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Research Note

Combining ability effects and nature of gene action for grain yield and quality parameters in Pop corn (*Zea mays var. everta*)

Goutam Rana[1], *Preeti Sharma[2], Mehar Chand Kamboj[2] and Narender Singh[2]

[1]Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar- 125004,
[2] CCS Haryana Agricultural University, Regional Research Station, Karnal -132001, Haryana, India
***E-Mail:** sharmapreeti.genetics@gmail.com

Abstract
The proficiency and efficacy of the parental selection programmes in most of the crops including popcorn can be significantly improved by estimating the combining ability and its effects. The present study was planned with an aim to assess the combining ability variances and effects in 28 cross combinations developed by crossing eight inbred lines of popcorn in half diallel fashion design (without reciprocals). The thirty eight genotypes including twenty eight hybrids along with their eight parents and two checks were evaluated in randomized complete block design to estimate the GCA and SCA of parents as well as crosses. Results for combining ability shown that mean sum of squares due to hybrids and parents vs. hybrids were significant, which in turn exhibits significant genotypic differences for all the characters under study except grain protein content. It was also apparent that both general combining ability and specific combining ability variances were significant for all the characters except grain protein content which indicated importance of both additive and non additive gene action in the inheritance of these traits. The inbred lines *viz*., HKI PC 1473-5, HKI PCBT 3, HKI PC 4B were found as good combiners and desirable for both grain yield and quality traits with high popping expansion. The cross combination HKI PC 1473-5 x HKI PCBT 3, HKI PC 4 x HKI PC 7 and HKI PC 4B x HKI PCBT 3 showed good SCA effects for grain yield, yield related traits and quality traits and thus indicated non additive gene effects is more pronounced and selection may prove reliable in maize hybridization programme for improvement of yield and other characters.

Keywords
Combining ability, gene effects, yield component traits, line x tester.

Maize crop has high yielding potential and being known as 'Miracle crop' or 'Queen of the Cereals' as it surpasses all the other cereal crops in terms of area and production. As per fourth advance estimate in India area under maize was 9.50 million ha with the total production of 26.30 million tonnes with the productivity 2630 kg/ha (Anonymous, 2017). India is additionally on the inception of maize revolution and Haryana has an adequate scope to extend its acreage and productivity (Sharma *et al*., 2017). The maize (commonly known as corn) is unique because of the most diverse grain crop found in the nature that include flint, dent, floury, sugery, waxy, popcorn and baby corn. Among the various types of corn the most wide-spread type is the "popcorn", is a type of corn (*Zea* maize *var. everta*) that has speciality of puffing up when heated and it has high profitability and great popular recognition (Sweley *et al*., 2011). Its utilization has incredibly broadened in later a long time because it is fibre rich, nutritious snack, and flavoured ready to eat products.

In expansion to this popping moreover decreases some of the hostile anti nutrients *viz*., phytates, tannins, acid detergent fiber, lignin and cellulose (Reddy *et al.,* 1991). The demand of pop corn is increasing day by day as it is being consumed as a snack food. As of presently in India, popcorn is commercially produced on a sensibly small scale. The genetic improvement work in popcorn is expelled in India and there is an extraordinary scope for its change in close future. In India, all the commercially developed grouping of popcorn is composite varieties *viz*., Amber popcorn, Jawahar popcorn and VL popcorn with low yield and reduced amount of popping quality. Looking at this fact, there is a need to develop single cross hybrids of popcorn for higher grain yield with better popping quality. In any case, these two characteristics appeared negative correlation for their inheritance (Viana and Matta, 2003; Pajic *et al*., 2008; Rangel *et al*., 2008).

