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# Elucidation of combining ability for earliness and popping expansion volume in popcorn (*Zea mays* var. *everta*) across different environments

**Munnesh Kumar, JP Shahi, Ashok Singhamsetti, Anima Mahato, Kumari Shikha and Kartik Madankar**

**Abstract**
Maize (*Zea mays* L., 2n =20), an economic crop, is a widely cross-pollinated annual, monoecious Poaceae family member native to Mexico and Central Africa. All twenty characters studied showed dominance gene action, except for traits like ear diameter and moisture content. The number of gene groups varied from one to six. Gene groups were involved and showed partial or over-dominance. Based on GCA and SCA studies, two good general combiners are identified as HKIPC-7 and WINPOP-29. Specific combiners for yield and popping characteristics are the WINPOP-47×HKIPC-7 cross for yield per plant, the WINPOP-8×HKIPC-7 and WINPOP-3×HKIPC-7 crosses for earliness and also the WINPOP-47×HKIPC-5 cross for popping expansion. G×E interaction is clearly indicated as narrow sense heritability is less than unity. In either the pedigree method or the bulk method, it is best to choose parents with dominant alleles for traits that affect yield.

**Keywords:** Popcorn, combining ability, popping volume, genetic parameters

## Introduction
Maize (*Zea mays* L., 2n =20) is the most diversified and versatile crop among cereal crops. It is an annual, monoecious, cross-pollinated plant with a native range of Mexico and Central Africa. It was domesticated from a wild maize ancestor (*Teosinte*) and is referred to as the "queen of cereals" due to its vast genetic base and high yield potential. In India, a highly populous country in which rice and wheat are staple food crops, followed by maize, which is the 3rd in area and 7th in production among corn-cultivated countries, accounting for approximately 4% of the global area and 2% of production (DACNET-2020) [1]. India's maize cultivation surpassed 9.2 million hectares in 2018-19 [1]. In 1950-51, it yielded 1.73 million metric tonnes (MT), which has climbed to 27.8 million metric tonnes (MT) in 2018-19, an increase of almost 16-fold (Sandhu, *et al.*, 2007) [2].

Popcorn is an extremely unique form of flint corn with a very hard endosperm and a low portion of soft starch and is characterised by its popping ability on heating the kernel, which is a unique quality of the endosperm (Acquaah, 2006) [3]. Popcorn swells and puffs up when heated and is a popular recreational snack with a high nutritional content (Rakshit, *et al.*, 2003) [4]. It is a globally popular snack because it is an excellent source of carbohydrates, energy and fibre. It's a healthy, tasty food that helps digestion by giving the body the fibre it needs (Rodovalho, *et al.*,) [5]. Indian popcorn cultivars have a lower popping ratio as compared to European and American cultivars. The high demand for popcorn has spurred research to discover traits that dictate its idiosyncratic popping ability and many attempts have been made to develop a popcorn industry, but it has been a hurdle because of the absence of stable and optimal hybrids with high popping volume and efficiency (Larish, and Brewbaker, 1999) [6] and also a lack of superior popcorn germplasm for popping characteristics, including popping volume, flake size, popping percent and high-yield (Robbins, and Ashman, 1984 and Dofing, 1999) [7, 8] due to narrow genetic background because most of the popcorn lines are descended from flint germplasm (Kantety, *et al*., 1995) [9]. However, it has relatively poor agronomic, yield and popping quality and also more susceptible and prone to disease and pests. These research, focused on designing new single-cross popcorn hybrids that are stable, uniform, early-maturing, with higher yields and better popping quality than composite cultivars. They need to be bred for a long time. The development of single-cross popcorn hybrids requires a proper road map to understand the genetic architecture of popcorn based on

the underlying diallel mating design in the breeding programme. The main object of this manuscript" Elucidation of combining ability, genetic effects for controlling certain traits and deciphering genetic component variance for yield and popping quality traits across different environment".

