancement of kernel sweetness in immature kernels (Coe et al. 1988; Hannah et al. 1993). Sugary varieties (having *sugary1* allele: *su1*) at the milky ripening stage contain nearly three times more sugar, while *sh2sh2*-based sweet corn possesses six-fold higher sweetness than ordinary maize (Feng et al. 2008). Due to higher level of

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sweetness in *sh2sh2*-type, it is popularly referred to as 'super sweet corn'. Further, the depletion of sugar level is much slower in *sh2sh2*-type compared to *su1su1*-type even without refrigeration. Super sweet corn varieties thus possess extended shelf life, and are better suited for prolonged transport and storage, due to which *sh2sh2*-based sweet corn cultivars are gaining popularity over the *su1su1*-type (Lertrat and Pulam 2007).

Maize germplasm for grain purpose possess wide genetic variation, and the breeding programmes worldwide have led to the successful development and commercialization of large number of maize hybrids. On contrary, only few centres in selected countries possess organized sweet corn breeding programme, and it warrants the development of diverse promising sweet corn hybrids adaptable to various agro-ecologies (Ko et al. 2016; Reid et al. 2016, Mehta et al. 2017). Identification of suitable environmental conditions is of paramount importance for successful commercialization of sweet corn hybrids (Ruan et al.1999; Barr et al. 2000; Welbaum et al. 2001; Rangarajan et al. 2002; Kwabiah 2004). So far very few studies have been undertaken on effects of either sowing- (Farsiani et al. 2011; Rogers et al. 2000) or harvest- (Khanduri et al. 2011; Szymanek et al. 2015) time on kernel sweetness and yield in sweet corn. To best of our knowledge, no study on simultaneous effects of both sowing- and harvest-time and their interactions on a set of super sweet corn hybrids have been carried out. It is important to study the changes in kernel sweetness, if any, under different sowing and harvest time. In view of the growing importance of sweet corn, to accelerate the pace of progress of sweet corn cultivar development and deployment to suitable growing conditions, the present study was undertaken to (i) evaluate the effects of sowing- and harvest-time on kernel sweetness, (ii) analyze the effects of sowing time on cob- and fodder-yield, and (iii) identify superior hybrids with higher kernel sweetness and productivity.

Materials and methods

Seven *sh2sh2*-based inbreds (MGUSCI-311 to 317) were crossed to generate 21 F_1s during *rabi* (post-rainy season) 2013-14 at Winter Nursery Centre, ICAR-Indian Institute of Maize Research (IIMR), Hyderabad, India. All the inbreds were of same maturity duration. The single cross experimental hybrids (MGUSCH-1 to -21) generated by crossing the inbreds were evaluated along with four checks [comprising three *sh2sh2*-based hybrids *viz*., ASKH-1, ASKH-2 and Sugar-75 and one *sh2sh2*-composite (Madhuri)] under three sowing dates (14th July, 04th August and 25th August) at Indian Agricultural Research Institute (IARI) experimental farm, New Delhi (28°08' N, 77°12' E, 229 MSL) during *kharif* 2014. The first, second and third dates of sowing referred hereafter to as S-I, S-II and S-III, respectively. ASKH-1 and ASKH-2 are the promising experimental hybrids earlier developed IARI, New Delhi. Madhuri is a public sector bred composite, while Sugar-75 is a hybrid developed by Syngenta India Limited.

The genotypes were planted in a Randomized Complete Block Design (RCBD) with two replications per entry, having two rows per replication with a plant-to-plant spacing of 20 cm and row-to-row spacing of 75 cm. Standard agronomic practices were followed for raising and maintenance of the plants. In each plot of 3 m length, a uniform plant stand of 30 plants were maintained by thinning. Days to 50% anthesis was recorded for each of the entries. Nine to ten plants in each of the genotype per replication were self-pollinated to avoid any xenia effect caused due to fertilization by foreign pollen. Three self-pollinated ears from each genotype were harvested at 20-, 24-, and 28-days after pollination (DAP) for estimation of kernel sweetness. Sweetness in the grain was estimated (Khanduri et al. 2011) using portable refractometer/ brix meter (Atago, Japan).