Grain yield may be an exceptionally imperative characteristic in popcorn, as in other corn types also and advanced plant breeding focuses to increase yield and quality together. The focus of any plant breeder for popcorn advancement is to create crossover with both increased grain yield and popping expansion and for this, development of superior inbred lines and hybrids is one of the major methodologies in popcorn breeding programmes for advancement of high yielding and greater popping expansion. Comes out from classical quantitative genetics and statistical analysis have appeared that both popping volume and grain yield are controlled by hereditary factors and it is troublesome to get predominant genotypes for both the characterstics (Li *et al*., 2007). But it is conceivable to create genotypes with great popping volume and acceptable yield (Pajic *et al.,* 2008). Both additive and dominant genetic effects plays very imperative and outstanding roles in the inheritance of popping characteristics (Dofing *et al*., 1991) and these impacts or effects are abused in population improvement programmes and advancement of inbred lines. Studies have appeared that the genotypes found incredible in execution might not basically deliver alluring hybrids. It is in this manner, essential to recognize lines on the premise of crosses utilizing suitable mating design. Information on combining ability is prerequisite that plays an imperative role inside the recognizable variation of parents and production of predominant lines for developing good and economically viable hybrids. It is most widely used biometrical genetical approach in plant breeding where the genetical potentiality of crosses, in segregating self-pollinated populations can be successfully predicted from the general combining ability of parents.

Success of development of high yielding and widely adapted hybrid depends on the specific combining ability of parental crosses. Hence, combining ability study is exceptionally imperative for the determination of parents and crosses for advancement in the character under consideration and also provides information on the nature of genetic variation present in the material under study. Among the accessible ordinary methods, diallel cross analysis is an efficient tool providing information on genetic mechanism conditioning various plant traits in one generation. Subsequently, for the development of pop corn hybrids with high yield and good popping quality, it is necessary that we should screen our pop-corn inbred lines for their genetic potential for yield and popping quality and combining ability of parents and their cross combinations using appropriate biometrical techniques along with the economic heterotic effects. Therefore considering the above facts, the present study has been embraced with the subsequent objectives. (1.) To study combining ability of popcorn lines for grain yield and popping quality (2.) To identify specific cross combinations having better yield and popping quality.

The experimental material for present analysis involved of 28 F'_1s (developed by crossing eight inbred lines of popcorn *viz*., HKI PC-1, HKI PC-3, HKI PC-4, HKI PC-7, HKI PC-4B, HKI PC BT-3, HKI PC-8B and HKI PC-1473-5) in half diallel fashion design (without reciprocals) during *rabi* 2014-15. During *kharif* 2015, the final experiment involving eight parents (inbred lines of popcorn), two checks (HM 4 hybrid of normal maize and Bajuara popcorn cultivar of popcorn) and 28 F_1s were grown to collect data on yield, component traits and quality traits. Genotypes used for investigation were made available from the Maize Section, Regional Research Station, Karnal.

The experimental material consisting 38 treatments (28 F_1's + 2 checks + 8 parents) were seeded in Randomized Block Design with three replications in one environment at the experimental area of CCS Haryana Agricultural University, Regional Research Station, Karnal during *Kharif*, 2015. The entries were sown in a two row plot of 4 m with inter and intra-row spacing of 60 cm and 20 cm, respectively. Karnal is located at latitude of 29^0 43ʹ42.19″ N longitude of 76^0 58ʹ49.88″ E and at an altitude of 253 meters above the mean sea level.

The meteorological data for the crop growth period was recorded in the meteorological observatory of Central Soil Salinity Research Institute, Karnal. The recorded data showed that 430.3 mm rain was received during the crop season, and the maximum and minimum temperature during the crop season wide-ranging from 41.6^{0}C to 29.8^{0}C and 16.5^{0}C to 27.9^{0}C, respectively. The soil of the experimental field was clay loam. Border rows were maintained at end of each replication to minimize border effect. Recommended cultural practices were adopted to maintain a healthy crop.

From every row 5 competitive plants were subjectively selected from each replication and interpretations on following fifteen quantitative characters *viz.,* Days to 50% tasselling, Days to 50% silking, Days to maturity, Plant height (cm), First cob placement (cm), Final plant stand per plot (numbers), Number of cobs per plot, Cob weight per plot (kg / plot), Shelling (%),Grain yield per plot (kg / plot), 100 grain weight (gm), Moisture per cent (%), Popping volume (cm^3/g), Popping Per cent (%) and grain protein content were recorded on plants leaving border plants in each replication. The data on days to 50% flowering and maturity were taken on the plot basis and quality traits were determined at quality laboratory by adopting following methods.