## Materials and Methods

The experimental genetic material was comprised of all the available popcorn inbred lines. The selected promising nine inbred line were planted in a crossing block during Rabi 2017 and all possible single cross combination carried out and their successive progenies are maintained by selfing and sib matting techniques. The thirty -six crosses thus formed along with the 9 parents popcorn inbreds and one standard check (Amber popcorn) was planted in completely randomized block design with three replication and each entry was planted in single row plot of 4m length maintaining in each season the inter-row spacing at 60 cm and Plant to plant spacing of 25 cm during *rabi*, 2017-18, *kharif*-2018 and *rabi* 2018-19 seasons.

| Sr. No. | Seasons and Year | Code No. |
|---|---|---|
| 1. | Rabi, 2017-18 | E1 |
| 2. | Kharif,2018 | E2 |
| 3. | Rabi,2018-19 | E3 |

### Phenotypic data collection

Five randomly selected plants from each entry in each replication are recorded based on underlying agro-morphological, yield and quality traits, whereas for kernel architectural and quality traits, data is recorded from one selfed plant from each entry in each replication. These data were recorded for twenty different agro-morphological, yield attributing and popping traits, *viz.*: number of leaves per plant, leaf area, plant height (cm), ear height (cm), primary branches per tassel, days to 50% anthesis, days to 50% silking, days to 75% maturity, number of ears per plant, ear length (cm), ear diameter (cm), number of kernels per ear, number of kernels per row, hundred seed weight (gm), grain yield per plant (g), moisture content, popping expansion volume, flake size, flake volume and popping rate (%). Mean over replications, in each season /environment, were used for the statistical analysis. Analysis of data was done with the help of statistical software Windostat V.8.5. The procedure for analysis of variance for the crosses and parents was followed as suggested (Panse and Sukhatme, 1978) [10]. The detailed procedure of both graphical and component analysis is done in according (Jinks, 1954 and Hayman, 1954a) [11, 12]. Statistical analysis in order to estimate the general and specific combining ability (GCA and SCA) variances and effects, as described (Griffing, 1956a) [13].

## Result and Discussion

All the twenty characters studied showed dominance gene action as $H_1$ is greater than D and leaf area, plant height, ear height, days to 50% silking, ear per plant, ear length, kernels per row, popping expansion volume, flake size, flake volume and popping rate characters contributed majorly by dominance gene action, hence selection lines based on these traits should be carried out in later generation rather than early segregating generation. Traits like ear diameter and moisture content are majorly contributed by additive gene action as D is greater than $H_1$. Number of gene groups varied around one to 6 gene groups are involved in controlling these twenty characters except traits like traits like moisture content and popping expansion volume controlled by a single gene in all three environment, similarly days to 50% silking, physiological maturity, ear diameter and hundred seed weight in E2 and ear per plant in E1, E2 are controlled by single gene as these traits recorded $h^2/H_2$ less than unity. Narrow sense heritability is measure of heritability as well as the contribution of genetic variance and environmental variance.

All the twenty characters studied recorded less than unity for narrow sense heritability indicating the phenotypic variance for these characters is mainly attributed by environmental influence rather than solely genotypic variance. This findings is congruity with (El-Moula, *et al.*, 2004) [14] for days to 50% silking and ear height, Kalla, *et al.*, (2001) [15] for ear length and hundred seed weight, (Kanagarasu, *et al*., 2010) [16] for grain yield per plant, ear diameter, cob length, plant height, ear height, leaf length, 100-grain weight, grain rows per cob, days to 50 per cent tasseling and days to 50 per cent silking (Rameeh, *et al.*, 2000) [17] for number kernels per row, (Vijayabharathi, *et al.*, 2009a) [18] for all the characters studied reported non- additive gene action.