At 28-DAP, green cobs from open pollinated plants were harvested. Husk percentage calculated by taking weight of three randomly selected cobs before and after husk removal, was used to calculate the dehusked cob yield per plot considering plant stand of 30/plot. Cob yield (without husk) was further transformed to tonnes/hectare (t/ha) using the following formula: cob yield (t/ha) = [cob yield (kg/plot) × 10000 m^2]/[4.5 m^2 × 1000]. Weight of the plants/plot was measured as fodder yield at 28-DAP. Fodder yield (kg/ plot) was converted to t/ha similar to the calculation of cob yield. Combined Analysis of variance (ANOVA) and critical difference (CD) were computed as per Sharma (1998) using Windostat 8.0. Percent contribution of each of the components in ANOVA was determined by the following formula: (sum of square /total sum of square) × 100%. Least significant difference was used to compare the means across sowing- and harvest dates. Pearson's simple correlation coefficients among traits were calculated based on the means achieved across sowing dates using MS-Office-Excel 2007.

Results

Influence of the environment

Sweet corn genotypes possessed significant variation for brix across sowing- and harvest-time (Table 1). The study revealed significance for sowing- and harvest-time. Sowing time accounted 9.1% of the total variation, while the same for harvest time was 3.9%. Brix also exhibited significant genotype × sowing time, genotype × harvest time and genotype × sowing time × harvest time interactions, accounting 13.8%, 8.2% and 18.9% of the total variation, respectively (Table 1). Sowing time also had significant influence on days to anthesis contributing 90.60%of total variation (Table 2). Cob yield accounted 20.5% of the total variation. However, sowing time had lesser influence (12.7% of the total sum of square) on fodder yield. Genotype × sowing time interactions were important for both cob- and fodder-yield, and were of similar magnitude (22.7% and 24.8% for cob- and fodder-yield, respectively). The same for days to anthesis was very low contributing 3.3% of the total variation.

Table 1. Combined ANOVA for kernel brix among sweet corn genotypes

Sources of variation	df	SS	MS
Sowing time	2	199.79	99.99**
Harvest time	2	86.57	43.28**
Genotype	24	744.92	31.04**
Replication	1	1.39	1.39
Genotype × Sowing time	48	303.32	6.32**
Genotype × Harvest time	48	181.22	3.78**
Genotype × Sowing time × harvest time	100	415.30	4.15**
Error	224	267.76	1.20
Total	449	2200.27	-

**: Significance at 1%,; df = degrees of freedom; SS = sum of square and MS = mean squares

Kernel sweetness at 20-DAP

At 20-DAP, brix ranged from 16.1-22.8% in S-I, while it was 17.5-24.0% and 18.4-25.3% in S-II and S-III, respectively (Table 3). The mean brix obtained in S-I was 19.8%, and the same in S-II and S-III was 20.3% and 21.3%, respectively. The average brix obtained across sowing dates was 20.5%. Among the newly derived hybrid combinations evaluated in S-I, MGUSCH-11 recorded the highest brix (22.8%), followed by MGUSCH-10 (22.6%), MGUSCH-2 (22.2%) and MGUSCH-4 (22.1%). In S-II, MGUSCH-11 (24.0%), MGUSCH-3 (23.0%) and MGUSCH-5 (23.0%) were the promising hybrids. Among the experimental hybrids evaluated in S-III, MGUSCH-2 recorded the highest brix (25.3%). Other promising hybrids include MGUSCH-11 (24.5%), MGUSCH-6 (23.6%) and MGUSCH-10 (23.1%). Considering average brix across sowing time, MGUSCH-11 (23.8%) and MGUSCH-2 (23.0%) were identified as the most promising hybrid combinations. Among checks, ASKH-1 (20.4%) was identified the best across environments, followed by Madhuri (20.0%), ASKH-2 (19.4%) and Sugar-75 (17.9%).

