Research Article

Grain Yield and Agronomic Performance of Maize (*Zea mays* L.) Hybrids Obtained From Improved Maize Populations

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Abstract | Hybrids obtained from genetically diverse populations are genetic reservoirs which can lead to greater adaptability and resilience and is therefore of great potential for food security in maize. Combining ability is a powerful tool to identify good parents, which indicates a measure of gene action and accumulate fixable parental genes. A set of 10 parents and their 45 hybrids were tested for General and Specific combining abilities (GCA and SCA) effects in Randomized Complete Block design with three replication in crop season 2015 and 2016 at the University of Agriculture Peshawar (UAP) and Cereal Crops Research Institute (CCRI) Nowshera. The combined ANOVA across locations and years revealed that genotypes and genotype × environment interactions were significant for yield and other yield traits. GCA and SCA variances were highly significant for the observed traits at both locations indicating the importance of both additive and non- additive gene actions in controlling these traits. However, the ratio of GCA/SCA variance revealed the preponderance of non-additive gene action in expression of these characters. Populations like Pop-8003, Pop-1325, Jalal and SHN 107 showed highly positive GCA effects for yield in both locations. Pop-8003 was found a good combiner by manifesting positive SCA effects on yield with most of the populations. Hybrid, Pop-8003 × Pop-2011 exhibited the highest positive SCA effects and *per se* performance on yield (8567 kg/ha) followed by Pop-8003 × Super-08, Pop-1325 × Pop-2011 and Pop-8003 × SW. Data across environments showed that 38% hybrids produced more yield than parent, Jalal with comparatively higher mean yield among all the parents (7046.9 kg/ha). Positive SCA values were recorded in 60% (CCRI) and 62% (UAP) hybrids. Our data also showed that population hybrids were statistically dissimilar from parents and can be competitive with single-cross commercial hybrids that provide an alternative to relying solely on elite inbred lines.

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Introduction

Being the most versatile crop with high adaptability, maize or corn (*Zea mays* L.) occupies an important position among field crops both as food and feed. It is an alternative source of food security, which can act as alternate food source when the conventional cereal grains i.e. wheat and rice are deficient (Shiferaw *et* *al*., 2011). The methods for the generation of maize inbred hybrid seed and up keep of parental lines are all well described. However, less attention has been paid to development, maintenance, and multiplication of hybrids derived from improved maize populations (Li *et al*., 2012). Maize populations like composites, gene pools, and advanced generations of varietal crosses, etc. are routinely developed by crossing genetically diverse maize types, which are then improved through recurrent selection (Sajjad *et al*., 2020). A specific combination from the improved populations can be released as an improved OPV or population hybrid for cultivation (Menkir and Akintunde, 2001). In spite of the fact that these population hybrids are not essentially uniform in agronomic attributes when contrasted with innate inbred hybrid, yet these can be acquired with significant decrease in time and resources and great yield than OPVs. It is relatively uniform and stable over time for important agronomic traits in its area of adaptation than inbred hybrids. If produced by crossing selected populations of similar maturity, plant and ear height, and other morphological traits, a population hybrid will be more uniform, more acceptable to farmers, and easier to maintain and produce seed for (Rehman *et al*., 2018). In some farming systems like small land holdings, low yield levels and high price of hybrid seed and other inputs relative to grain price, the use of commercial inbred hybrids by farmer might not be economically advantageous (Cisar and Cooper, 2002). Therefore a good alternative, in the form of improved population hybrids or even improved OPVs are particularly advantageous if the money saved from using these alternatives instead of hybrid seed is used to purchase additional inputs (fertilizer, herbicide or hiring additional labor). Therefore, promising populations and their hybrids once identified could be used as population hybrids for commercial seed production (Rehman *et al*., 2018).

