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Yield Improvement by Two Cycles of Mass Selection in Two Sweet Corn Populations

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ABSTRACT : Mass selection (MS) is an efficient selection method to directly improve highly heritable traits. In the present study, two cycles of MS for ear length were conducted on two sweet corn populations, BC2-10 and BC1-10 × Syn-II after introgression of exotic germplasm. The improved populations generated from these selections were evaluated in comparison with the base populations at two locations, to determine the genetic gains and performance of the improved populations. The two base populations showed varied average realized responses to MS. In BC2-10 derived population, the realized responses were 9.1% in BC2-10 C1 and 1.2% in BC2-10 C2, whereas in BC1-10 × Syn-II derived population, the realized responses were 5.6% in BC1-10 × Syn-II C1 and 2.9% in BC1-10 × Syn-II C2. All the improved populations showed longer ears than their respective base populations and the check varieties. Ear length, which was used as the selection criterion in this study, showed high broad-sense heritability in the BC2-10 and BC1-10 × Syn-II derived populations, while fresh ear yield revealed low heritability, indicating that selection for ear length in these populations would be more effective than direct selection for yield. Results of this study indicate that MS conducted on BC2-10 and BC1-10 × Syn-II had significantly increased ear length and fresh ear yield in both populations. The improved populations obtained would serve as better germplasm sources and further selection in these populations could offer better responses.

Keywords: response to selection, mass selection, sweet corn

Recurrent selection methods have been used to improve performance of corn populations for quantitatively inherited traits. A number of efficient intra-population improvement schemes have been developed, their operational details carefully studied, and suitable modifications have been suggested to further improve their efficiency (Hallauer & Miranda, 1988; Roger *et al.*, 1998).

Mass selection was reported to be effective for highly heritable traits, however, research results reported were not consistent until the method was modified and improved by Gardner (1961). The major modification suggested was dividing the entire selection unit into smaller sub-units (grids) to minimize environmental effects. The improved techniques and positive results reported since its modification, attracted the attention of plant breeders to use mass selection for the improvement of maize and other crop species.

Mass selection, as modified by Gardner (1961), has been used to increase number of ears and to change maturity (Hallauer & Sears, 1972), to improve grain yield (Gardner, 1977) and to change ear length (Salazar & Hallauer, 1986; Ali & Saleh, 2003). However, Salazar & Hallauer (1986) reported that the increase in ear length caused undesirable changes in other agronomic traits. Yield was decreased, while plant height, ear height and days to maturity were increased with selection for increased ear length. Reports on the effectiveness of mass selection in sweet corn breeding programmes are very limited, especially in Malaysia. Thus, there is a need to generate more information on the effectiveness of mass selection in the local sweet corn breeding programme.

In this study, two cycles of mass selection were conducted on two sweet corn base populations (*Zea mays* L. *saccharata*), following introgression of exotic germplasm into elite local populations. The improved populations (BC2-10 C1, BC2-10 C2, BC1-10 × Syn-II C1 and BC1-10 × Syn-II C2) were evaluated with their respective base populations (BC2-10 C0 and BC1-10 × Syn-II C0) at two locations. The objectives of this study were to estimate predicted and realized responses to the two cycles of mass selection performed on the two sweet corn populations, to estimate heritability of the traits measured, and to determine correlations among traits measured in the populations.

MATERIALS AND METHODS

Plant materials

Plant materials used in this study were two base populations (BC2-10 C0 and BC1-10 × Syn-II C0) and improved populations by mass selection (BC2-10 C1, BC2-10 C2, BC-10 × Syn-II C1 and BC-10 × Syn-II C2) from these two base populations. BC2-10 C1 and BC2-10 C2 were populations developed following one and two cycles of mass selection, respectively, performed on BC2-10 C0. BC-10 × Syn-