Kernel sweetness at 24-DAP

Brix at 24-DAP varied from 16.7-24.2%, 17.0-24.5% and 19.0-25.2% in S-I, S-II and S-III, respectively (Table 3). The average brix across genotypes in S-I was 20.5%. The same for S-II, S-III and pooled analyses was 21.0%, 22.0% and 21.2%, respectively. MGUSCH-1 in S-I recorded the highest brix (24.2%), followed by MGUSCH-10 (23.4%) and MGUSCH-2 (23.2%). In S-II, MGUSCH-6 and MGUSCH-19 had the highest brix (24.5%), followed by MGUSCH-5 (24.0%). Other promising experimental hybrids included MGUSCH-3, MGUSCH-10 and MGUSCH-11,

Table 2. Combined ANOVA for days to 50% anthesis, cob- and fodder-yield among sweet corn genotypes

Source of variation	df	MF		CY		FY	
		SS	MS	SS	MS	SS	MS
Sowing time	2	2897.61	1448.81**	78.04	39.04**	258.73	129.37**
Genotype	24	283.33	11.81**	303.47	12.64**	1654.09	68.92**
Genotype × Sowing time	48	182.39	3.80**	147.79	3.08**	866.14	18.04**
Error	75	48.00	0.64	65.61	0.87	513.61	6.85
Total	149	3411.33	-	594.91	-	3292.57	-

**: Significance at 1%; df = degrees of freedom; MS = mean squares; MF = Days to 50% anthesis; CY = cob yield and FY = fodder yield

Table 3. Mean performance of *sh2sh2*-based sweet corn hybrids for kernel sweetness, cob- and fodder-yield

