Maize (*Zea mays* L.) cyclical populations response over diverse environments - developed via recurrent selection

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Abstract

The recurrent selection currently exists as a cyclical breeding technique that has been widely used for improvement in maize (*Zea mays* L.). In Pakistan maize crop is mainly grown in two seasons i.e., spring (sown during February 10 to March 10) and summer (sown during June 20 to July 20). Maize base population 'PSEV3' was developed through selfed progeny recurrent selection for three years in five consecutive crop seasons (during spring and summer - 2014 and 2015, and spring - 2016). During Summer 2017, the present study was aimed to assess the mean performance of maize improved populations C_1 (based on S_1 lines) and C_2 (based on S_2 lines) developed through selfed progeny recurrent selection, in comparison to base population (PSEV3-C0) and check genotypes (cultivars Azam and Jalal, and hybrid Kiramat) for earliness and yield traits across four environments (two each location and planting time). Genotypes, locations, and planting times exhibited significant ($p \leq 0.01$) differences for the majority of the traits. However, genotype by location, genotype by planting time, and genotype by location by planting time interactions were nonsignificant for most of the variables. By comparing with base population and check genotypes, the improved maize populations [PSEV3 (S_1)-C_1 and PSEV3 (S_2)-C_2] showed the best performance by having early maturity with increased grain yield across the locations and planting times. However, the C_2 population was leading, followed by C_1 as compared to the original population (C_0) and check genotypes for the majority of the traits. Overall, the selfed progeny recurrent selection was found effective in improving maize base population 'PSEV3' for maturity and yield related traits.

Introduction

Maize (*Zea mays* L.) is the third consequential cereal after wheat and rice crops, widely grown in tropical, sub-tropical and temperate zones both under irrigated and rain-fed conditions worldwide (Ali, 2015; Andorf et al., 2019). Being the highest yielding cereal crop, maize procured great importance to meet the demand of rampantly increasing population in Pakistan which has already outstripped food supplies (Ullah et al., 2019; Sajjad, 2018; Sajjad et al., 2016, 2020). Maize is a short day annual plant that efficiently utilizes solar radiation. Maize has wide adaptability on global basis as its cultivation ranges from 50°N to 40°S latitude and an altitude of 3300 meter (Martin et al., 2006). Medium textured soil with a pH of 6.5 to 7.5 is most opportune for its prosperous cultivation. Maize has got increasing importance in monocropping areas in the Northern hills and Azad Jammu and Kashmir, Pakistan due to its short duration as compared to other cereals, legumes and oilseed crops (Khan et al., 2018; Ali et al., 2019, 2020). Recurrent selection serves as a basis for maize breeding which was initiated in Nebraska - USA by Lonnquist in 1943 and Iowa - USA by Sprague in the 1940s (Hallauer and Carena, 2012). These empirical findings highlight the efficacy of phenotypic recurrent selection predicated on phenotype of the selfed ears from individual plants. The selfed seeds from the selected ears were acclimated to sustain new populations for further maize yield improvement.

Recurrent selection is an efficient breeding method used for improvement in maize which enhances the occurrence of favorable genes through regular cycles of selection along with the preservation of genetic variation in the breeding populations (Kolawole et al., 2017). Effectiveness of recurrent selection depends on genetic variation, heritability in the traits under selection and gene frequencies within the pristine population. The recurrent selection has been prosperously used to enhance the performance of maize populations especially for quantitatively inherited traits (Kolawole et al., 2019). Noor et al. (2010) also fortified the past findings that recurrent selection is a viable selection technique to ameliorate morphological as well as yield traits in maize. In recurrent selection, the cyclical process in maize implies three steps, a) families generation, b) families evaluation, and c) families recombination (Sheikh et al., 2019).