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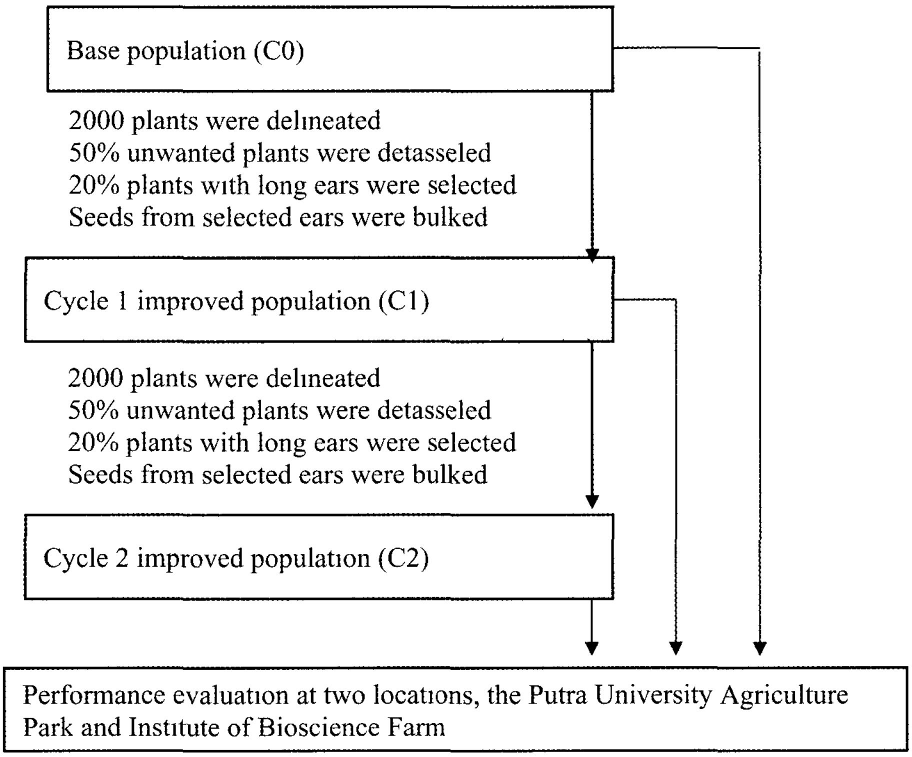

Fig. 1. Schematic illustration of two cycles of mass selection conducted on each of the two sweet corn populations.

II C1 and BC-10 × Syn-II C2 were populations generated from one and two cycles of mass selection, respectively, performed on BC-10 × Syn-II C0.

BC2-10 was an advanced population which has undergone yield improvement, and was developed through crossing of the local population, Manis Madu with exotic germplasm, Hybrid 368, followed by mass selection and then two generations of backcrossing to the local parent. On the other hand, BC1-10 × Syn-II was developed at the initial stage of this study, by crossing of Syn-II population to BC1-10, which was an elite population obtained from just one generation of the above mentioned backcrossing to the local parent. Syn-II was an exotic population possessing genes for earliness, kernel sweetness and plant shortness, while BC1-10 was a local population possessing genes for high yield and well adapted to the local environmental conditions, but was late in maturity, with less sweet kernels and tall plants. In both source populations, the shrunken-2 gene (*sh2*), located on Chromosome 3 was responsible for accumulation of sugars (sweetness) in the kernels.

Selection procedures

Mass selection (MS) was conducted on the two base populations (BC2-10 C0 and BC1-10 × Syn-II C0) for two consecutive cycles at the Institute of Bioscience (IBS) Farm, University of Putra Malaysia (UPM). The selection experiments were conducted from June 2002 to July 2003 following the procedure illustrated in Fig. 1.

The two base populations were each planted in 26 rows of 32 m long, with spacings of 0.75 m × 0.25 m between and within rows, respectively. From each of the selection field, an area consisting of 2000 plants were delineated and then divided into four grids of equal size to minimize effects of the environment (Gardner, 1961). Plants with undesirable traits were detasseled, leaving behind 1000 plants as selection unit. From each grid, 50 plants were selected based on dehusked ear length and other desirable traits (like disease and insect pest tolerance). Ears from the 200 selected plants were harvested and equal amount of seeds were bulked from each selected ear to form the population of the first cycle (C1). Population of the second cycle (C2) was formed from C1 following the same selection procedure. The improved populations (BC2-10 C1, BC2-10 C2, BC1-10 × Syn-II C1 and BC1-10 × Syn-II C2) and the base populations (BC2-10 C0 and BC1-10 × Syn-II C0) were included in the evaluation experiment.

Evaluation of populations generated from selection

The populations generated from the two cycles of mass selection (BC2-10 C1, BC2-10 C2, BC1-10 × Syn-II C1 and

BC1-10 × Syn-II C2) and the base populations (BC2-10 C0 and BC1-10 × Syn-II C0) were evaluated at the University Agriculture Park (UAP) and IBS Farm, UPM in 2004. A randomized complete block design with four replications was used. Each plot consisted of five rows of 5 m long, with spacings of 0.75 m × 0.25 m between and within rows, respectively. Recommended cultural practices were followed for each location.