The objective of this study was to compare grain yield and agronomic performance of 45 maize population hybrids and their 10 parents and sort out the best hybrids as alternatives to commercial single-cross hybrids. These population hybrids also provide elite sources of new inbred lines. Inbred lines developed from such broad-based populations carry the advantage of having good combining ability with lines derived from more than one heterotic group (Carena, 2005). Therefore we also tested these population crosses as a source of elite inbred lines in line × tester experiment and identified some good lines based on their combining ability and grain yield performance (Rehman *et al*., 2018). Crossing these diverse maize populations will also enrich the available maize gene pool, thus enhancing the maize genetic diversity in reserve.

Materials and Methods

The study was conducted across two locations i.e. Cereal Crops Research Institute (CCRI) Nowshera, which is located on left bank of Kabul River; its elevation is 288 m and located on the intersection of longitude 74^0 E and latitude 32^0 N in district Nowshera and the University of Agriculture (UAP) Peshawar, Pakistan, which is located at longitude 71^0 E and latitude 34^0 N with its elevation of 361 m in district Peshawar. CCRI is characterized by a subtropical, semi-arid climate with hot summers and cold winters. The area experiences distinct seasons, with hot and dry summers and cold, dry winters. Similarly, UAP represent a warm to hot, semi-arid, and subtropical climate 22.7°C with average annual temperature and about 445 mm annual rainfall. About 42% of the total rainfall occurs during the February to April period.

Table 1: *Origin, agronomic features and general combinign ability (GCA) of maize populations developed at CCRI nowshera and used as parents of population hybrids.*

Population	Genetic background	Agronomic features			GCA effects
		Maturity	Grain Type	Stature	
Pop-8003	Sarhad white × Babar	Long	Dent	Tall	545.35
Pop-1325	FRW4 × Iqbal	Medium	Semi dent	Medium	529.85
Sarhad white	Vikram(b57 × b37) × Akbar	Long	Dent	Tall	56.8
Jalal	Chsw × azam	Long	Flint	Tall	234.6
Pop-2009	Jalal × Sarhad white	Medium	Flint	Medium	-206.15
Pahari	7930 × Shaheen	Early	Flint	Short	-748.85
Azam	(7930xzia) × 7930	Medium	Flint	Medium	-502.2
Pop-2011	Sarhad white × FRW4	Early	Flint	Medium	21.05
SHN-107	Shaheen × FRW3	Medium	Semi flint	Medium	314.3
Super-08	Pahari × FRW6	Medium	Semi flint	Medium	-244.75

The study comprising a set of 10 improved maize populations (Table 1) was conducted during maize crop growing seasons 2015 and 2016. These populations have undergone several cycles of repeated recurrent selection at Cereal Crops Research Institute, Nowshera. These populations were crossed in a diallel pattern excluding reciprocals at CCRI and obtained 45 population hybrids following the procedure described by Russell and Hallauer, (1980) during maize season 2014. About 15 crosses were made in each combination and all the cobs were harvested to get sufficient seed for future evaluation across locations and years. The 45 population hybrids along with ten parental populations were planted in a randomized complete block (RCB) design with three replications at both locations. Each entry was planted in a two rows plot with 5 m row length having 75 cm row to row and 20 cm plant to plant distance.

Two seeds per hill were sown and fertilizer was applied in the form of diamonium phosphate (DAP) and urea at the rate of 150 and 250 kg ha-1 respectively and top dressed with additional N at 60 kg/ha at four weeks after sowing at each location. Recommended package of practices of both locations (CCRI and UAP) were used to raise a healthy crop and pre-emergence herbicide (Primextra gold @ 600ml/acre) was also used to control weeds after ploughing and harrowing before sowing. Hand weeding was also done when necessary to control weeds during the growing period.

The data were recorded on ten randomly selected plants from each replication at appropriate growth stages for each of the studied parameter *viz.*, days to flowering, ear height, ear length, kernel rows per ear, 100-grains weight and grain yield. For grain yield in kg ha^{-1} the following standard formula was adopted.

$$\text{Grain Yield Kg ha}^{-1} = \frac{(100 - \text{MC}) \times \text{FEW} \times \text{Shelling Co-efficient} \times 10{,}000}{(100 - 15) \times \text{Plot Area}}$$

Where,
MC = moisture content (%) in grains at harvest
FEW=Fresh ear weight (kg) at harvest
Shelling Co-efficient = Shelling % age/100.