Selfed progeny recurrent selection is considered more efficient than full-sib and half-sib families selection in corn (Sohail et al., 2018; Khamkoh et al., 2019). The S_1 progeny recurrent selection is an excellent option for procuring amelioration within maize populations, particularly improving yields (Badu-Apraku et al., 2013; Noor et al., 2013). The S_2 recurrent selection is an alternate source for improving the performance of maize lines and hybrid populations. Selection in cycle-2 produced maximum grain yield with consequential genetic gain and it could be concluded that S1 recurrent selection has been found efficacious for yield traits genetic improvement in maize (Khan et al., 2018; Chen et al., 2019).

Breeders mostly aim to reach desirable variations in the original population for further selection in maize (Ali et al., 2017; Sampoux et al., 2020). The variations in the population are due to the combined effects of genotypes (genetic variance) and environments (environmental variance) and genotype by environment interactions. Genotypic variance is durable, heritable and desirable for breeders while environmental variance is non-transferable to the next generation and fluctuates with the environment (Ali, 2015; Annor et al., 2019; Cobb et al., 2019). Genotypic potential, variability and planting time have consequential effects on yield and associated traits of maize (Rahman et al., 2015).

Climate change might have positive impact on maize production if adaptation options are efficiently utilized (Hunt et al., 2019). Higher grain yield with optimum maize planting was attributable to a longer growing period (Ahmad et al., 2010; Verma et al., 2012). Planting maize with longer vegetative period might face the negative impact of increasing temperatures on maize yield (Huang et al., 2018). Optimum maize planting was recommended, however, adjustment of the planting time could result in reducing high temperatures useful for maize yield (Rahimi-Moghaddam et al., 2018). Additionally, the growers must have to rely on early maturing maize genotypes to ascertain physiological maturity before the advent of chilling low temperatures. Therefore, the present study was conducted with the objective to assess the performance of improved maize populations (C_1 and C_2) in comparison to base population (C_0) and check genotypes (cultivars Azam and Jalal, and hybrid Kiramat) across different environments (two each location and planting time) for earliness and yield correlated traits.

Materials and Methods

Development of breeding material, sites, and procedure

Maize original population PSEV3 was derived from a cross between maize cultivar Azam and hybrid CHSW (Single cross hybrid, white kernels with late maturity from CIMMYT). For improving maize base population 'PSEV3' for earliness and grain yield through selfed

Table 1 -Genotypes evaluated during the study

S. No.	Genotype	Source	Type	Kernel shape and Colour	Plant height	Maturity	Pedigree
1	PSEV3C0	CCRI	OPP	Flint white	Medium	Medium	Cross between Azam and CHSW (Single cross hybrid, white kernels with late maturity from CIMMYT)
2	PSEV3(S1)C1	CCRI	OPP	Flint white	Medium	Medium	Derived from recombining S_1 selected
3	PSEV3(S1)C2	CCRI	OPP	Flint white	Medium	Medium	Derived from recombining S_2 selected
4	Azam	CCRI	OPV	Flint white	Medium	Medium	Derived from cross (Akbar × Vikram)
5	Kiramat	CCRI	HV	Flint white	Medium	Medium	Derived from cross [FRHW-20-4 × FRHW-22(F_2)-5]
6	Jalal	CCRI	OPV	Flint white	Tall	Medium	Derived from cross (Azam × CHSW)

CCRI: Cereal Crops Research Institute, Nowshera - Pakistan, OPP: Open pollinated population, SP: Selfed population, OPV: Open pollinated variety, HV: Hybrid variety progeny recurrent selection, the breeding material was developed for three years in five consecutive crop seasons (during spring and summer - 2014 and 2015, and spring - 2016) at Cereal Crops Research Institute (CCRI), - Nowshera, Pakistan (Table 1).

The improved populations (PSEV3 (S_1)-C1 and PSEV3 (S_2)-C_2) developed during the two cycles of selfed progeny recurrent selection (S_1 and S_2 lines) were evaluated during summer crop season 2017 in comparison with an original population (PSEV3-C0), and three check genotypes viz., Azam and Jalal (OPV - open-pollinated cultivars with medium maturity), and Kiramat (a local single cross hybrid) at two locations *i.e.*, CCRI, Nowshera, and The University of Agriculture, Peshawar (UAP) and two planting times (early and late July). At each location, the split-plot design was used for experimental layout, three times replicated. Planting times were treated as main-plots whereas maize genotypes were considered as sub-plot factors at each location. Each sub-plot comprised four rows, 5 m long, 0.75 m apart, with plant spacing of 0.25 m.