S.No.	Hybrids	S-I						S-II						S-III					
		20-Bx (%)	24-Bx (%)	28-Bx (%)	MF (days)	CY (t/ha)	FY (t/ha)	20-Bx (%)	24-Bx (%)	28-Bx (%)	MF (days)	CY (t/ha)	FY (t/ha)	20-Bx (%)	24-Bx (%)	28-Bx (%)	MF (days)	CY (t/ha)	FY (t/ha)
1.	MGUSCH-1	20.1	24.2	24.1	50.0	8.5	31.2	20.0	20.5	20.0	45.0	9.1	26.0	22.6	23.0	22.2	38.5	10.7	27.5
2.	MGUSCH-2	22.2	23.2	22.6	49.0	7.9	33.3	21.5	23.0	17.5	43.0	10.0	26.7	25.3	24.7	23.8	39.5	8.9	18.5
3.	MGUSCH-3	20.6	22.7	21.4	49.0	9.0	20.9	23.0	23.5	18.5	43.5	11.2	21.2	21.7	21.5	20.0	36.5	13.9	22.0
4.	MGUSCH-4	22.1	21.2	19.9	47.5	7.4	22.7	21.0	22.5	20.5	41.0	7.8	15.9	21.6	23.9	24.4	38.5	8.9	17.1
5.	MGUSCH-5	16.1	20.0	19.9	48.5	6.7	23.7	23.0	24.0	18.5	42.5	8.6	23.1	19.7	23.0	24.1	36.0	9.4	22.5
6.	MGUSCH-6	16.3	20.5	23.2	49.0	7.7	16.7	21.0	24.5	25.5	43.0	8.4	19.9	23.6	22.2	21.6	38.0	8.6	25.7
7.	MGUSCH-7	21.9	21.5	18.7	49.5	5.2	19.5	18.0	19.0	20.0	43.5	7.6	20.5	19.3	21.2	18.4	41.0	9.4	16.5
8.	MGUSCH-8	20.2	20.2	18.6	50.5	6.4	20.1	19.5	21.0	19.0	45.5	9.3	19.0	20.5	20.1	19.6	39.0	10.0	26.6
9.	MGUSCH-9	17.9	19.3	20.0	48.0	6.7	20.7	19.0	19.0	21.5	41.0	6.4	19.9	19.8	21.4	20.6	36.0	9.5	19.0
10.	MGUSCH-10	22.6	23.4	22.5	49.5	7.0	21.4	21.5	23.5	20.0	45.0	9.4	18.4	23.1	22.1	23.6	40.0	9.1	18.7
11.	MGUSCH-11	22.8	22.8	20.8	48.0	6.5	23.2	24.0	23.5	19.0	42.5	7.6	16.9	24.5	24.6	24.9	38.0	9.5	18.3
12.	MGUSCH-12	18.2	22.5	23.0	50.0	10.2	23.9	21.5	22.5	17.5	43.0	13.1	21.5	21.4	21.0	21.6	40.5	10.8	30.0
13.	MGUSCH-13	18.6	17.5	18.0	48.5	9.0	19.0	19.5	19.0	18.0	43.5	6.8	16.3	19.4	22.4	21.7	37.5	8.8	19.6
14.	MGUSCH-14	19.4	18.6	18.9	48.0	5.8	18.1	19.0	23.0	18.0	39.5	7.4	12.9	21.4	23.4	20.9	38.5	7.0	18.4
15.	MGUSCH-15	19.9	21.3	18.6	50.0	5.6	15.2	21.0	20.0	22.0	42.0	6.4	14.5	20.4	20.9	18.8	35.5	9.4	17.3
16.	MGUSCH-16	19.9	19.7	19.1	51.0	8.7	23.8	21.5	21.0	19.5	46.0	8.8	17.0	20.2	19.5	19.9	40.5	9.1	20.3
17.	MGUSCH-17	21.7	21.9	17.3	48.0	7.2	19.9	18.0	19.5	20.0	37.5	10.0	19.5	22.3	20.4	18.3	41.0	10.6	17.7
18.	MGUSCH-18	20.1	19.3	17.1	47.0	9.3	18.7	17.5	20.0	19.5	43.5	7.3	14.8	20.7	22.9	23.5	40.5	8.3	15.3
19.	MGUSCH-19	21.6	22.8	22.7	48.0	7.7	20.7	21.0	24.5	20.5	40.0	9.3	15.8	22.4	25.2	25.2	36.0	5.7	22.6
20.	MGUSCH-20	19.1	18.5	17.6	50.5	8.0	12.5	19.0	18.5	17.5	45.5	7.0	12.8	21.5	19.0	18.1	40.5	9.8	15.4
21.	MGUSCH-21	18.7	18.9	18.7	48.0	8.1	26.9	21.5	19.0	18.5	41.0	6.7	18.7	20.3	21.6	20.1	38.0	9.3	18.6
22.	Madhuri	18.5	18.3	21.4	49.0	5.3	14.9	20.0	20.0	19.0	40.5	4.1	13.1	21.5	21.9	20.3	36.0	5.9	15.5
23.	Sugar-75	17.4	16.7	16.4	52.5	8.9	20.1	18.0	20.5	18.0	44.0	10.1	18.6	18.4	21.4	19.1	39.5	11.1	22.9
24.	ASKH-1	19.2	18.4	16.8	46.5	12.2	25.9	20.0	17.5	17.0	41.5	9.4	16.3	21.9	21.9	22.1	36.0	10.5	19.6
25.	ASKH-2	20.2	19.8	18.9	48.5	8.2	19.2	19.0	17.0	17.5	41.5	10.5	15.3	19.1	21.1	20.1	35.5	13.2	26.0
	Mean	19.8	20.5	19.8	49.0	7.7	21.3	20.3	21.0	19.3	42.6	8.5	18.2	21.3	22.0	21.3	38.3	9.5	20.5
	CD 5%	2.07	2.48	1.74	1.63	1.61	4.59	2.53	2.28	3.05	1.99	1.72	4.56	2.01	2.27	2.25	1.23	2.33	6.42
	CD 1%	2.8	3.35	2.35	2.21	2.19	6.22	3.43	3.09	4.14	2.71	2.33	6.18	2.73	3.07	3.05	1.66	3.16	8.69

S-I = First date of sowing; S-II = Second date of sowing; S-III = Third date of sowing; Bx-20 = Brix at 20 DAP; Bx-24 = Brix at 24 DAP; Bx-28 = Brix at 28 DAP; MF = Days to 50% anthesis; CY = Cob yield and FY = Fodder yield all of which possessed 23.5% brix. For S-III, MGUSCH-19 was identified to have the highest brix (25.2%), followed by MGUSCH-2 (24.7%), and MGUSCH-11 (24.6%). Based on the average brix across environments, MGUSCH-19 (24.2%) was identified as the most promising hybrid combination. Other promising experimental hybrids were MGUSCH-2 (23.6%), MGUSCH-11 (23.6%) and MGUSCH-10 (23.0%). Across environments, Madhuri among checks, recorded the highest brix of 20.1%, followed by Sugar-75 (19.5%), ASKH-1 (19.3%) and ASKH-2 (19.3%).