Combined analysis of variance (Gomez and Gomez, 1983) procedure for randomized complete block (RCB) design for across locations and years were used to estimate components of variance and detect if significant variation exist among genotypes for the standard plant parameters. Mean data were subjected for analysis of general combining ability (GCA) and specific combining ability (SCA) as per method-II (parents and one set of F_1's without reciprocals) and model-I (fixed effect) given by Griffing (1956).

Results and Discussion

The mean sum of squares due to various sources of variation for the studied traits *viz.*, days to flowering, ear height, kernel rows per ear, 100-grains weight and grain yield are presented in Table 2. The combined ANOVA across locations and years showed that

Table 2: *Mean square values for the studied traits in maize populations and their hybrids evaluated across two locations in 2015 and 2016.*

SOV	FD	FD	EH	EL	KRPE	GW	GY
Year (Y)	1	291.34^{NS}	394.09^{NS}	3.50^{NS}	1.8^{NS}	9.18^{NS}	13685756.7^{NS}
Location (L)	1	7976.86^{NS}	11636.80^{NS}	381.99^{NS}	142.2*	4491.7*	469112580.9*
Y × L	1	193.65**	106.13^{NS}	10.41*	0.31*	6.26*	577202.8^{NS}
Rep/Y × L	8	11.50	783.02	11.01	4.3	4.12	1230256.4
Gen	54	21.13**	849.22**	24.40**	11.3**	162.7**	9626195.3**
G × Y	54	2.21**	35.61^{NS}	1.24^{NS}	2.2^{NS}	3.6^{NS}	420663.4^{NS}
G × L	54	17.31**	317.00**	13.45**	10.1**	88.2**	5754751.3**
G × Y × L	54	2.17**	52.34^{NS}	1.59^{NS}	1.7^{NS}	5.04**	416783.9^{NS}
Error	432	1.33	155.51	2.72	2.2	2.77	367087.9
Total	659	-	-	-	-	-	-
CV %	-	2.18	20.67	10.82	10.41	5.10	9.07

**, ** Significant at 5 and 1 % level of probability, respectively, SOV= Source of Variation, FD= flowering days, EH= ear height, EL= ear length, KRPE= kernel rows per ear, GW= 100-grains weight, GY= grain yield.*

mean squares for genotypes were highly significant for all the studied traits. Locations mean squares were significant for kernel rows per ear, 100-grains weight and grain yield only. Year × location interaction was significant for all the traits except ear height and grain yield. Genotype × year interaction was non-significant for all traits except days to flowering whereas the genotype × location interactions were highly significant for all the traits considered in this study. Interaction due to genotype × year × location were non-significant for all traits except days to flowering. The results revealed the existence of sufficient variability among the parents and cross combinations at both locations for all of the characters studied in the present investigation. The significant mean squares recorded for genotypes for all the studied traits in the current study indicated that the genotypes responded differently to the test locations (environments) which call for the need to identify high-yielding and stable genotypes across locations (Haruna *et al*., 2017; Moghaddam and Pourdad, 2009). Also, the highly significant genotype by location interaction for grain yield and other traits of the population-cross hybrids seeks to justify the need for testing of the hybrids in multiple locations over years before recommendation. Significant differences for interaction between genotype and locations may be because the parents used for hybrids were of diverse genetic backgrounds as previously reported by Uguru, (2005) stating that genotypes perform differently in a given location for characteristics controlled by diverse genetic factors.