Crop husbandry

Maize is a shallow-rooted crop, and it requires fine good tilth and well-prepared soil for successful germination and growth of crop. To get this, the field was ploughed with deep plough then harrowed with planking each time to make the soil loose, fine, levelled and pulverized. The stubbles of the previous crop left in the field were also removed. A recommended fertilizer dose at the rate of 200:90:90 NPK kg ha^{-1} was applied. Half dose of nitrogen (N), full doses of phosphorus (P_2O_5) and potash (K_2SO_4) were applied during land preparation and just before planting in the form of Urea, Single Super Phosphate (SSP) and Sulphate of Potash (SOP), respectively. The remaining half N was applied in the form of Urea as side-dressing about 4-5 weeks after germination. Weeds were controlled with Primextra Gold @ 1.5 L ha^{-1} as a pre-emergence application. The left over weeds were manually controlled carrying out weeding and earthing-up operations. Maize borer was controlled by using Confidor (WP- 60) at the rate of 50 g per 10 kg of maize seed through seed treatment before planting. After one month of germination, Furadon (3%) granules @ 20 kg ha^{-1} were applied in the whirls. The crop was irrigated at the proper interval when required, until one week before harvesting. All the entries were equally treated during the cropping season at both locations.

Agronomical and morphological recorded traits

Data were recorded on each plant in each replication and then averaged before the analysis for days to tasseling (days counted from planting when 50% of the plants were tasseled in the plot), plant height (plant height was quantified as an average distance from the soil surface to the node of flag leaf in cm in each plant), cobs per m2 (total cobs were counted at harvest in each plot and then cobs per m2 were calculated on simple calibration), kernel rows per cob (average number of kernel rows were counted in desultorily selected cobs in each plot), 100-kernel weight (a hundred kernels were taken arbitrarily from the grain lot of each entry and weighed in grams with the help of electric balance). Grain yield (kg ha-1) was calculated using the following formula (Carangal et al., 1971).

$$Grain\ yield\ (kg\ h^{-1}) = \frac{(100 - MC) \times FEW \times Shelling\ coefficient \times 10{,}000}{(100 - 15) \times Plot\ area}$$

Where

MC = Moisture content (%) in grains at harvest

FEW = Fresh ear weight (kg) at harvest

Shelling coefficient = 0.80

Statistical analysis

All the recorded data regarding evaluation and comparison of cyclical populations [PSEV3-C_0, PSEV3 (S_1)-C_1, and PSEV3 (S_2)-C_2] and check genotypes across environments (location × planting time) were subjected to analysis of variance utilizing Statistix 8.1 software (Statistix, Analytical Software, Tallahassee, FL, USA 1985-2003) useful for genotype by environment interaction study (Gomez and Gomez, 1984). Means were further dissevered and compared using Fisher's LSD test.

Results and discussion

Breeders mostly expose the new developed cultivars to diverse environments to ascertain the impact of the climatic conditions on the performance of genotypes. The environment affects the genotypes differently; and the most desirable genotype is considered to be that which is least affected by the environment. Therefore, the tenaciousness of congruous planting time is very crucial for achieving greater yield in maize. The recurrent selection has been widely used for yield improvement in maize populations and accommodates as a substructure in maize breeding programs worldwide (Khamkoh et al., 2019). The recurrent selection is an efficient technique of maize improvement which increases the frequency of favourable genes by multiple cycles of selection while simultaneously maintaining genetic variation within the breeding populations (Hallauer and Carena, 2012; Noor et al., 2010, 2013).