Among all the parents HKIPC-7, HKIPC-8-3 can exploited for the yield per plant, number of kernel row per ear, ear diameter and ear length, as both parents showed significant high positive GCA effect for respective characters. Parents HKIPC-7, WINPOP-29 can exploited for developing early maturing inbred lines as these parents showed highest negative GCA effect for days to 50% anthesis, days to 50% silking and physiological maturity. Parents HKIPC-7, WINPOP-47 can exploited for developing more number of leafs per plant and leaf area in a inbred lines as these parents showed highest positive GCA effect for days to 50% anthesis, days to 50% silking and physiological maturity. WINPOP-47 for popping expansion volume, WINPOP-29 and HKIPC-5 for popping rate, WINPOP-3 for flake volume, WINPOP-8 and HKIPC-8-3 for flake volume. WINPOP-13 and WINPOP-29 parents can be exploited for developing dwarf inbreed lines as these parents showed highest negative GCA effect.

**SCA:** Based on SCA effect HKI PC-5×HKIPC-7 cross can utilized to obtain desirable segregants for yield per plant and number of leafs per plant.

The WINPOP-8×HKIPC-7, WINPOP-3×HKIPC-7 cross can utilized to obtain desirable segregants for hundred seed weight and earliness. WINPOP-3×HKIPC-8-3 cross can utilized to obtain desirable segregants for number of kernels per ear, ear diameter and ear length. WINPOP-3×WINPOP-29 cross can utilized to obtain desirable segregants for flake volume, ear per plant and earliness. WINPOP-47×HKIPC-5 cross can utilized to obtain desirable sergeants for popping expansion volume and number of leafs per plant. WINPOP-8×WINPOP-47 cross can utilized to obtain desirable segregants for ear per plant and primary branches per tassel. This findings are congruity with reported that a cross combination which were of SCA high x SCA high and high SCA x low GCA parents exhibited greater heterosis (Singh, *et al.*, 2002) [19] found out that two popcorn combinations with low GCA x high GCA (Moterle, *et al.* 2012) [20] reported one popcorn cross combination with high GCA x high GCA as good specific combiners with higher *per se* performance (Vieira, *et al.*, 2011) [21].

**Table 1:** ANOVA of 9x9 half diallel design (excluding reciprocal) for twenty different characters studied under *rabi* 2017-18 (E1), *kharif*: 2018 (E2) and rabi, 2018:19 (E3)