Data collection and analysis

Data collected in this experiment include fresh ear yield, ear length, ear diameter, plant height, number of kernel rows per ear, number of kernels per row, total soluble solids and days to tasseling.

The data were analyzed using Statistical Analysis System computer package (SAS Institute Inc., 2001). The analyses of variance (ANOVA) were conducted first for individual locations, and the combined ANOVA was then conducted for traits that showed homogeneous error variances revealed by Bartlett's test undertaken following method suggested by Snedecor & Cochran (1980).

The predicted response to selection was estimated using the formula suggested by Falconer & Mackay (1996), as follows:

$$R = ih^2\sigma,$$

where: R = predicted response to selection,
i = the intensity of selection,
h^2 = heritability of a trait, and
σ = phenotypic standard deviation of the parental population.

The intensity of selection (i) of 1.4 was taken for 20% selection intensity.

The cumulative responses to mass selection were estimated as a percentage of the base population (C0), while the responses from individual cycles were estimated as a percentage of their respective preceeding parental populations. The realized response to selection was estimated using the formula suggested by Simmonds (1979), as follows:

$$\text{Realized response (\%)} = \frac{C_n - C_{n-1}}{C_{n-1}} \times 100,$$

where Cn and Cn-1 are mean values for improved and preceeding populations, respectively. Results of predicted and realized responses to selection were compared using chi-square test as suggested by Townend (2002).

Broad-sense heritability (h^2_B) over locations was calculated using the variance components method as suggested by Holland *et al.* (2003). Phenotypic correlations among plant traits studied were calculated using the formula by Gomez & Gomez (1984).

RESULTS AND DISCUSSION

Predicted response to mass selection

Results of predicted response to mass selection for ear length estimated for BC2-10 and BC1-10 × Syn-II populations are shown in Table 1. The predicted responses from individual cycles in BC2-10 derived population were 24.7 and 18.8% in Cycle 1 (C1) and Cycle 2 (C2), respectively. The cumulative response after two cycles of selection was 47.2% for the same population. The predicted responses from individual cycles in BC1-10 × Syn-II derived populations were 22.3 and 16.0% in C1 and C2, respectively, while the predicted cumulative response after two cycles of selection was 41.6%.

Table 1. Mean values, standard deviation and estimates of heritability and predicted response to selection for ear length measured on improved sweet corn populations generated from BC2-10 and BC1-10 × Syn-II, following two cycles of mass selection.

Population	Mean ear length (cm)	Standard deviation	Heritability (%)	Predicted* response (%)	
				A	B
BC2-10					
C0	13.8	3.32	73.4		
C1	16 5	3.05	72.9	24.7	
C2				18.8	47.2
S.E	1.59				
BC1-10 × Syn-II					
C0	11.9	2.89	65.6		
C1	14.4	2.55	64 3	22.3	
C2				16 0	41.6
S.E.	1.50				

*A: response to individual cycles; B. cumulative response

Realized response to mass selection

Results of the realized response to mass selection for ear length revealed by BC2-10 and BC1-10 × Syn-II derived populations, from evaluations at UAP and IBS Farm, are shown in Table 2.

The realized responses to mass selection from individual cycles in BC2-10 populations, at UAP were 7.4% in BC2-10 C1 over BC2-10 C0, and 4.0% in BC2-10 C2 over BC2-10 C1. The realized cumulative response to mass selection in BC2-10 C2 over BC2-10 C0 was 11.7%. At IBS Farm, the realized responses to mass selection from individual cycles increased from 3.3% in BC2-10 C1 over BC2-10 C0 to 5.0% in BC2-10 C2 over BC2-10 C1. The cumulative realized response was 8.4% in BC2-10 C2 over BC2-10 C0.

At UAP, the realized responses from individual cycles in BC1-10 × Syn-II populations were 8.3% in BC1-10 × Syn-II C1 over BC1-10 × Syn-II C0, and 2.8% in BC1-10 × Syn-II C2 over BC1-10 × Syn-II C1, while the cumulative realized response was 11.4% in BC1-10 × Syn-II C2 over BC1-10 × Syn-II C0. At IBS Farm, the realized responses to selection in BC1-10 × Syn-II populations were 3.1% in BC1-10 × Syn-II C1 over BC1-10 × Syn-II C0 and 2.4% in BC1-10 × Syn-II C2 over BC1-10 × Syn-II C1, whereas the cumulative realized response in BC1-10 × Syn-II C2 over BC1-10 × Syn-II C0 was 5.6%.