Table 2 - Mean squares of maize cyclical populations (PSEV3-C_0, C_1, C_2) and check genotypes for various traits across locations and planting times

Source of variation	d.f.	Days to tasseling	Plant height	Ears m-2	Kernel rows ear-1	100-grain weight	Grain yield
Locations (L)	**1**	62.35*	1020.01	5.40*	2.72*	84.50**	15297.98
Error	4	6.10	217.61	1.15	0.90	6.25	1761132.26
Planting times (P)	1	2508.68**	1953.13	11.36**	6.72**	50.00 *	63884859.23*
L × S	1	17.01	3240.13	1.16	3.56*	14.22	1610509.67
Error	4	5.85	427.17	0.50	0.18	3.36	3014741.17
Genotypes (G)	5	114.31**	628.99 *	0.40	8.13**	20.70**	2812111.65*
G × L	5	10.25	111.41	0.28	2.39*	10.97	1019174.16
G × P	5	10.11	137.59	0.18	1.19	13.67*	522067.62
G × L × P	5	7.11	366.79	0.19	2.22*	5.89	754191.87
Error	40	7.01	250.19	0.31	0.83	5.51	834439.78
CV (%)	-	3.32	9.98	12.05	6.41	8.26	18.36

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

A combined analysis of variance was performed on six genotypes, two each location and planting time for earliness, morphological and yield related traits (Table 2). For sites, the mean differences were consequential (p≤0.01) for 100-grain weight; however, the differences were significant (p≤0.05) for days to tasseling, ears per square meter and kernel rows per ear. Planting time averages revealed significative (p≤0.01) differences for all the traits except plant height. Genotypes (G) showed significant (p≤0.01) differences for all the traits except ears per square meter. The genotype by location (G × L), the genotype by planting time (G × P), and the genotype by location by planting time (G × L × P), the interactions were nonsignificant for all the traits except kernel rows per ear for which the mean differences were significant (p≤0.05). The traits results are discussed herein.

Present results revealed that improved maize populations, and check genotypes revealed significant genetic differences for earliness, plant architectural, and yield traits across environments and suggested subsequent selection for further improvement. Positive responses to ear traits were observed in maize populations after two cycles of S1 recurrent selection (Khalil et al., 2010; Khan et al., 2011). Large differences were reported among the S1 lines test-crosses for maturity traits, plant height, ear height, kernel rows per ear and other yield traits while nonsignificant for anthesis-silking-interval in maize (Annor et al., 2019). Consequential differences were observed among the genotype by environment interactions for earliness and yield related traits which revealed that maize families perform differently under diverse environments (Da-Cunha et al., 2012).

In maize S_1 populations, the variations were significant for ear length, kernel rows per ear, and other yield-related traits (Rahman et al., 2015; Khamkoh et al., 2019). In previous studies, the maize half-sib families revealed significant (p≤0.01) differences for earliness and grain yield characters which made easy the recommendation of maize genotypes for a specific environment (Sohail et al., 2018; Sheikh et al., 2019). Highly significant differences were reported for kernel rows per ear, 1000-kernel weight, and grain yield while significant for ear length and prolificacy in selected S_1 populations of maize (Ali et al., 2018, 2019). Planting times and genotype × planting time revealed consequential differences for earliness, morphological and yield-related traits in maize (Ahmed et al., 2011; Gaile, 2012). However, some studies revealed that genotype by environment interactions were nonsignificant for days to flowering, plant height, ear height, and 100-grain weight (Amjadian et al., 2013; Buriro et al., 2015; Ali et al., 2020).

Days to tasseling

Data recorded for the genotypes under study in the two locations indicated that, on average basis, days to tasseling were lower at UAP (78.83 days) as compared to CCRI (80.69 days) (Table 3). For planting time means, the genotypes with late planting showed minor days to tasseling (73.86 days) than early planting ones (85.67 days). For location and planting time interaction, the average days to tasseling ranged from 72.44 (UAP - late planting) to 86.11 days (CCRI - early planting). However, genotypes with late planting took less days

Table 3 - Mean performance of maize cyclical populations (PSEV3-C_0, C_1, C_2) and check genotypes for various traits across locations and planting times