Kernel sweetness at 28-DAP

At 28-DAP, the range for brix was 16.4-24.1% in S-I, while it was 17.0-25.5 % and 18.1-25.2%, in S-II and S-III, respectively (Table 3). Average brix was 19.8%, 19.3%, 21.3% and 20.1% in S-II, S-III and pooled analyses, respectively. Promising experimental hybrids in S-I with higher brix included MGUSCH-1 (24.1%), MGUSCH-6 (23.2%) and MGUSCH-12 (23.0%). In S-II, MGUSCH-6 was the best genotype with highest brix (25.5%), while in S-III, MGUSCH-19 (25.2%), MGUSCH-11 (24.9%), MGUSCH-4 (24.4%) and MGUSCH-5 (24.1%) were the promising hybrid combinations. Across environments, MGUSCH-6 was identified as the best genotype with 23.4% brix. Among the checks, Madhuri recorded the highest brix (20.2%) across environments, followed by ASKH-2 (18.8%), ASKH-1 (18.6%) and Sugar-75 (17.8%).

Mean performance for kernel sweetness

The mean brix across harvest time was 20.0% in S-I, while it was 20.2% and 21.5% in S-II, and S-III, respectively (Table 3). Across sowing dates, 20.4%, 21.2% and 20.1% brix was recorded at 20-, 24- and 28-DAP, respectively. In general, brix attained peak at 24-DAP as compared to 20- and 28-DAP. For example, in S-I, peak for mean brix across genotypes was found to be the highest at 24-DAP (20.5%), as compared to 20-DAP (19.8%) and 28-DAP (19.9%) (Table 3). However, hybrids *viz.,* MGUSCH-11, MGUSCH-16, MGUSCH-17, MGUSCH-20 and MGUSCH-21 had the highest brix across environments at 20-DAP. Very few hybrids *viz.,* MGUSCH-6 and MGUSCH-9 also attained peak at 28-DAP.

Effect of sowing time on anthesis

Date of anthesis ranged from 46.5-52.5 days in S-I, while the same was 37.5-46.0 days and 35.5-41.0 days in S-II and S-III, respectively (Table 3). Average date of anthesis in S-I was observed to be 49.0 days, and it decreased to 42.6 days and 38.3 days in S-II and S-III, respectively, with an overall mean of 43.3 days. Based on the means across environments, MGUSCH-19 (41.3 days) and MGUSCH-9 (41.7 days) were the most promising genotypes for earliness. Among checks, Sugar-75 across environments had anthesis in 45.3 days, followed by Madhuri (41.8 days), ASKH-2 (41.8 days) and ASKH-1 (41.3 days).

Effect of sowing time on cob yield

The cob yield in S-I ranged from 5.2-12.2 t/ha with a mean of 7.7 t/ha. S-II recorded mean cob yield of 8.5 t/ha with a range of 4.1-13.1 t/ha (Table 3). In S-III, cob yield varied from 5.7-13.9 t/ha having an average of 9.5 t/ha. Among the newly developed hybrids, MGUSCH-12 in S-I recorded the highest yield (10.2 t/ha), followed by MGUSCH-18 (9.3 t/ha). In case of S-II, MGUSCH-12 (13.1 t/ha), MGUSCH-3 (11.2 t/ha), MGUSCH-2 (10.0 t/ha) and MGUSCH-17 (10 t/ha) were the most promising hybrids. Among the hybrids evaluated in S-III, MGUSCH-3 was identified as the best hybrid with a 13.9 t/ha of cob yield, followed by MGUSCH-12 (10.8 t/ha), MGUSCH-1 (10.7 t/ha) and MGUSCH-17 (10.6 t/ha). Across environments, MGUSCH-3 and MGUSCH-12 were the most promising ones with 11.3 t/ha of average cob yield. In case of checks, ASKH-1 had 10.7 t/ha of cob yield across environments, followed by ASKH-2 (10.6 t/ha) and Sugar-75 (10.0 t/ha).