The combing ability analysis were carried out at individual location due to significant differences of genotype × location interaction. Analysis of variance for combining ability and estimates of genetic components of variance at Cereal Crops Research Institute (CCRI), Nowshera and the University of Agriculture, Peshawar (UAP) for different characters under study are presented in Table 3. General combining ability and specific combining ability variances were highly significant ($P<0.01$) for all the traits at both locations which indicated the involvement of both simple and complex gene actions in controlling these characters. Similar findings of significant GCA and SCA have been also reported by Uddin *et al*. (2008); Dhoot *et al*. (2017); Aguiar *et al*. (2003); Phudenpa *et al*. (2006) and Kumar *et al*. (1998). Furthermore, the ratio of σ^2GCA / σ^2SCA was less than one at both CCRI and UAP for all the traits, except for ear height at CCRI, thereby indicating the preponderance of non-additive gene effects in the expression of these traits and thus corroborates with other findings, Das and Islam, (1994) and Alamerew and Warsi, (2015). Such results of non-additive gene actions not only disclose a call for hybrid development corresponding to the breeding objectives but also later generation selection. Positive GCA effects at both locations were exhibited by three parents for ear length; two parents for kernel rows per ear; five parents for 100-grains weight and four parents for grain yield, whereas, GCA effects in negative direction were exhibited by four parents for ear height and two parents for flowering days (Table 4). Highest positive GCA effects for ear

Table 3: *Combining ability analysis for various traits in 45 maize hybrids from a population diallel at both locations.*

Characters	Cereal crops research institute, nowshera					University of agriculture peshawar				
	Mean squares		Variance components			Mean squares		Variance components		
	GCA	SCA	σ^2GCA	σ^2SCA	σ^2GCA/ σ^2SCA	GCA	SCA	σ^2GCA	σ^2SCA	σ^2GCA/ σ^2SCA
Flowering days	0.58*	0.71**	0.02	0.42	0.05	20.7**	2.7**	1.7	2.6	0.65
Ear height(cm)	149.2**	61.7	7.42	1.55	4.79	231.4**	95.4**	17.0	68.3	0.25
Ear length(cm)	10.9**	2.3**	0.88	1.88	0.47	3.5**	2.4**	0.3	1.9	0.16
Kernel rows ear^{-1}	1.2**	1.8**	0.07	1.43	0.05	3.7**	1.5**	0.3	1.3	0.23
100-grain weight(g)	64.9**	22.1**	5.4	21.8	0.25	13.2**	12.4**	1.05	11.8	0.09
Grain yield(kg/ha)	1952174**	791474**	155351.1	703512.7	0.22	3734580**	1147364**	307720.9	1105435.2	0.28

**, ** Significant at 5 % and 1 % level of significance, respectively.*

Table 4: *General combining ability effects of 10 parents for different traits in maize.*

genotypes	Flowering days		Ear height		Ear length		Kernel rows ear^{-1}		100-grains weight		Grain yield	
	CCRI	UAP	CCRI	UAP	CCRI	UAP	CCRI	UAP	CCRI	UAP	CCRI	UAP
Pop-8003	0.4	1.6	1.6	-0.6	0.9	0.4	-0.3	-0.9	3.6	2.0	595.8	494.9
Pop-1325	0.2	1.6	2.7	-0.8	2.1	1.1	-0.2	-0.6	2.0	0.4	457.3	602.4
Sarhad white	0.2	-0.9	-4.4	-6.5	-0.2	-0.3	-0.3	0.6	-2.7	-0.2	360.9	-247.3
Jalal	-0.1	0.1	2.3	0.6	0.3	0.3	0.3	0.1	2.4	0.3	25.7	443.5
Pop-2009	-0.1	-1.0	-5.1	-0.2	-1.0	0.0	-0.3	0.2	0.3	0.4	-240.8	-171.5
Pahari	0.0	-1.6	-1.5	-4.7	-1.0	0.1	0.4	-0.1	-4.0	-1.6	-423.5	-1074.2
Azam	0.1	-1.2	0.9	1.6	-0.5	-0.9	-0.2	-0.4	-1.6	-1.3	-348.4	-656.0
Pop-2011	-0.2	-1.2	-4.0	-1.2	-0.2	-0.3	0.4	1.0	-0.3	-0.8	115.1	-73.0
SHN 107	-0.2	1.0	2.5	1.5	0.5	0.1	-0.3	0.4	-0.2	-0.1	82.8	545.8
Super-08	-0.3	1.4	5.1	10.1	-0.7	-0.4	0.4	-0.3	0.4	0.8	-624.8	135.3
$CD_{(0.05)}$	0.49	0.36	7.16	4.81	0.56	0.65	0.56	0.42	0.57	0.71	273.9	189.1