Genotypes	CCRI		UAP		Means
	Early planting	Late Planting	Early planting	Late Planting	
Days to tasseling (days)					
PSEV3 C_0	87.33	74.33	87.33	74.00	80.75
PSEV3 (S_1) C_1	82.00	72.67	81.33	71.67	76.92
PSEV3 (S_2) C_2	81.67	71.67	81.00	70.33	76.17
Azam	85.33	74.33	83.00	72.00	78.67
Jalal	89.67	79.33	88.33	70.00	81.83
Kiramat	90.67	79.33	90.33	76.67	84.25
Means (days)	86.11	75.28	85.22	72.44	
Location means (CCRI: 80.69, UAP: 78.83), Planting time means (Early: 85.67, Late : 73.86), LSD0.05 Genotypes: 2.18, Planting times: 1.58, Locations: 1.616, G × S × L : NS, NS: Non-significant					
Plant height (cm)					
PSEV3 C_0	151.67	132.67	165.67	146.67	149.17
PSEV3 (S_1) C_1	156.33	144.33	150.00	156.33	151.75
PSEV3 (S_2) C_2	172.33	154.67	176.00	169.00	168.00
Azam	168.67	135.67	159.67	167.33	157.83
Jalal	174.00	145.00	169.33	170.33	164.67
Kiramat	176.67	144.33	143.67	172.67	159.33
Means (cm)	166.61	142.78	160.72	163.72	
Location means (CCRI: 154.69, UAP: 162.22), Planting time means (Early: 163.67, Late: 153.25), LSD0.05 Genotypes: 13.05, Planting times: 13.53, Locations: 9.65, G × S × L: NS, NS: Non-significant					
Ears m^{-2} (#)					
PSEV3 C_0	4.75	3.64	4.89	4.27	4.39
PSEV3 (S_1) C_1	5.15	4.18	5.42	4.13	4.72
PSEV3 (S_2) C_2	5.13	4.00	5.64	4.76	4.88
Azam	4.69	3.80	5.33	5.02	4.71
Jalal	4.78	3.76	5.11	5.07	4.68
Kiramat	4.85	3.69	4.71	4.62	4.47
Means (#)	4.89	3.85	5.18	4.65	
Location means (CCRI: 4.37, UAP: 4.92), Planting time means (Early: 5.04, Late: 4.24), LSD0.05 Genotypes: NS, Planting times: 0.30, Locations: 0.70, G × S × L: NS, NS: Non-significant					

to tasseling at both locations (72.44 and 75.28 days) as compared to early planting ones (85.22 and 86.11 days) with a reduction of 11.81 days (13.79%) in days to tasseling.

For days to tasseling, the genotype means over locations and planting times ranged from 76.17 to 84.25 days (Table 3). Minimum and same days to tasseling were observed in improved populations C_2 (76.17 days) and C_1 (76.92 days). However, the maximum days to tasseling were observed in check hybrid Kiramat (84.25 days), followed by OPV cultivar Jalal (81.83 days) and base population C0 (80.75 days). For the interaction of

Table 4 - Mean performance of maize cyclical populations (PSEV3-C_0, C_1, C_2) and check genotypes for various traits across locations and planting times