Effect of sowing time on fodder yield

Fodder yield varied from 12.5-33.3 t/ha in S-I, while the same was 12.8-26.7 t/ha and 15.3-30.0 t/ha in S-II and S-III, respectively (Table 3). The average fodder yield across all hybrids was 21.3 t/ha (S-I), 18.2 t/ha (S-II) and 20.5 t/ha (S-III). Among the experimental hybrids, MGUSCH-2 (S-I: 33.3 t/ha; S-II: 26.7 t/ha) recorded the highest fodder yield, followed by MGUSCH-1 (S-I: 31.2 t/ha; S-II: 26.0 t/ha). In S-III, MGUSCH-12 was identified as the most promising hybrid with 30.0 t/ha of fodder yield. Across environments, MGUSCH-1 (28.2 t/ha), MGUSCH-2 (26.2 t/ha) and MGUSCH-12 (25.1 t/ha) were the top three hybrid combinations for fodder yield. Among checks, ASKH-1 across environments had the highest fodder yield (20.6 t/ha), while the same was 20.5 t/ha, 20.2 t/ha and 14.5 t/ha for Sugar-75, ASKH-2 and Madhuri, respectively.

Association among the traits

Cob yield had significant positive association with fodder yield (r=0.56). Brix at 20-DAP was positively correlated with brix at 24-DAP (r=0.76**) and 28-DAP (r=0.56**). Brix at 24-DAP also showed association with brix-28 (r=0.83**) in the positive direction. Brix exhibited no correlation with cob- and fodder- yield. Days to 50% anthesis also did not show any association with brix (20-, 24- and 28-DAP), cob- and fodder- yield.

Discussion

The refractometer/brix meter has been effectively utilized as a rapid method to determine sugar concentration in sweet corn kernel (Randle et al. 1984; Zhu et al. 1992; Kardoso et al. 2002; Zhao et al. 2002; Khanduri et al. 2010, 2011). Significant variation in brix across environments suggested the presence of wide genetic variation for kernel sweetness among the experimental hybrids. Though all sweet corn hybrids possessed the recessive *shrunken2* gene, the effects of QTL/modifier genes (Qi et al. 2009) and/or specific genes in the carbohydrate biosynthesis pathway might have influenced kernel sweetness (Whitt et al. 2002). Wide genetic variation for kernel sugar among sweet corn hybrids has been earlier reported by Khanduri et al. (2010, 2011), Farsiani et al. (2011) and Solomon et al. (2012a). Cob- and fodder-yield also showed wide genetic variation and indicated the diverse nature of the inbreds. Several researchers have reported the existence of genetic variation for cob yield among various sweet corn hybrids (Khanduri et al. 2010, 2011; Solomon et al. 2012a,b; Rosa 2014). Recently, Mehta et al. (2017) analyzed 24 *sh2*-based inbreds using SSRs, and reported presence of wide genetic variation.

In the present study, genotypes contributed 33.9% of the total variance of the kernel sweetness, while rest proportion is due to other contributing factors. Of the several factors, sowing time had influence of 9.1% of the total variation in brix. The mean brix was highest in S-III, and was significantly superior to brix obtained in S-I and S-II. 68% of the genotypes attained peak at S-III, while 12% and 16% possessed highest brix in S-I and S-II, respectively. 4% of the hybrids had peak in both S-I and S-III. This indicates sowing on 4th August (third sowing) was favourable for kernel sweetness over earlier planting dates. This is possibly due to the favourable weather conditions that each of the hybrids encountered during reproductive stage, compared to the earlier date of sowings. In contrast to sowing time, the contribution of genotype × sowing time was more. For example, MGUSCH-5 (at 20-DAP) attained highest brix (23.0%) in S-II, but dipped to 16.1% in S-I and further increased to 19.7% in S-III. At 24-DAP, MGUSCH-4 recorded 21.2% brix in S-I, and it further increased to 22.5% and 23.9% during S-II and S-III, respectively. Thus each of the genotypes interacted differently with sowing time, and different hybrids attained highest kernel sweetness at different sowing time. Farsiani et al. (2011) planted a single cross sweet corn hybrid, SC403 at four different dates, and reported the significance of genotype × sowing time interactions for sugar content.