CCRI= Cereal Crops Research Institute, UAP= University of Agriculture Peshawar, CD= Critical Difference

length, 100-grains weight and grain yield were showed by parents Pop-8003 and Pop-1325 and followed by Jalal and could be successively used in the development of synthetic varieties of maize for future breeding. Negative SCA effects for flowering days were exhibited by 24 hybrids with hybrids Pop-8003 × Jalal, Pop-1325 × Pahari, SW × Pop-2009, Jalal × SHN 107 and Pahari × Super-08 exhibiting highest negative SCA effects at CCRI. Negative SCA effects in these hybrids could be effectively exploited for development of early maturing hybrid.

At location UAP, 28 hybrids showed negative SCA for this trait with hybrids Pop-8003 × Super-08, Pop-1325 × Pahari, SW × SHN 107 and Jalal × Azam showing highest negative SCA at this location while 12 hybrids showed negative SCA at both locations (Table 5). Reduction in ear height was observed in 21 hybrids at CCRI and 20 hybrids at UAP. Highest SCA values in negative direction for this trait were observed in hybrids, Jalal × Azam and Pahari × Pop-2011 at CCRI and for hybrids Jalal × Azam, Pop-2009 × Pop-2011 and Azam × Pop-2011 at UAP. Similarly SCA effects in positive direction at both locations were exhibited by 12 hybrids for ear length, 11 for kernel rows per ear, 16 for 100-grains weight and 18 for grain yield. The highest values of positive SCA for ear length was obtained for hybrids Pop-8003 × SHN 107, Pop-1325 × Pop-2009, Pop-2011 × SHN 107 at CCRI and for hybrids Pop-8003 × SHN 107 and Pop-1325 × Pop-2011 at UAP location. Three hybrids (Pop-8003 × SHN 107, Pop-8003 × Super-08, Pop-2011 × Super-08) at CCRI and four hybrids (Pop-8003 × Pahari, Pop-1325 × Azam, SW × Pop-2011 and Azam × SHN 107) at UAP were identified the best specific combiners with highest positive SCA for kernel rows per ear. For 100-grains weight, 56% and 62% hybrids while for grain yield 60% and 62% hybrids exhibited positive SCA at CCRI and UAP, respectively. Hybrids Pop-8003 × Pop-2011, Pop-8003 × Super-08, Pop-1325 × Pop-2011, Pop-8003 × SW, Pop-1325 × Azam and Pop-2011 × Super-08were the best hybrids with positive SCA for grain yield and 100-grains weight and good *per se* performance across both locations (Table 6). Dhoot *et al.* (2017) and Fan *et al.* (2008) published similar results for identification of parents and their hybrids on the basis of GCA and SCA effects for grain yield and yield components in maize.

Conclusions and Recommendations

Results of our investigations suggest that majority of the population hybrids (60% at CCRI and 62% at UAP) produced higher yield than their parental populations. Our results also suggest that some of the parents that may not be superior in their *per se* performance could provide desirable gene combinations in their hybrids (Figure 1). For instance hybrid Pahari × Super-08 is a cross between bad × medium GCA effect parents for grain yield that showed high positive SCA effects for grain yield (GCA > +600 at both locations) with good *per se* performance compared to individual performance of parental populations. Also population hybrids among promising populations can provide elite sources of new inbred lines having good general and specific combining ability as confirmed in our

Table 5: *Specific combining ability effects for flowering days, ear height and ear length in 45 maize hybrids from a population diallel.*