Genotypes	CCRI		UAP		Means
	Early planting	Late planting	Early planting	Late planting	
Kernel rows ear^{-1} (#)					
PSEV3 C_0	13.67	13.00	14.67	13.67	13.75
PSEV3 (S_1) C_1	16.33	13.67	14.00	15.00	14.75
PSEV3 (S_2) C_2	15.33	14.00	17.00	15.67	15.50
Azam	13.00	13.33	13.00	13.67	13.25
Jalal	14.67	12.67	14.33	14.67	14.08
Kiramat	14.00	14.00	13.67	13.00	13.67
Means (#)	14.50	13.45	14.45	14.28	
Location means (CCRI: 13.97, UAP: 14.37), Planting time means (Early: 14.48, Late: 13.86), LSD0.05 Genotypes: 0.75, Planting times: 0.28, Locations: 0.62, G × S × L: 1.50					
100-grain weight (g)					
PSEV3 C_0	28.00	25.67	25.67	26.33	26.42
PSEV3 (S_1) C_1	31.00	26.67	30.67	25.00	28.33
PSEV3 (S_2) C_2	33.67	32.33	29.33	26.33	30.42
Azam	28.67	28.67	28.67	26.33	28.08
Jalal	30.67	29.67	28.00	24.33	28.17
Kiramat	27.33	31.67	29.33	28.00	29.08
Means (g)	29.89	29.11	28.61	26.06	
Location means (CCRI: 29.50, UAP: 27.33), Planting time means (Early: 29.25, Late: 27.58), LSD0.05 Genotypes: 3.87, Planting times: 1.20, Locations: 1.64, G × S × L: 3.87					
Grain yield (kg ha^{-1})					
PSEV3 C_0	4846.00	3137.00	5344.00	3866.00	4298.25
PSEV3 (S_1) C_1	6524.00	4082.00	5354.00	4585.00	5136.25
PSEV3 (S_2) C_2	7793.00	4326.00	6240.00	4623.00	5745.50
Azam	5199.00	3460.00	5825.00	4574.00	4764.50
Jalal	5780.00	3947.00	6042.00	3408.00	4794.25
Kiramat	6165.00	4258.00	5883.00	4122.00	5107.00
Means (kg ha^{-1})	6051.17	3868.33	5781.33	4196.33	
Location means (CCRI: 4959.75, UAP: 4988.90), Planting time means (Early: 5916.28, Late: 4032.36), LSD0.05 Genotypes: 750.0, Planting times: 1114.0, Locations: NS, G × S × L: NS, NS: Non-significant					

genotype × location × planting time, the days to tasseling ranged from 70.00 to 90.67 days. Least and at par days to tasseling were obtained by improved populations i.e., C_2 at UAP (70.33 days) and CCRI (71.67 days), C_1 (71.67 days) and check genotype Jalal (70.00 days) at UAP with late planting. However, check hybrid Kiramat with early planting at both locations took maximum and similar days to tasseling i.e., CCRI (90.67 days) and UAP (90.33 days).

On average, the improved maize populations C_1 and C_2 took less days to tasseling as compared to base population (C_0) and check genotypes, and showed early maturity across the environments. Due to intensive selection and reiterated self-pollination, the favourable genes might have been accumulated in C_1 and C_2 populations which amended the cyclical populations and showed stability in early maturity. Predicated upon the negative expected responses, a decrease in days to tasseling, pollen shedding, and silking were observed in the progenies of selected maize S_1 lines (Khalil et al., 2010; Buriro et al., 2015). Da-Cunha et al. (2012) examined 42 full-sib families of maize and after the direct selection, the observed response was -0.87 days for flowering with positive gain for yield traits. The reduction in days to tasseling and increment in grain yield was noted in maize S_1 populations (Shah et al., 2012). Results further elucidated that across the environments, on average all the genotypes with late planting took less days to tasseling at both locations. Late planting had significantly reduced the days to tasseling and silking, however, plant height and grain yield were negatively affected in maize (Ahmad et al., 2010, 2011; Verma et al., 2012). Past studies also revealed that late planting implied significantly lower mean values for earliness and yield traits in maize (Khan et al., 2011; Moosavi et al., 2012; Shah et al., 2012). Maize genotype performance was promising with optimum planting while negative effects were reported on the performance of genotypes with late planting (Beiragi et al., 2011; Verma et al., 2012; Sajjad, 2018).