| Source of variation | Env. | DF | Traits | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LP | LA | PBPT | PHT | EHT | DFA | DFS | PM | EPP | EL |
| Replicates | E1 | 2 | 2.107 * | 1475.514 *** | 16.647 *** | 491.613 ** | 21.037 * | 3.030 | 2.696 | 2.467 | 0.094 ** | 3.858 |
| | E2 | 2 | 2.590 * | 2088.553 | 26.912 *** | 1686.489 *** | 2092.368 *** | 7.385 | 4.452 | 14.319 ** | 0.062 ** | 2.107 |
| | E3 | 2 | 9.286 *** | 677.896 * | 101.775 *** | 1140.234 *** | 337.484 *** | 4.289 | 4.356 | 6.200 | 0.257 *** | 4.050 |
| Treatments | E1 | 44 | 4.058 *** | 4722.470 *** | 22.972 *** | 1420.262 *** | 370.603 *** | 28.954 *** | 30.038 *** | 30.294 *** | 0.121 *** | 10.668 *** |
| | E2 | 44 | 2.730 *** | 5021.721 *** | 18.357 *** | 997.494 *** | 314.309 *** | 9.520 *** | 13.030 *** | 4.963 * | 0.045 *** | 13.374 *** |
| | E3 | 44 | 3.870 *** | 4230.461 *** | 26.621 *** | 1604.018 *** | 565.045 *** | 26.355 *** | 29.767 *** | 32.418 *** | 0.038 * | 10.404 *** |
| Parents | E1 | 8 | 0.851 | 2291.461 *** | 1.429 | 669.487 *** | 122.302 *** | 11.750 *** | 11.426 *** | 11.593 *** | 0.052 * | 3.111 * |
| | E2 | 8 | 2.127 *** | 2912.433 * | 12.455 *** | 391.898 *** | 176.141 ** | 0.954 | 3.500 | 1.870 | 0.018 | 5.059 |
| | E3 | 8 | 1.092 | 1541.256 *** | 6.416 | 797.579 *** | 190.507 *** | 8.787 ** | 9.917 ** | 11.759 *** | 0.005 | 3.096 * |
| Hybrids | E1 | 35 | 3.516 *** | 3003.657 *** | 13.408 *** | 571.720 *** | 226.139 *** | 12.580 *** | 11.470 *** | 11.470 *** | 0.123 *** | 3.263 ** |
| | E2 | 35 | 1.741 *** | 3302.508 *** | 12.034 *** | 565.659 *** | 222.861 *** | 10.092 *** | 14.174 *** | 5.588 ** | 0.050 *** | 8.283 ** |
| | E3 | 35 | 3.021 *** | 2651.947 *** | 15.525 *** | 564.376 *** | 382.947 *** | 12.580 *** | 11.686 *** | 11.470 *** | 0.035 * | 3.202 ** |
| Parent Vs.Hybrids | E1 | 1 | 48.672 *** | 84329.010 *** | 530.086 *** | 37125.440 *** | 7413.261 *** | 739.674 *** | 828.817 *** | 838.757 *** | 0.626 *** | 330.317 *** |
| | E2 | 1 | 42.196 *** | 82068.480 *** | 286.891 *** | 20956.470 *** | 4620.330 *** | 58.017 *** | 49.202 *** | 7.824 | 0.063 * | 258.061 *** |
| | E3 | 1 | 55.809 *** | 80992.100 *** | 576.600 *** | 44443.000 *** | 9934.783 *** | 649.007 *** | 821.400 *** | 930.891 *** | 0.400 *** | 320.937 *** |
| Error | E1 | 88 | 0.449 | 38.722 | 1.013 | 72.240 | 5.180 | 2.507 | 2.318 | 2.292 | 0.019 | 1.487 |
| | E2 | 88 | 0.563 | 1315.545 | 3.010 | 91.012 | 64.447 | 2.537 | 1.793 | 2.788 | 0.010 | 4.055 |
| | E3 | 88 | 0.743 | 169.145 | 5.581 | 102.734 | 24.729 | 2.827 | 2.787 | 2.745 | 0.022 | 1.449 |
| Total | E1 | 134 | 1.659 | 1598.114 | 8.457 | 521.133 | 125.406 | 11.199 | 11.425 | 11.490 | 0.054 | 4.537 |
| | E2 | 134 | 1.305 | 2544.035 | 8.406 | 412.476 | 176.759 | 4.902 | 5.522 | 3.674 | 0.022 | 7.086 |
| | E3 | 134 | 1.897 | 1510.305 | 13.925 | 611.178 | 206.814 | 10.574 | 11.670 | 12.540 | 0.031 | 4.428 |
| GCA | E1 | 8 | 2.418 *** | 1798.982 *** | 6.330 *** | 534.881 *** | 146.890 *** | 9.629 *** | 8.621 *** | 8.722 *** | 0.024 *** | 1.401 ** |
| | E2 | 8 | 1.028 *** | 2091.958 *** | 7.165 *** | 304.048 *** | 112.536 *** | 4.631 *** | 5.945 *** | 1.414 | 0.017 *** | 0.500 |
| | E3 | 8 | 2.356 *** | 1146.063 *** | 10.722 *** | 617.136 *** | 251.258 *** | 9.116 *** | 8.760 *** | 9.111 *** | 0.008 | 1.342 ** |
| SCA | E1 | 36 | 1.116 *** | 1524.196 *** | 7.952 *** | 459.763 *** | 118.344 *** | 9.656 *** | 10.322 *** | 10.404 *** | 0.044 *** | 4.035 *** |
| | E2 | 36 | 0.884 *** | 1581.007 *** | 5.887 *** | 338.820 *** | 103.044 *** | 2.849 *** | 3.987 *** | 1.708 * | 0.014 *** | 5.337 *** |
| | E3 | 36 | 1.053 *** | 1468.841 *** | 8.463 *** | 516.348 *** | 174.369 *** | 8.711 *** | 10.180 *** | 11.183 *** | 0.014 * | 3.940 *** |
| Error | E1 | 88 | 0.150 | 12.907 | 0.338 | 24.080 | 1.727 | 0.836 | 0.773 | 0.764 | 0.006 | 0.496 |
| | E2 | 88 | 0.188 | 438.515 | 1.003 | 30.337 | 21.482 | 0.846 | 0.598 | 0.929 | 0.003 | 1.352 |
| | E3 | 88 | 0.248 | 56.382 | 1.860 | 34.245 | 8.243 | 0.942 | 0.929 | 0.915 | 0.007 | 0.483 |
| GCA/SCA Ratio | E1 | | 0.213 | 0.107 | 0.072 | 0.107 | 0.113 | 0.091 | 0.075 | 0.075 | 0.043 | 0.023 |
| | E2 | | 0.110 | 0.132 | 0.115 | 0.081 | 0.101 | 0.172 | 0.143 | 0.057 | 0.115 | -0.019 |
| | E3 | | 0.238 | 0.070 | 0.122 | 0.110 | 0.133 | 0.096 | 0.077 | 0.073 | 0.007 | 0.023 |
| Predictability Ratio | E1 | | 0.299 | 0.177 | 0.125 | 0.176 | 0.185 | 0.153 | 0.130 | 0.131 | 0.079 | 0.044 |
| | E2 | | 0.180 | 0.208 | 0.187 | 0.139 | 0.169 | 0.256 | 0.223 | 0.102 | 0.187 | -0.040 |
| | E3 | | 0.322 | 0.123 | 0.196 | 0.180 | 0.210 | 0.161 | 0.133 | 0.127 | 0.015 | 0.043 |