Grain yield per plot (kg / plot): All the cobs of each plot were threshed and sun drying to 15% moisture, the grain weight was calculated**; 100 grain weight (gm):** One hundred sun dried seeds from each plot five randomly selected cobs of each genotype were collected replication wise and weighed in gram with the help of meter

Moisture per cent (%): was measured in each genotype replication wise with the help of grain moisture meter at the time of harvest.

Twenty five **g** of grain were collected from each genotype replication wise. These were popped by traditional method on an iron tawa over an open flame. After popping these popped corn were putted onto flask and its volume was recorded in cm^3. The popping volume was recorded by following formula.

$$\text{Popping volume (cm}^3) = \frac{\text{Volume of 25 g popped corn}}{25}$$

And it was recorded in cm^3/g.

After recording the data on popping volume the data was recorded on total grains and no. of popped grains in 25g sample and the popping percent (%) was recorded by following formula

$$\text{Popping volume (cm}^3) = \frac{\text{No. of popped grains}}{\text{Total of popped grains}} \times 100$$

After recording the data on cob weight per plot, five randomly selected cobs were taken; total weight of these five cobs was recorded. These five cobs were threshed and grain weight was recorded by the following formula.

$$\text{Shelling (\%)} = \frac{\text{Grain weight of five cobs}}{\text{Total weight of five cobs}} \times 100;$$

The protein content was measured by NIR's analyzer (Infratec™ 1241 grain analyzer) developed by Foss solution. In this machine estimation is done by near infrared analysis, a non destructive spectroscopic technique that make use of naturally occurring electromagnetic spectrum. The NIR region in the area of the spectrum defined by wave length as between 700 mm and 2500 mm .The infratec™ has a wave length 570-1100 mm.

The Analysis of Variance was carried out utilizing mean values of observations on five randomly selected plants for each character. At first the test of significance between the genotypes involving crosses and parents was estimated. Means of five plants over three replications of 36 progenies were arranged in a diallel table. The general combining ability (gca) and specific combining ability (sca) analysis was carried out according to method 2 (Parents and one set of F_1s without reciprocals) Model-I (fixed effects) of Griffing (1956). In this model, experimental material was observed as population about which conclusion was to be drawn and combining ability effects of parents may well be compared when parents themselves are utilized as tester to recognize good combiner. Assessment of the combining ability, sum of squares, effects and their testing was done by the method given by Griffing (1956) by utilizing SPSS software program. For testing significance of dissimilarity between two effects, the critical difference was divided by respective standard error of difference and compared with table value of 't' at error degree of freedom.

The ANOVA for pooled combining ability (**Table 1**) exposed that mean sum of square were significant for nearly all the characters ($P \leq 0.01$) except grain protein content which in turn exhibited significant genotypic differences for the characters under study. Similar results were observed Kumar *et al*. (2016), Krupakar *et al*. (2013), Amiruzzaman *et al.* (2013), Izhar and Chakraborty (2013) and Dar *et al.* (2015). For effective hybridization program parents need to be chosen not because on the basis of their genetic diversity but too on the basis of their combing ability. The parents which combine well with one another are most desirable ones. From this analysis, it was evident that both general combining ability and specific combining ability variances were significant for all the characters except grain protein content which indicated importance of both additive and non additive gene action in the inheritance of these traits. Similar findings were reported by Dar *et. al*. 2018, Miotto *et al*. (2016), Rajitha *et al*. (2014) and Vijaya bharathi *et al*. (2009) also reported similar findings.