Plant height

For location means over genotypes, the genotypes showed minimum plant height at CCRI (154.69 cm) as compared to UAP (162.22) (Table 3). For planting time means, the least plant height was observed in genotypes with late planting (153.25 cm) than optimum planting (163.67 cm) with a reduction of 10.42 cm (6.37%) in plant height. For location by planting time interaction effects, the means for plant height ranged from 142.78 (CCRI - late planting) to 166.61 cm (CCRI - early planting). Genotype means over locations and planting times ranged from 149.17 (C_0) to 168.00 cm (C_2) for plant height (Table 3). The C_0 and C_1 populations and check genotypes Kiramat and Azam showed the least and alike plant height over locations and planting times, ranging from 149.17 to 159.33 cm. However, improved maize population C_2 (168.00 cm) and check genotype Jalal (164.67 cm) showed an enhanced plant height. For genotype × location × planting time interaction means, plant height ranged from 132.67 (C_0 at CCRI with late planting) to 176.67 cm (Kiramat at CCRI with early planting). The improved populations C_1 (144.33 cm), C_0 (132.67 cm) and check genotype Azam (135.67 cm) with late planting at CCRI showed minimum plant height. However, check genotypes Kiramat and Jalal at CCRI, and improved population C_2 at UAP with early planting manifested maximum and same plant height ranged from 174.00 to 176.67 cm.

Overall, the populations C_0 and C_1 showed minimum and homogeneous plant height while improved population C_2 showed enhanced plant height. The increase in plant height might be the result of heterosis achieved after recombining the selected S_1 lines. Observed responses for plant height were significantly enhanced with S_1 line recurrent selection in maize (Khalil et al., 2010). Similarly, significant genetic variability was reported among different maize populations for plant and ear heights (Ullah, 2013; Khamkoh et al. 2019). Original maize population, selected genotypes and hybrids were evaluated and showed a significant variation for morphological and yield traits (Rahman et al., 2015).

Ears per square meter

For locations, on average the genotypes showed maximum ears per square meter at UAP (4.92), followed by CCRI (4.37) (Table 3). In case of planting times, genotypes with early planting achieved maximum ears/m^2 (5.04) than late planting (4.24) at both locations, and the number of ears/m^2 minimized by 0.80 (15.87%) with late planting. Location by planting time means ranged from 3.85 (CCRI with late planting) to 5.18 ears/m^2 (UAP with early planting).

Genotype means over locations and planting times revealed that maximum number of ears per square meter was recorded in improved populations i.e., C_2 (4.88) and C_1 (4.72), followed by check genotypes Azam (4.71) and Jalal (4.68) (Table 3). However, the base population C_0 (4.39), followed by Kiramat (4.47) showed the minimum number of ears per square meter. In genotype × location × planting time interactions, the maximum and same number of ears per square meter was recorded in improved populations C_2, C_1, and check genotypes (Jalal and Azam) at UAP with early planting ranged from 5.33 to 5.64. Least number of ears per square meter was observed in the original population C_0 (3.64), and check hybrid Kiramat (3.69) at CCRI with late planting.

Kernel rows per ear

For location means, on average the genotypes with maximum kernel rows per ear were recorded at UAP (14.37), followed by CCRI (13.97) (Table 4). For planting times, overall the early planted populations showed maximum kernel rows per ear (14.48) as compared to late planted genotypes (13.86) at both locations. However, kernel rows per ear minimized by 0.61 (4.22%) with late planting. In location × planting time interactions, the maximum kernel rows per ear were obtained with early planting at CCRI (14.50) and UAP (14.45), while minimum were observed with late planting at CCRI (13.45).

Genotype means over locations and planting times revealed that maximum kernel rows per ear were recorded in improved maize population C_2 (15.50), followed by C_1 (14.75) and check genotype Jalal (14.08) (Table 4). However, the least number of grain rows per ear was noted in check genotype Azam (13.25). In genotype by location by planting time interactions, the maximum and an equal number of kernel rows per ear were recorded in advanced population C_2 with early (17.00) and late planting (15.67) at UAP, and check cultivar Jalal with early planting at CCRI (16.33). However, minimum kernel rows per ear were delivered by check cultivar Azam with late planting at CCRI (12.67).