*≤0.05, **≤0.01,R-18- *rabi*, 2017-18, K-18- *kharif*-2018, R-19- *rabi*,2018-19, DF- Degree of freedom, LPP-No. of leafs per plant; LA- Leaf area; PBPT- No. of primary branches per tassel; EHT-Ear height; DFA- Days to 50% anthesis; DFS- Days to 50% silking, DM-days to75% maturity, EPP-No. of Ears per plant, EL- Ear length, ED-Ear diameter, KRPE- No. of kernels rows per ear, KPR- No. of kernels per row, YPP-Yield per plant, HSW- Hundred seed weight, MC- Moisture content, PEV-Popping expansion volume, FS- Flake size, FV- Flake volume, PR-Popping rate

**Table 2:** ANOVA of 9x9 half diallel design (excluding reciprocal) for twenty different characters studied under *rabi* 2017-18 (E1), *kharif*: 2018 (E2) and rabi, 2018:19 (E3)

| Source of variation | | DF | traits | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ED | KRPE | KPR | YPP | HSW | MOI | PEV | FZ | FV | PR |
| Replicates | E1 | 2 | 0.021 | 0.647 | 25.697 | 63.379 | 0.087 | 1.369 | 0.291 | 0.036 | 438.337 | 15.814 |
| | E2 | 2 | 0.292 | 3.941 | 17.783 | 27.282 | 2.987 | 4.298 * | 0.431 | 0.038 | 58.454 | 15.814 |
| | E3 | 2 | 0.022 | 1.443 | 30.561 | 74.658 | 2.681 | 4.241 ** | 0.128 | 0.022 | 51.526 | 27.528 |
| Treatments | E1 | 44 | 0.249 *** | 3.951 *** | 74.112 *** | 2292.279 *** | 11.069 *** | 1.264 *** | 12.876 *** | 0.514 *** | 5558.506 *** | 110.186 *** |
| | E2 | 44 | 0.375 *** | 3.848 * | 30.873 *** | 1821.063 *** | 3.416 *** | 3.636 *** | 14.791 *** | 0.875 *** | 8761.368 *** | 110.186 *** |
| | E3 | 44 | 0.218 *** | 4.033 *** | 76.874 *** | 2310.482 *** | 15.059 *** | 1.790 ** | 14.547 *** | 0.713 *** | 7835.882 *** | 107.879 *** |
| Parents | E1 | 8 | 0.403 *** | 6.196 *** | 23.318 | 128.659 ** | 3.198 * | 0.975 | 4.944 *** | 0.227 *** | 676.957 *** | 70.055 *** |
| | E2 | 8 | 0.027 | 1.148 | 13.794 * | 96.329 ** | 1.536 | 2.494 * | 19.429 *** | 0.300 *** | 5168.207 *** | 70.055 *** |
| | E3 | 8 | 0.377 *** | 6.193 *** | 22.378 | 260.347 ** | 3.972 ** | 5.008 *** | 6.616 *** | 0.408 *** | 575.006 | 59.929 |
| Hybrids | E1 | 35 | 0.205 *** | 1.755 | 12.947 | 1600.284 *** | 8.021 *** | 1.339 *** | 12.244 *** | 0.234 *** | 3307.802 *** | 37.698 *** |
| | E2 | 35 | 0.276 *** | 3.838 * | 20.359 *** | 1190.019 *** | 3.799 *** | 3.921 *** | 11.136 *** | 0.702 *** | 6263.460 *** | 37.698 *** |
| | E3 | 35 | 0.179 *** | 1.806 | 16.462 | 1608.156 *** | 8.108 *** | 1.101 | 14.939 *** | 0.406 *** | 4630.131 *** | 68.767 ** |
| Parent Vs. Hybrids | E1 | 1 | 0.574 ** | 62.853 *** | 2621.262 *** | 43821.040 *** | 180.706 *** | 0.963 | 98.475 *** | 12.607 *** | 123385.600 *** | 2968.301 *** |