genotypes	Flowering days		Ear height		Ear length	
	CCRI	UAP	CCRI	UAP	CCRI	UAP
Pop-8003 × Pop-1325	-0.6	0.1	-8.8	-5.7	-1.2	-2.8
Pop-8003 × SW	-0.9	-1.7	-3.3	13.8	1.9	-0.5
Pop-8003 × Jalal	-1.3	-0.3	-4.5	-5.2	-0.4	0.0
Pop-8003 × Pop-2009	0.5	-0.3	-2.6	6.6	1.5	0.1
Pop-8003 × Pahari	0.6	-0.2	1.0	11.5	0.5	0.4
Pop-8003 × Azam	0.2	-0.7	10.0	2.2	1.7	1.7
Pop-8003 × Pop-2011	-0.5	0.0	4.7	4.8	-1.1	1.9
Pop-8003 × SHN 107	0.6	-1.5	5.4	7.1	2.6	4.3
Pop-8003 × Super-08	0.0	-2.8	8.3	4.0	0.3	-1.0
Pop-1325 × SW	0.5	0.0	13.6	5.4	0.1	1.4
Pop-1325 × Jalal	-0.4	-1.2	9.1	-1.1	0.4	-0.6
Pop-1325 × Pop-2009	-0.1	-2.1	-3.4	-2.1	2.7	-0.5
Pop-1325 × Pahari	-2.1	-2.1	-2.3	13.0	0.9	1.1
Pop-1325 × Azam	0.5	-1.6	-8.9	-3.8	1.3	-1.4
Pop-1325 × Pop-2011	0.0	-1.0	11.6	20.0	-1.7	2.8
Pop-1325 × SHN 107	0.6	0.1	3.4	3.4	-0.1	-0.1
Pop-1325 × Super-08	-0.6	1.9	5.2	-2.7	0.0	1.0
SW × Jalal	0.4	-1.1	-6.0	8.5	1.6	-0.2
SW × Pop-2009	-1.2	0.5	2.4	1.6	-1.4	-3.0
SW × Pahari	-0.4	3.7	-4.1	-2.3	-0.1	0.1
SW × Azam	-1.1	0.9	2.6	0.3	0.2	1.6
SW × Pop-2011	0.0	-0.9	-7.7	-1.2	-0.5	-0.7
SW × SHN 107	0.1	-1.9	-2.9	-5.9	-1.2	-0.6
SW × Super-08	1.4	-1.5	-1.3	6.9	-1.8	0.3
Jalal × Pop-2009	-0.1	2.8	-3.9	-9.3	-0.6	-0.7
Jalal × Pahari	1.2	0.5	3.9	11.5	0.4	1.5
Jalal × Azam	-0.1	-2.1	-20.2	-8.9	-0.4	1.0
Jalal × Pop-2011	-0.3	-1.0	4.5	-4.6	0.3	-1.6
Jalal × SHN 107	-1.4	-0.4	7.3	7.5	-1.7	-1.6
Jalal × Super-08	0.1	-1.0	4.2	13.7	0.7	-0.7
Pop-2009 × Pahari	-0.2	0.5	-4.2	5.6	-2.5	0.8
Pop-2009 × Azam	0.1	-1.4	3.4	-0.9	2.3	0.0
Pop-2009 × Pop-2011	-0.7	0.2	-2.8	-8.7	-0.7	1.0
Pop-2009 × SHN 107	1.0	1.4	2.6	5.3	-0.3	-0.7
Pop-2009 × Super-08	-0.3	0.3	18.1	5.4	-0.6	1.1
Pahari × Azam	0.9	-0.3	-3.3	3.5	-3.7	0.3
Pahari × Pop-2011	-0.5	-0.9	-10.0	-1.5	0.4	-0.1
Pahari × SHN 107	-0.1	-0.7	3.5	-2.6	0.6	2.0
Pahari × Super-08	-1.7	-0.8	-3.8	-4.7	-0.2	0.4
Azam × Pop-2011	0.7	-0.3	9.5	-6.1	-0.2	-0.9
Azam × SHN 107	-0.9	1.3	4.4	2.7	0.6	0.2
Azam × Super-08	-0.2	-0.2	-0.1	12.3	0.5	1.3
Pop-2011 × SHN 107	0.5	0.2	4.3	-2.9	2.8	-2.0

Pop-2011 × Super-08	-0.4	0.2	0.3	15.8	0.9	0.3
SHN 107 × Super-08	0.3	-1.4	-9.2	-2.7	-2.1	-0.1
$CD_{(0.05)}$	0.44	0.32	6.40	4.28	0.51	0.58

CCRI= Cereal Crops Research Institute, UAP= University of Agriculture Peshawar, CD= Critical Difference.