Comparison of predicted and realized responses

Results of comparison between the predicted and realized

Table 2. Mean values and realized responses to two cycles of phenotypic mass selection for ear length that was measured on improved sweet corn populations derived from BC2-10 and BC1-10 × Syn-II, and evaluated at the University Agriculture Park (UAP) and Institute of Bioscience (IBS) Farm, UPM.

Population	*At UAP*			*At IBSFarm*			*Average*		
	Mean ear length (cm)	Response[1] (%) A	Response[1] (%) B	Mean ear length (cm)	Response[1] (%) A	Response[1] (%) B	Mean ear length (cm)	Response[1] (%) A	Response[1] (%) B
BC2-10									
C0	16.2			15.4			15.8		
C1	17 4	7.4		15.9	3.3		16 6	5 1	
C2	18.1	4.0	11.7	16.7	5.0	8.4	17.4	4.8	10.1
Mean	17.2	5.7		16.0	4.1		16.6	3.9	
S.E.	0.55			0 38			0.46		
BC1-10 × Syn-II									
C0	16.7			16.1			16.4		
C1	18.1	8 3		16.6	3.1		17 3	5 6	
C2	18 6	2.8	11.4	17 0	2.4	5 6	17.8	2.9	8.5
Mean	17.8	5 5		16.7	2.7		17.2	4 2	
S E.	0 57			0.26			0.41		

[1]A. response to individual cycles; B: cumulative response.

Table 3. Comparison between predicted and realized responses to two cycles of selection for ear length conducted on BC2-10 and BC1-10 × Syn-II sweet corn populations.

Population	Predicted response (%)	Realized response (%)	Calculated χ^2
BC2-10			
C1	24 7	5.1	15 6**
C2	18.8	4.8	10.4**
Cumulative	47.2	10.1	29 2**
BC1-10 × Syn-II			
C1	22.3	5.6	12.7**
C2	16.0	2.9	10.7**
Cumulative	41.6	8.5	26.3**

** significant at $p \leq 0.01$

responses to mass selection for ear length conducted on the two sweet corn base populations are presented in Table 3. Based on the results of test, there was a significant difference between predicted and realized responses to mass selection on the two base populations. The predicted responses were significantly higher than the realized. This could be attributed to the over estimation of predicted response to selection that resulted from the use of broad-sense heritability estimates, which was composed of additive and dominant variances in equal proportion (Holland *et al.*, 2003).

Realized responses to mass selection revealed by populations generated from the two base populations were reasonably high, indicating that mass selection significantly increased ear length in the improved populations.

Mass selection conducted on the two base populations also significantly increased fresh ear yield and number of kernels per row. In BC2-10 derived populations, this method of selection significantly reduced plant height and days to tasseling. Hence, the two cycles of mass selection conducted on the two base populations were effective in increasing ear length and modifying the expression of fresh ear yield, plant height and days to tasseling. Direction of correlated response to selection depended on population under selection and correlation between directly and indirectly selected traits.

Performance of improved populations

There were significant differences among the populations evaluated for the traits measured on the populations (Table 4). Performances of the improved populations were superior to their respective base populations and check varieties for fresh ear yield, ear length and number of kernels per row. For dehusked fresh ear yield, BC2-10 C2 had higher mean value (11,115 kg/ha) than BC2-10 C1 (10,108 kg/ha), BC1-10 × Syn-II C0 (9,654 kg/ha) and the check variety, Mas Madu (9,331 kg/ha). For dehusked ear length, all the four improved populations (BC2-10 C2, BC2-10 C1, BC1-10 × Syn-II C2 and BC1-10 × Syn-II C1) showed longer ears than their respective base populations and the check varieties. However, there was no significant difference in ear length among the four improved populations. BC2-10 C1 had shorter plants (178.6 cm) than did its base population (186.9 cm). High and comparable mean values for total soluble solids were obtained from BC1-10 × Syn-II C0 (17.0 %) and BC1-10 × Syn-II C1 (15.6%).

The two improved populations of BC1-10 × Syn-II (BC1-10 × Syn-II C1 and BC1-10 × Syn-II C2) showed longer ears and fresh ear yield than the base population as well as the check varieties, indicating that mass selection for ear length was effective in increasing ear length and fresh ear yield.