| | E2 | 1 | 6.609 *** | 25.785 ** | 535.489 *** | 37705.450 *** | 5.069 * | 2.788 | 105.638 *** | 11.508 *** | 124933.400 *** | 2968.301 *** |
| | E3 | 1 | 0.348 * | 64.688 *** | 2627.258 *** | 43292.950 *** | 347.042 *** | 0.160 | 64.274 *** | 13.888 *** | 178124.200 *** | 1860.380 *** |
| Error | E1 | 88 | 0.082 | 1.342 | 12.131 | 41.959 | 1.238 | 0.527 | 0.626 | 0.018 | 181.913 | 13.311 |
| | E2 | 88 | 0.104 | 2.456 | 6.625 | 27.875 | 1.186 | 0.963 | 0.483 | 0.026 | 145.508 | 13.311 |
| | E3 | 88 | 0.076 | 1.396 | 12.210 | 71.888 | 1.445 | 0.852 | 0.566 | 0.032 | 283.934 | 32.085 |
| Total | E1 | 134 | 0.136 | 2.188 | 32.685 | 781.190 | 4.449 | 0.782 | 4.643 | 0.181 | 1951.189 | 45.158 |
| | E2 | 134 | 0.196 | 2.935 | 14.753 | 616.674 | 1.945 | 1.890 | 5.180 | 0.305 | 2973.297 | 45.158 |
| | E3 | 134 | 0.122 | 2.262 | 33.717 | 806.990 | 5.933 | 1.210 | 5.150 | 0.255 | 2760.209 | 56.904 |
| GCA | E1 | 8 | 0.331 *** | 1.891 *** | 12.167 ** | 939.305 *** | 4.611 *** | 1.207 *** | 3.165 *** | 0.053 *** | 572.545 *** | 31.402 *** |
| | E2 | 8 | 0.133 *** | 1.180 | 7.985 ** | 545.521 *** | 1.158 ** | 1.747 *** | 5.253 *** | 0.052 *** | 1567.462 *** | 31.402 *** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | E3 | 8 | 0.261 *** | 1.773 *** | 9.486 * | 924.469 *** | 4.358 *** | 2.033 *** | 3.433 *** | 0.238 *** | 378.864 *** | 29.881 ** |
| SCA | E1 | 36 | 0.028 | 1.190 *** | 27.490 *** | 725.157 *** | 3.485 *** | 0.247 | 4.543 *** | 0.198 *** | 2137.344 *** | 37.912 *** |
| | E2 | 36 | 0.123 *** | 1.305 * | 10.803 *** | 620.687 *** | 1.134 *** | 1.093 *** | 4.859 *** | 0.345 *** | 3221.121 *** | 37.912 *** |
| | E3 | 36 | 0.031 | 1.249 *** | 29.211 *** | 735.870 *** | 5.167 *** | 0.277 | 5.164 *** | 0.238 *** | 3108.205 *** | 37.310 *** |
| Error | E1 | 88 | 0.027 | 0.447 | 4.044 | 13.986 | 0.413 | 0.176 | 0.209 | 0.006 | 60.638 | 4.437 |
| | E2 | 88 | 0.035 | 0.819 | 2.208 | 9.292 | 0.395 | 0.321 | 0.161 | 0.009 | 48.503 | 4.437 |
| | E3 | 88 | 0.025 | 0.465 | 4.070 | 23.963 | 0.482 | 0.284 | 0.189 | 0.011 | 94.645 | 10.695 |
| GCA/SCA Ratio | E1 | | 42.908 | 0.177 | 0.031 | 0.118 | 0.124 | 1.318 | 0.062 | 0.022 | 0.022 | 0.073 |
| | E2 | | 0.102 | 0.067 | 0.061 | 0.080 | 0.094 | 0.168 | 0.099 | 0.012 | 0.044 | 0.073 |
| | E3 | | 3.888 | 0.152 | 0.020 | 0.115 | 0.075 | 3.498 | 0.059 | 0.091 | 0.009 | 0.066 |
| Predictability Ratio | E1 | | 0.988 | 0.261 | 0.059 | 0.191 | 0.199 | 0.725 | 0.110 | 0.043 | 0.043 | 0.128 |
| | E2 | | 0.169 | 0.119 | 0.109 | 0.138 | 0.158 | 0.251 | 0.165 | 0.023 | 0.080 | 0.128 |
| | E3 | | 0.886 | 0.233 | 0.038 | 0.187 | 0.131 | 1.022 | 0.106 | 0.154 | 0.017 | 0.116 |