Table 6: *Specific combining ability effects for kernel rows ear^{-1}, 100-grains weight and grain yield in 45 maize hybrids from a population diallel.*

genotypes	Kernel rows ear^{-1}		100-Grains weight		Grain yield	
	CCRI	UAP	CCRI	UAP	CCRI	UAP
Pop-8003 × Pop-1325	-0.4	-1.0	-4.4	-2.4	159.7	-1231.8
Pop-8003 × SW	1.4	0.7	6.2	3.0	73.9	1716.0
Pop-8003 × Jalal	-0.6	-0.5	8.6	2.3	120.5	683.8
Pop-8003 × Pop-2009	1.4	1.1	5.7	-0.4	165.4	98.1
Pop-8003 × Pahari	-1.3	2.2	-1.6	-1.8	-1215.1	520.2
Pop-8003 × Azam	1.6	-1.7	4.2	0.6	-365.0	223.6
Pop-8003 × Pop-2011	-0.6	-1.4	2.8	3.0	1256.1	1387.1
Pop-8003 × SHN 107	3.0	0.5	-2.9	5.3	268.0	764.8
Pop-8003 × Super-08	2.0	-0.1	2.4	3.7	1023.6	1256.5
Pop-1325 × SW	0.9	0.9	-1.1	0.4	-1650.7	829.9
Pop-1325 × Jalal	-2.0	1.2	-1.6	4.4	515.5	294.5
Pop-1325 × Pop-2009	1.2	1.3	-3.0	2.4	-351.7	422.4
Pop-1325 × Pahari	-0.7	-0.2	-2.5	4.1	-522.1	1530.3
Pop-1325 × Azam	-0.5	1.8	1.7	4.3	253.7	1540.6
Pop-1325 × Pop-2011	-0.8	-1.2	6.5	3.7	900.4	1111.0
Pop-1325 × SHN 107	0.9	-0.6	4.7	-1.2	1091.7	-59.1
Pop-1325 × Super-08	-0.8	-1.1	2.9	2.5	549.8	-957.8
SW × Jalal	0.8	0.9	1.7	0.7	277.8	11.5
SW × Pop-2009	-2.0	-1.5	2.3	-1.2	1325.6	-324.1
SW × Pahari	0.7	-0.8	10.0	2.6	911.4	-367.3
SW × Azam	-0.7	0.3	-8.5	3.7	1270.6	560.8
SW × Pop-2011	-0.3	2.7	-3.0	-5.5	414.1	858.8
SW × SHN 107	0.0	-1.4	4.2	-1.0	565.4	-353.7
SW × Super-08	-1.0	-1.0	-3.5	-0.8	-783.7	-590.4
Jalal × Pop-2009	-0.6	1.1	4.4	-6.0	-1.3	-231.6
Jalal × Pahari	-0.2	0.4	-1.7	-0.5	-77.5	-901.4
Jalal × Azam	1.6	1.5	2.9	0.7	-996.8	982.9
Jalal × Pop-2011	1.4	0.5	-2.0	-3.9	1105.9	-856.8
Jalal × SHN 107	-1.6	-0.6	0.5	1.5	-1137.7	507.1
Jalal × Super-08	-0.3	-1.5	-6.8	1.9	-1545.5	1280.7
Pop-2009 × Pahari	0.0	-2.1	0.9	0.9	283.5	384.6
Pop-2009 × Azam	-0.8	0.2	2.0	-1.6	1313.8	-347.6
Pop-2009 × Pop-2011	-1.7	0.0	-2.3	2.4	-221.0	-16.7
Pop-2009 × SHN 107	0.3	0.7	-9.2	0.4	505.3	70.4
Pop-2009 × Super-08	1.3	0.9	3.7	1.9	-644.1	1020.7
Pahari × Azam	0.9	-0.9	-6.1	1.5	-310.9	-492.9
Pahari × Pop-2011	-0.3	0.3	0.4	-1.9	626.8	-1526.1
Pahari × SHN 107	1.0	-1.9	-2.8	0.5	634.4	775.8