Selection for ear length also modified the expression of some other traits, where BC2-10 C1 had shorter plants than its base population, while no significant improvement was obtained for plant height in BC1-10 × Syn-II derived populations over the preceeding and the base populations. The comparable mean values of the improved and the base populations for total soluble solids in BC1-10 × Syn-II popula-

Table 4. Mean values for traits measured on populations generated from mass selection and the base populations of BC2-10 and BC1-10 × Syn-II, when data from locations were combined.

	Mean							
Population	Fresh ear yield (kg/ha)	Ear length (cm)	Ear diameter (mm)	Plant height (cm)	Number of rows/ear	Number of kernels/row	Total solids soluble (%)	Days to tasseling
BC2-10 C0	10229 bcd	16.0 cd	41.0 ab	186.9 b	13.3 a	39.1 bcd	13.9 de	50 6 cde
BC2-10 MS C1	10108 bcd	17.0 ab	41.8 a	178.6 c	13.0 a	39.4 bcd	15.5 b	49.5 ef
BC2-10 MS C2	11115 a	17 1 ab	40.9 abc	185.2 bc	13.7 a	42.9 a	15.0 bcd	48.6 f
BC1-10 × Syn-II C0	9654 cd	16.4 bc	40 8 abc	184.0 bc	14.0 a	40.1 abcd	17.0 a	44 4 g
BC1-10 × Syn-II MS C1	10271 abcd	17.4 a	40.7 abc	178.4 c	13 5 a	41 6 abc	15 6 ab	45 5 g
BC1-10 × Syn-II MS C2	10616 ab	17.8 a	39.9 bc	182.5 bc	13.2 a	40.4 abcd	15.4 bc	46.0 g
Manis Madu	10291 abc	15.4 de	39.2 c	201.2 a	13.8 a	42.1 ab	13.1 e	54.9 a
Mas Madu	9331 d	14.6 e	41.0 ab	183.2 bc	13.6 a	8.5 cd	14.0 cde	52.7 ab
Mean	10342	16.8	41.0	185.8	13.6	40 2	15 2	49.6
S.E.	398	0.4	0 5	1 7	0.2	1 7	0 5	0.5
c.v. (%)	9.1	5.3	4.4	4.4	4.7	8.2	9.4	3.4

Mean values followed by the same letter in the same column are not significantly different at $p \leq 0.05$, based on DNMRT.

tions, showed that the first cycle of selection did not affect kernel sweetness. Similarly, selection for longer ears had no significant effect on days to tasseling of BC1-10 × Syn-II derived populations, as was reflected by the comparable number of days to tasseling between the improved and the base populations.

In general, significant improvement was achieved on increasing ear length and fresh ear yield of the improved populations developed by mass selection on the two base populations. Earliness and kernel sweetness were also significantly improved in BC2-10 derived populations, whereas no significant improvement for earliness and kernel sweetness were observed on BC1-10 × Syn-II derived populations.

Broad-sense heritability

Results of broad-sense heritability (h^2_B) estimates for traits measured on populations developed from mass selection conducted on BC2-10 and BC1-10 × Syn-II, estimated from variance components in the combined analysis of variance, are presented in Table 5.

In BC2-10 derived populations, high broad-sense heritabilities were revealed by ear length (75.0%), days to tasseling (72.0%), total soluble solids (67.0%) and number of kernels per row (64.8%), while moderate estimate was shown by plant height (54.3%). On the other hand, fresh ear yield and number of kernel rows per ear showed low heritability, with estimates of 27.3% and 12.5%, respectively. The high broad-sense heritability estimates in BC2-10 derived populations for ear length, days to tasseling, total soluble solids and number of kernels per row, indicate that variations on these traits were greatly influenced by genetic factors. Plant height showed moderate broad-sense heritability, indicating that this trait was equally influenced by both genetic and environmental factors. In this population, fresh ear yield and number of kernel rows per ear showed low heritability estimates, indicating that these two traits were highly influenced by environmental factors, as expected of highly quantitative traits.

For populations derived from BC1-10 × Syn-II, broad-sense heritability estimates were high for days to tasseling (97.6%), number of rows per ear (66.7%) and ear length (66.6%), whereas estimates were moderate for all other traits. In these populations, traits that had high broad-sense heritability estimates, show that variations of the traits were highly influenced by genetic factors, whereas heritability estimates were moderate for all other traits, implying that variations on the remaining traits were equally influenced by both genetic and environmental factors. These results agree with those of Saleh *et al.* (2001) of high heritability estimates for days to tasseling and ear length.