The 24-DAP can be regarded as the best date for harvest of sweet corn cobs. However, there were also some genotypes that attained peak at 20-DAP. Khanduri et al. (2011) observed highest brix at 20-DAP in majority of genotypes. In the present study, across sowing dates, 64% of the genotypes attained peak at 24-DAP, while, 24% genotypes had the highest brix at 20-DAP. 12% of the sweet corn entries possessed highest brix at 28-DAP. Hence, it may not be always possible to fix 24-DAP as the best time of harvest for sweet corn hybrids in general. Brix for the same hybrid may attain peak at different DAP once sowing date is altered. It is therefore, important to verify the brix values of individual hybrids at different dates and accordingly date of harvest should be recommended.

The effects of genotype × harvest time interaction were prominent in many of the hybrid combinations. For example, MGUSCH-6 (in S-III possessed 23.6% brix at 20-DAP compared to 22.2% and 21.6% at 24- and 28-DAP, respectively. In case of S-II, MGUSCH-2 attained 23.0% at 24-DAP, while the same had 21.5% and 17.5% brix during 20- and 28-DAP. In S-I, MGUSCH-12 could achieve highest brix (23.0%) at 28-DAP, as compared to 18.2% in 20-DAP and 22.5% in 24-DAP. Thus genotypes behaved differently in different harvest dates (Khanduri et al. 2011). The influence of genotype × sowing time × harvest time interaction was more than genotype × sowing time and genotype × harvest time interactions. This indicates, that genotype also interacted simultaneously with sowing and harvest time. For example, MGUSCH-4 had the highest brix at 20-DAP in S-I, 24-DAP in S-II and 28-DAP in S-III. MGUSCH-18 also exhibited similar trend where the highest brix in S-I was achieved at 20-DAP, wherein the peak was attained at 24-DAP and 28-DAP in S-II and S-III, respectively.

Despite the presence of genotype × sowing time, genotype × harvest time and genotype × sowing time

× harvest time interactions, some of the hybrids possessed stability in kernel brix across sowing time. MGUSCH-4, MGUSCH-8, MGUSCH-10, MGUSCH-13, ASKH-2 and Sugar-75 displayed stable brix at 20-DAP during all sowing dates. Similarly, MGUSCH-8, MGUSCH-12, MGUSCH-15 and MGUSCH-20 possessed similar kernel sweetness at 24-DAP under different sowing time. MGUSCH-8, MGUSCH-9, MGUSCH-16 and MGUSCH-20 were the promising hybrids at 28-DAP that did not show much variation in brix at different sowing dates. Some of the hybrids also exhibited stable nature of brix across harvest time. For example, MGUSCH-16 had brix of 19.9%, 19.7% and 19.1% at 20-, 24- and 28-DAP, respectively in S-I. MGUSCH-11 recorded similar brix (24.5%, 24.6% and 24.9%) at 20-, 24- and 28-DAP, respectively in S-III. Similar observations were also found for MGUSCH-2, MGUSCH-10, MGUSCH-13 and MGUSCH-14 in S-I; MGUSCH-1 in S-II; and MGUSCH-1, MGUSCH-3, MGUSCH-10 and MGUSCH-16 in S-III. For these hybrids with stable brix, harvest can be undertaken at any time during 20-28 DAP. This characteristic feature provides opportunity to the farmers to have much larger window for harvest compared to hybrids that attains peak at specific date. Considering both sowing- and harvest- time, MGUSCH-8, MGUSCH-16, MGUSCH-10 and MGUSCH-12 were identified as promising hybrids with moderate stability in brix. These hybrids therefore hold significant promise for cultivation at diverse sowing- and harvest- time.