Estimates of GCA effects with respect to eleven characters were worked out for different traits and best combining inbreds along with the poorest combiners for various traits are presented in **Table 1.** The perusal of data revealed that among the eight inbred lines, HKI PCBT 3, HKI PC 1473-5 and HKI PC 4B was the best combiner for grain yield per plot because of higher estimates of GCA effects. Among them HKI PCBT 3 also showed the highest positive GCA effects for popping % and popping volume. Estimates of GCA effects for flowering traits indicates that among parents, inbred HKI PC 4 were having highly significant negative GCA effects for days to 50% silking, days to maturity and HKI PC 3 was the best combiner for days to 50% tasellings having the probable advantage of inbred lines for the development of early maturing hybrids. These findings are in conformity with earlier results of Singh *et al.* (2012), Amiruzzaman *et al.* (2013), Khan *et al.* (2014) and Alamerew and Warsi (2015).

Popcorn plants are more slanted to dislodging than is common maize. Ear height is crucial since this characteristic in addition significantly related to plant dislodging (Ji *et al*., 2006). Inbred lines HKI PCBT 3, HKI PC 4B, and HKI PC 4 have the highest positive significant gca effects for first cob placement which indirectly relates to higher plant height. This trait may sometimes be useful also because it is both positively and negatively correlated with grain yield. In contrast, results for ear height were reported by Aminu *et al*., 2014 and Alamerew and Warsi (2015) entailing the tendency of the lines to reduce ear height.

However, none of the parental inbred lines appeared substantial GCA effects within the desired direction at the same time for all the traits studied. But HKI PC 1473-5 was the best combiner for grain yield, maturity traits and quality traits simultaneously *viz*. days to 50% taselling, days to 50% silking, the no. of cobs per plot, cob weight per plot, grain yield per plot, 100 grain weight, popping (%), popping volume. Inbred HKI PCBT 3 was the second best combiner, which combined best for first cob placement, the number of cobs, cob weight per plot, grain yield per plot, 100 grain weight, popping % and popping volume followed by HKI PC 4B which was the best combiner for days to 50% silking, first cob placement, cob weight per plot, Grain yield per plot, 100 grain weight and popping volume. Though, considering the economic importance of various characters HKI PC 1473-5, HKI PCBT 3, HKI PC 4B among the all inbred lines were found most suitable for producing hybrids with high popping expansion. These lines may be used for further crossing for the development of new inbred lines with high grain yield and better popping quality and utilizing these lines for the development of single cross hybrids superior in grain yield and popping quality.

Table 1. Analysis of variance of parental inbred lines, hybrids and combining ability for different traits of popcorn crosses

Source of Variation	DF	Days to 50% tasselling	Days to 50% silking	Days to maturity	First Cob placement (cm)	No. of cobs per plot	Cob weight per plot (kg/plot)	100 grain weight (g)	Grain yield per plot (kg/plot)	Shelling (%)	Popping (%)	Popping volume (cm³/g)	Grain protein content
Due to GCA	7	11.95**	15.54**	55.58**	722.03**	161.18**	3.01**	101.55*	9.57**	39.29**	34.53**	42.76**	1.90
Due to SCA	27	7.38**	9.48**	10.78**	311.23**	69.14**	2.91**	8.94*	2.60**	9.34**	17.85**	5.94**	1.38
Error	70	0.16	0.21	0.24	4.81	3.18	0.02	0.05	0.01	1.63	2.49	0.60	0.91
GCA/SCA		1.62	1.64	5.16	2.32	2.33	1..03	11.36	3.68	4.21	1.94	7.20	1.38

GCA = general combining ability; SCA = specific combining ability; d.f. = degrees of freedom;
"**" and "*" Significant at 1% and 5% level of significance respectively.

Table 2. Estimates of GCA effects of different inbred lines for different traits in popcorn