Pahari × Super-08	0.4	1.6	5.5	2.0	602.3	735.5
Azam × Pop-2011	-0.1	-0.6	0.7	-2.5	-1605.7	-1617.7
Azam × SHN 107	-1.8	1.7	3.2	0.4	-431.6	255.4
Azam × Super-08	0.2	-0.3	-3.3	1.8	48.6	860.2
Pop-2011 × SHN 107	0.0	-0.7	2.6	-2.6	-391.8	-524.5
Pop-2011 × Super-08	2.3	0.7	-5.2	-4.2	709.6	711.9
SHN 107 × Super-08	-2.4	0.3	-0.7	1.8	-168.4	-43.3
$CD_{(0.05)}$	0.49	0.38	0.51	0.63	244.7	168.6

CCRI= Cereal Crops Research Institute, UAP= University of Agriculture Peshawar, CD= Critical Difference.

investigation by using these population hybrids as sources for new inbred line development in a line × tester experiment (data not shown here). Population hybrids with good GCA and grain yield like Pop-8003 × Pop-2011, Pop-8003 × Super-08, Pop-1325 × Pop-2011, Pop-8003 × SW, Pop-1325 × Azam and Pop-2011 × Super-08 could be recommended for general cultivation after confirming their superiority as cheap alternative to the expensive inbred hybrids and/or comparatively low performing OPVs. Hence, promising populations and their hybrids, when carefully selected, offer a practical alternative to commercial inbred hybrids by providing uniformity, ease of seed production and cost savings that can be reinvested in other crop management practices.

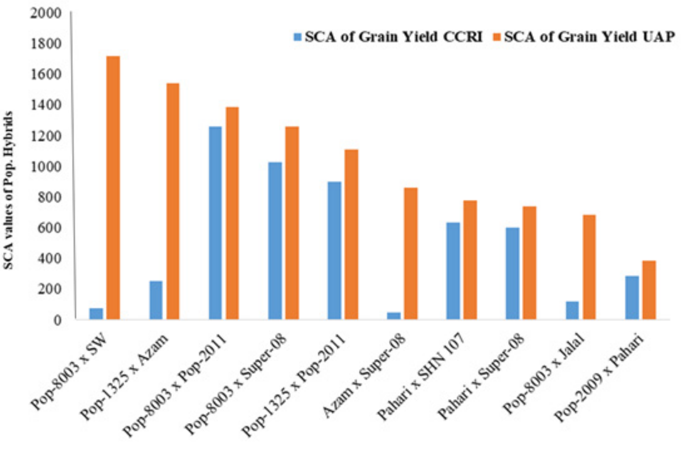

Figure 1: *Grain yield performance reflected by their specific combining abilities (SCA) values of selected population hybrids obtained by crossing parents with good, medium and poor/bad general combining abilities (GCA) effects.*

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Novelty Statement

The development and use of innate inbred hybrids have been extensively exploited in maize for achieving high yields. These hybrids requires comprehensive research and resources utilization which also make them expensive for the farmers. However, Compared to these commercial inbred hybrids, little attention have been paid to the idea of population hybrids. Assessing and identifying the commercial potential of improved maize populations can provide elite sources of new inbred lines and cheap population hybrids. A specific combination from the improved populations once identified could be released as an improved OPV or population hybrid for cultivation. An attempt was made in the current study to compare the grain yield and agronomic performance of 45 maize population hybrids and their 10% and sort out the best hybrids as alternatives to commercial single-cross hybrids.

Author's Contribution

Monsif Ur Rehman: Designed and conducted the study and drafted the manuscript.
Mushtaq Ahmad Khan, Muhammad Ali, Samrin Gul and Aamir Iqbal: Helped in data analyses and help in drafting the manuscript.

Generative AI or AI assisted technology statement
The authors declare that there is no AI generated/assisted materials used in this manuscript.

Conflict of interest
The authors declare that there is no conflict of interest in publishing this manuscript.

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