Date of anthesis was found to be highly influenced by sowing date. Nearly six days earliness was observed in second sowing as compared to first sowing, and nearly four days earliness was recorded in third sowing as compared to second sowing. Thus overall, nearly 10 days of earliness in flowering was exhibited between first- and third-sowing, that were sown 40 days apart. The silking date of individual plants varied from 3-5 days according to planting dates of sweet corn hybrid ‘Combella-90’ in Korea (Yang et al. 2007). Khan et al. (2010) while working on sweet corn landraces reported that days to tasseling and silking enhanced with the delayed planting. Mild environments prevailed during the later stages of sowing possibly helped in achieving the reproductive stage early compared to early sowing.

The present study also reported that the cob yield is influenced by sowing time. Third date of sowing being the most favourable, first sowing had the least cob yield. Mild weather conditions during growth and reproductive stages (for 25th August sowing) possibly contributed to higher cob yield. Several researchers (Khan et al. 2010; Farsiani et al. 2011; Rosa 2014) also observed the suitability of later plating for achieving higher yield. Genotype × sowing time interactions was also apparent in many hybrids. For example, MGUSCH-19 recorded cob yield of 7.7 t/h in S-I; while it increased to 9.3 t/ha in S-II. It got further reduced to 5.7 t/ha in S-III. On the other hand, MGUSCH-21 produced 8.1 t/ha, 6.7 t/ha and 9.3 t/ha of cob yield in S-I, S-II and S-III, respectively. Farsiani et al. (2011) and Khan et al. (2011) reported the presence of genotype × sowing time interactions for grain yield. Despite this interaction, MGUSCH-16 had stable cob yield across sowing dates.

The extent of influence of sowing time on fodder yield was much less compared to cob yield. First sowing produced highest fodder yield, and was comparable to yield achieved in second sowing. Sowing × genotype interaction for fodder yield was also of significance, and contribution was comparable to cob yield. For example, MGUSCH-2, MGUSCH-12, MGUSCH-17 and MGUSCH-21 possessed fodder yield that varied to a high extent across sowing time. Farsiani et al. (2011) did not however record any significant influence of sowing time and genotype × sowing time interaction for fodder yield. In the present study, several hybrids *viz*., MGUSCH-3, MGUSCH-5 and MGUSCH-9 were identified as stable genotypes in all three sowing dates. Based on kernel sweetness, stability of brix, cob- and fodder-yield, MGUSCH-12 was identified as the best sweet corn hybrid.

Brix values at different harvest dates were correlated, and it is expected as same set of genes would regulate the starch biosynthesis pathway during 20-28-DAP. The present study also indicated that it is possible to develop sweet corn hybrids with high yield and sweetness (Saleh et al. 2002; Khanduri et al. 2010; Solomon et al. 2012b). Positive association between fodder- and cob yield suggested that high yielding sweet corn hybrids will tend to have higher fodder yield that would generate additional income to the farmers (Bian et al. 2015).

The study depicted the presence of wide genetic variation for kernel sweetness, anthesis, cob- and fodder-yield. Selection of suitable sowing- and harvest-time is of paramount importance for achieving true potential of sweet corn hybrids. Sweet corn hybrids also interacted with sowing- and harvest-time alone or in combination. Though genotype was the most important factor for kernel sweetness, cob- and fodder-yield, sowing time was the most important determining factor for flowering time. In general, late sowing was favourable for both sweetness and cob yield, while 24-DAP was ideal time for harvest to achieve high kernel sweetness. However, some hybrid combinations exhibited highest performance in different sowing- and harvest-dates. It is also possible to develop sweet corn hybrids with high -yield potential and -kernel sweetness. The information generated here is of immense significance in the sweet corn breeding programme.

Authors' contribution

Conceptualization of research (FH, HSG); Designing of the experiments (FH, MV); Contribution of experimental materials (FH, JCS); Execution of field/ lab experiments and data collection (BKM); Analysis of data and interpretation (RUZ); Preparation of manuscript (FH, MV).

Declaration

The authors declare no conflict of interest.

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