Sr. No.	Inbreds	Days to 50% taselling	Days to 50% silking	Days to maturity	First Cob placement (cm)	No. of cobs per plot	Cob weight per plot(kg/ plot)	100 grain weight (g)	Grain yield per plot(kg/ plot)	Shelling (%)	Popping (%)	Popping volume (cm³)	Grain protein content
1	HKI PC 1	1.37* *	1.48* *	-0.32	-8.88* *	-2.48* *	-0.72**	-4.27* *	-0.62* *	-2.58**	0.00	-2.16* *	-0.36*
2	HKI PC 3	-1.00* *	-0.13	-1.05* *	-1.61* *	1.58* *	0.03	1.02* *	0.04	1.00**	0.20	0.95* *	0.04
3	HKI PC 4	-0.77**	-1.03* *	-2.75* *	0.33*	0.95* *	-0.07* *	-0.18* *	-0.04	0.46*	-1.10* *	0.14	0.13
4	HKI PC 7	1.00* *	0.24* *	0.88 **	-1.94* *	2.78* *	-0.05*	-0.32* *	-0.03	0.31	-0.30	0.08	-0.06
5	HKI PC 4B	-0.13	-0.29* *	0.82 **	6.19* *	-2.55* *	0.22* *	0.93* *	0.18* *	0.21	-1.66* *	0.58* *	0.16
6	HKI PC 8B	0.17*	0.01	1.05 **	0.26*	-3.12* *	0.08* *	1.54* *	0.04	0.69**	0.37	-0.56* *	0.20
7	HKI PC 1473-5	-0.50* *	-0.46**	0.08	-0.98*	1.25* *	0.24* *	0.34* *	0.20* *	0.60*	0.67*	0.60* *	0.28
8	HKI PCBT 3	-0.13	0.18*	1.28 **	6.63* *	1.58* *	0.24* *	0.95* *	0.23* *	0.66**	1.83* *	1.83* *	-0.39*
	SE(d)	0.07	0.08	0.08	0.37	0.30	0.02	0.04	0.02	0.22	0.27	0.13	0.16

SCA effect is an imperative criterion to determine the prospective and efficacy of hybrids. The estimates of specific combining ability effects of the twenty-eight crosses for various traits, given in **Table 3**, exposed that none of the cross combination possessed high SCA effects for all the traits. Perusal of data publicized that the cross combination HKI PC 1473-5 x HKI PCBT 3 showed the maximum and best SCA effects for grain yield and the same cross also presented the highest SCA effects for quality parameters (for popping volume and popping %), signifying scope for improving both popping quality as well as grain yield simultaneously.

The cross HKI PC 4B x HKI PCBT 3 showed the significant SCA effects among all the crosses for the traits grain yield, 100 grain weight, the no. of cobs per plant, days to 50% tasselling, days to 50% silking, days to maturity and quality parameters (for popping volume and popping %). The second best combiner among all the hybrids was HKI PC 4 x HKI PC 7 showing the significant SCA effects for the traits *viz.,* grain yield, 100 grain weight, first cob placement, days to 50% tasselling, days to 50% silking, days to maturity and quality parameters (popping volume and popping %) and it was resultant of poor x poor combiners. This too proposed that the per se performance of the hybrids was not necessarily associated with the GCA effects of the parents. These disclosures are in assertion to the findings of Rajitha *et al*. (2014) Viana *et al*. (2011) and Munhoz *et al*. (2009).

The cross HKI PC 1 x HKI PC 3 was good specific combiner for days to 50% tasselling, days to maturity and days to 50% silking, indicating them to have vigour for earliness. The cross combination HKI PC 3 x HKI PC 1473-5 were having the highest SCA effects for days to 50% silking. The cross HKI PC 4 x HKI PC 4B exhibited good SCA effects for the number of cobs per plant and it was good x good combiner combination. High positive SCA effects for cob weight per plot, grain yield per plot, popping percentage and popping volume were depicted by hybrid HKI PC 3 x HKI PC 7 and the second highest positive SCA effects for cob weight per plot, grain yield per plot were depicted by hybrid HKI PC 4 x HKI PC 7.