Hundred-grain weight

For location means, on average the maize genotypes revealed a maximum hundred-grain weight at CCRI (29.50 g), followed by UAP (27.33 g) (Table 4). In the case of planting times, the genotypes with early planting showed a maximum of 100-grain weight (29.25 g) as compared to late planting (27.58 g). The 100-grain weight was decremented by 1.67 g (5.71%) due to late planting. In location by planting time interaction means, 100-grain weight ranged from 26.06 (UAP with late planting) to 29.89 g (CCRI with early planting).

Genotype means exhibited that maximum 100-grain weight was obtained in improved population C_2 (30.42 g), followed by check hybrid Kiramat (29.08 g) and improved population C_1 (28.33 g) (Table 4). The least value for the said trait was obtained in the original population C_0 (26.42 g). In genotype × location × planting time interactions, the maximum 100-grain weight was recorded in check hybrid Kiramat with early (33.67 g) and late planting (32.33 g), genotype Azam with late planting (31.67 g), and improved population C_1 with early planting (31.00 g) at CCRI. However, a minimum of 100-grain weight was obtained in check OPV cultivar Jalal with late planting at UAP (24.33 g).

Grain yield

For location means, on average maximum grain yield was recorded in genotypes at UAP (4988.90 kg ha^{-1}), followed by CCRI (4959.75 kg ha^{-1}) (Table 4). Genotypes with early planting revealed the highest grain yield (5916.28 kg ha^{-1}), followed by late planting (4032.36 kg ha^{-1}). Overall, the reduction in grain yield due to late planting was 1883.92 kg ha^{-1} (31.84%) for all the genotypes. Location × planting time interactions revealed that maximum grain yield was observed in the genotypes with early planting at CCRI (6051.17 kg ha^{-1}) and UAP (5781.33 kg ha^{-1}). However, genotypes with late planting at CCRI showed the least grain yield (3868.33 kg ha^{-1}).

Genotype means over both environments revealed that maximum grain yield was produced by improved population C_2 (5745.50 kg ha^{-1}), followed by C_1 (5136.25 kg ha^{-1}) and check hybrid Kiramat (5107.00 kg ha^{-1}) (Table 4). However, the base population C_0 revealed minimum grain yield (4298.25 kg ha^{-1}). Means for genotype × location × planting time revealed that highest and same grain yield was recorded for check cultivar Jalal (7793.00 kg ha^{-1}) and improved population C_2 (6524.00 kg ha^{-1}) with early planting at CCRI. However, minimum grain yield was observed in the base population C_0 at CCRI with late planting (3137.00 kg ha^{-1}).

Across genotypes and genotype × location × planting time, on average the improved population C_2 showed best performance, followed by C_1 as compared to check genotypes Jalal and Kiramat for ears m^{-2}, kernel rows ear^{-1}, 100-grain weight and grain yield. On average, the above promising populations revealed best performance for yield related traits at CCRI with early planting. While base population C_0 exhibited ineffective mean performance for yield traits with early and late planting at both locations. The S_1 maize population showed higher mean values for yield related traits with increased grain yield as compared to original population (Shah et al., 2012; Rahman et al., 2015). In maize improved populations, the recurrent selection effectively enhanced the accumulation of desirable alleles for quantitative traits (Kolawole et al., 2019). Realized progress in breeding program largely depends upon accurate recognition of better genotypes for the specific environment and the accuracy with which the studies are conducted.

Results also revealed that increased grain yield in improved population C_2 was associated with early flowering and maturity. Present findings also got support from past investigations showing significant response in S_1 maize population for earliness and grain yield (Khamkoh et al., 2019). Though late flowering genotypes resulted high yielders due to accumulation of comparatively larger quantity of photosynthates during vegetative growth; however, earliness in flowering is equally desirable to escape maize crops from biotic and abiotic stresses usually experienced at later growth stages.

Conclusions

The cyclical populations C_2 and C_1 performed better than base population (C_0) and check genotypes, for the majority of the evaluated traits; however, C_2 population was superior. Genotypes with early planting showed the best performance while late seeding has a significant impact on the performance of the genotypes by causing a reduction in the grain yield. Selfed progeny recurrent selection was found to be effective in improving maturity and yield traits in maize.

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