Ear length, which showed high heritability estimates in both populations, was positively correlated with fresh ear yield, implying that it was the appropriate trait for indirect selection to improve fresh ear yield. Other researchers (Saleh *et al.*, 2002; Ali & Saleh, 2003) also reported moderate to high heritability estimates for ear length using variance components method.

In general, ear length, days to tasseling, total soluble solids and number of kernels per row had moderate to high heritability estimates, indicating that there were low to moderate environmental effects on the expression of these traits. These characters which revealed less sensitivity to environmental factors in the populations under study are desirable traits to be exploited in developing stable genotypes that could perform well under varied environmental conditions.

Correlations among traits

Results of phenotypic correlations among traits measured

Table 5. Genetic variances (σ^2_G), phenotypic variances (σ^2_P) and broad-sense heritability (h^2_B) estimates for traits measured on BC2-10 and BC1-10 × Syn-II derived populations.

Trait	BC2-10			BC1-10 × Syn-II		
	σ^2_G	σ^2_P	h^2_B (%)	σ^2_G	σ^2_P	h^2_B (%)
Fresh ear yield	42714	156397	27.3	132293	241889	54 7
Ear length	0.30	0.40	75.0	0.21	0.32	66 6
Ear diameter	-0.21	0.26	-80 8	0.56	0.90	62.2
Plant height	8 77	16.09	54.3	12.49	20.69	60.4
Number of rows per ear	0.01	0.08	12.5	0.06	0.09	66.7
Number of kernels per row	2.01	3 10	66.8	0 77	1.96	39 3
Total soluble solids	0 61	0.91	67.0	0.35	0.57	61.4
Days to tasseling	0.96	1.34	72.0	8 70	8.92	97.6

Table 6. Simple phenotypic correlations among traits measured on populations generated from two base populations following two cycles of mass selection

Trait	Ear length	Ear diameter	Plant height	Number of rows/ear	Number of kernels/row	Total soluble solids	Days to tasseling
Fresh ear yield	0.41**	0.36**	0.09	0.15	0.09	0.08	-0.08
Ear length		0 19	0.08	0 06	0.17	0.44**	-0.26*
Ear diameter			0.03	0.23*	-0.25*	0.01	0 01
Plant height				0.21	0.03	0.10	0.35**
Number of kernel rows per ear					0.20	0.28*	0.06
Number of kernels per row						0.16	0.02
Total soluble solids							-0.32*
Days to tasseling							

**, *significant at $p \leq 0.01$ and 0.05, respectively.

on populations derived from BC2-10 and BC1-10 × Syn-II are presented in Table 6.

Based on data across locations, fresh ear yield showed high ($p \leq 0.01$) positive correlations with ear length (r = 0.41) and ear diameter (r = 0.36), indicating that plants with long ears and large ear diameters gave high yield. Strong positive association between fresh ear yield and ear length was also reported by Saleh *et al.* (2002) and Ali & Saleh (2003). Ear length also revealed high ($p \leq 0.01$) positive correlation with total soluble solids (r = 0.44), but showed low ($p \leq 0.05$) negative correlation with days to tasseling (r = -0.26), showing that plants with long ears had high total soluble solids content and low number of days to tasseling. Therefore, selection for plants with longer ears could result in improvement of kernel sweetness and earliness simultaneously.

On the other hand, ear diameter showed ($p \leq 0.05$) positive correlation (r = 0.23) with number of kernel rows per ear, but ($p \leq 0.05$) negative correlation (r = -0.25) with number of kernels per row.

Plant height was highly ($p \leq 0.01$) correlated with days to tasseling (r = 0.35). On the other hand, there was a positive association between number of kernel rows per ear and total soluble solids (r = 0.28). Similarly, total soluble solids revealed negative correlation with days to tasseling (r = -0.31). Kernel total soluble solids revealed negative correlation with days to tasseling, implying that early flowering plants produced higher total soluble solids than late flowering ones.

In conclusion, results of this study have indicated the success of mass selection for ear length in improving ear length and some correlated traits of the base populations. Improved populations from both base populations (BC2-10 C0 and BC1-10 × Syn-II C0) showed significant progress in ear length, fresh ear yield and number of kernels per row, whereas improved populations from BC2-10 alone revealed significant improvement for earliness and shortness. Hence, continuing selection for ear length in these two populations could offer better responses.

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