Table 3. Estimates of SCA effects for different traits in popcorn crosses

Sr. No.	Cross	Days to 50% tasselling	Days to 50% silking	Days to maturity	First cob place ment (cm)	No. of cobs per plot	Cob weight per plot (kg/plot)	100 grain weight (g)	Grain yield per plot (kg/ plot)	Shelling (%)	Popping (%)	Popping volume (cm³/g)	Grain protein content
1	HKI PC 1 x HKI PC 3	-2.42**	-2.30* *	-4.17**	-0.45	1.70*	-0.12	-0.32**	-0.09	0.78	-5.27**	1.12* *	-0.16
2	HKI PC 1 x HKI PC 4	0.59* *	0.93* *	0.86* *	10.95* *	3.33* *	-0.35* *	-2.46* *	-0.34* *	-4.98**	-3.31* *	-0.96* *	-0.11
3	HKI PC 1 x HKI PC 7	-0.98* *	-1.00* *	-0.77* *	3.22* *	-2.50* *	0.05	-1.17* *	0.03	-0.19	3.84* *	1.36* *	0.47
4	HKI PC 1 x HKI PC 4B	2.95* *	3.20* *	0.30	-5.25* *	0.50	-0.27* *	2.38* *	-0.28* *	-0.16	-3.74* *	-1.23* *	0.35
5	HKI PC 1 x HKI PC 8B	-0.02	-1.44* *	1.40* *	5.02* *	-5.94* *	-0.03	-0.06	-0.06	-2.66**	1.89*	-3.36* *	0.78
6	HKI PC 1 x HKI PC 1473-5	0.65* *	0.70* *	1.36* *	1.58*	2.36* *	-0.23* *	-2.96* *	-0.17**	1.09*	1.93*	0.77*	0.37
7	HKI PC 1 x HKI PCBT 3	2.29* *	3.06* *	2.83* *	-25.35*	-2.97* *	-0.19*	-0.06	-0.11*	3.16**	0.09	-0.42	-2.58
8	HKI PC 3 x HKI PC 4	1.39* *	0.53*	2.93* *	10.35* *	-1.74*	0.24* *	-0.28**	0.20* *	0.20	1.16	0.29	0.46
9	HKI PC 3 x HKI PC 7	0.19	0.26	-0.37	4.95* *	1.76*	0.27* *	1.66* *	0.18* *	-1.92**	2.64* *	1.91* *	-0.26
10	HKI PC 3 x HKI PC 4B	1.42* *	2.13* *	2.03* *	2.48*	3.76* *	0.15*	0.49* *	0.15* *	0.78	0.06	-0.95* *	-0.21
11	HKI PC 3 x HKI PC 8B	0.12	0.50*	3.80* *	-14.25**	-6.34* *	0.20* *	0.59* *	0.14* *	-1.05*	-0.64	-0.99* *	-0.46
12	HKI PC 3 x HKI PC 1473-5	2.22* *	-3.04**	0.10	3.65* *	-3.00**	0.02	-1.13* *	0.02	0.20	1.73*	0.99* *	-0.30
13	HKI PC 3 x HKI PCBT 3	1.42* *	1.33* *	-0.77* *	2.05*	1.30	-0.95* *	-0.66* *	-0.74* *	0.63	1.89*	0.46	-0.47
14	HKI PC 4 x HKI PC 7	-1.48* *	-1.17* *	-1.34* *	7.68* *	1.40	0.77* *	1.63* *	0.67* *	2.22**	1.99* *	0.27	-0.72
15	HKI PC 4 x HKI PC 4B	0.25	-0.64*	-1.27* *	-1.79	6.06* *	-0.01	1.90* *	0.02	1.76**	-2.31* *	-0.39	0.27
16	HKI PC 4 x HKI PC 8B	0.12	0.73* *	-0.17	1.15	-5.37* *	0.47* *	0.14	0.34* *	-1.31*	-0.34	0.60	-0.41
17	HKI PC 4 x HKI PC 1473-5	-0.88* *	-0.47*	-1.54* *	-6.29* *	1.93*	-0.18*	-0.88* *	-0.12	1.44*	-1.31	-0.15	-0.09
18	HKI PC 4 x HKI PCBT 3	0.92* *	-0.77* *	-2.07* *	-2.89* *	-1.40	-0.50* *	-0.93* *	-0.41* *	0.27	1.19	0.55	0.14
19	HKI PC 7 x HKI PC 4B	1.22* *	1.43* *	-0.57*	-11.19**	2.90* *	-1.21* *	-3.46* *	-0.99* *	0.37	-3.44* *	-1.21* *	0.32
20	HKI PC 7 x HKI PC 8B	-1.42* *	-1.20* *	0.53*	13.75* *	-7.54* *	0.69* *	0.99* *	0.51* *	-1.66*	0.53	-1.05* *	0.04
21	HKI PC 7 x HKI PC 1473-5	2.25* *	1.93* *	-2.50* *	-9.69* *	2.10*	-0.81* *	-0.87* *	-0.65* *	0.53	-0.44	-0.27	-0.30
22	HKI PC 7 x HKI PCBT 3	2.22* *	1.96* *	1.63* *	-3.29* *	-3.24**	0.07	1.60* *	0.08	0.56	-0.36	-1.33* *	0.19
23	HKI PC 4B x HKI PC 8B	-1.85* *	-3.00* *	-0.40	12.95* *	-4.54*	0.41* *	0.19	0.34* *	0.38	-0.77	-0.37	-0.54
24	HKI PC 4B x HKI PC 1473-5	-0.52* *	-1.20* *	0.56*	22.18* *	-4.90* *	0.02	2.13* *	-0.04	-2.14**	2.59* *	1.20* *	-0.45
25	HKI PC 4B x HKI PCBT 3	-1.22* *	-1.17* *	-0.97**	1.25	3.10* *	0.62* *	0.34* *	0.54* *	0.59	3.09* *	2.48* *	-0.12
26	HKI PC 8B x HKI PC 1473-5	2.19* *	2.50* *	-2.00* *	-2.89* *	-6.00* *	-1.02* *	0.65* *	-0.82* *	0.52	-0.11	0.26	0.24
27	HKI PC 8B x HKI PCBT 3	-0.85* *	0.80* *	-0.54*	1.85	5.00* *	-0.25* *	-0.98* *	-0.19* *	0.43	-1.61*	-0.43	0.07
28	HKI PC 1473-5 x HKI PCBT 3	0.15	0.33	2.10* *	0.75	-10.37**	1.00* *	1.53* *	0.78* *	-1.59*	4.01* *	2.98* *	0.13
	SE(d)	0.18	0.21	0.22	1.00	0.81	0.07	0.10	0.05	0.58	0.72	0.35	0.43

"**" and "*" indicate significant at 1% and 5% level of significance, respectively.

Regarding quality parameters the best hybrid was HKI PC 1473-5 x HKI PCBT 3 (for popping volume and popping %) and it was resultant of good x good combiner combination suggesting that might have possibly resulted from the absorption and interaction of encouraging alleles contributed by both the parents. Hence, it signifies that the heterosis breeding is ideal for genetic improvement of most of the yield and quality characteristics due to preponderance of non additive gene action in inheritance of these traits. These results are in conformity with earlier findings of Chinthiya *et. al*., (2019), Jat *et al*., (2018) and Purushottam and Kumar (2017). For grain protein content hybrid, HKI PC 1 x HKI PC 8B exhibited the highest SCA effects and followed by hybrid HKI PC 1 x HKI PC 7. The cross combination HKI PC 1 x HKI PC 4B showed the highest SCA for 100 grain weight. All these were combination of good x poor combiner parents indicating that additive type of gene action to be more important which is fixable and the results are in general agreement and in the light of their usefulness in the future breeding programmes with the findings of several workers, Amiruzzaman *et al.* (2013) and Netravati *et al*. (2014).

These finding showed that parents HKI PC 1473-5, HKI PCBT 3 and HKI PC 4B have been recognized as the good combiners for grain yield and yield related traits. Cross combinations HKI PC 1473-5 x HKI PCBT 3, HKI PC 4 x HKI PC 7 and HKI PC 4B x HKI PCBT 3 showed good SCA effects for grain yield, yield related traits and quality traits. Hence, there is need to test these crosses their further testing in varying environments. High performance of cross combination indicated that non-additive or epistatic gene action was more pronounced and these crosses can be used directly or exploited for future hybrid breeding programmes. Selection may prove reliable in maize hybridization programme for the improvement of yield and other characters and this could be resulted in achieving quantum jump in maize improvement.

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