*≤0.05, **≤0.01,R-18- *rabi*, 2017-18, K-18- *kharif*-2018, R-19- *rabi*,2018-19, DF- Degree of freedom, LPP-No. of leafs per plant; LA- Leaf area; PBPT- No. of primary branches per tassel; EHT-Ear height; DFA- Days to 50% anthesis; DFS- Days to 50% silking, DM-days to75% maturity, EPP-No. of Ears per plant, EL- Ear length, ED-Ear diameter, KRPE- No. of kernels rows per ear, KPR- No. of kernels per row, YPP-Yield per plant, HSW- Hundred seed weight, MC- Moisture content, PEV-Popping expansion volume, FS- Flake size, FV- Flake volume, PR-Popping rate

**Table 3:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Number of leafs per plant | | | | | | Leaf area | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 12.90 | -0.371 ** | 11.00 | -0.270 * | 12.90 | -0.313 * | 204.76 | -8.972 *** | 221.38 | -6.108 | 211.47 | -7.304 *** |
| 2 Parent | 13.23 | -0.538 *** | 12.17 | 0.224 | 11.90 | -0.701 *** | 206.99 | 2.904 ** | 210.67 | 2.781 | 203.37 | 1.008 |
| 3 Parent | 12.63 | -0.289 * | 12.33 | -0.094 | 12.63 | -0.250 | 246.89 | 16.164 *** | 260.33 | 17.897 ** | 230.40 | 9.623 *** |
| 4 Parent | 12.16 | -0.175 | 11.00 | -0.170 | 12.17 | -0.098 | 195.18 | -8.510 *** | 204.75 | -8.803 | 195.43 | -6.480 ** |
| 5 Parent | 12.00 | -0.520 *** | 11.00 | -0.280 * | 12.00 | -0.429 ** | 203.78 | -6.802 *** | 206.00 | -7.473 | 203.77 | -4.635 * |
| 6 Parent | 13.00 | 0.547 *** | 12.50 | 0.242 | 13.00 | 0.477 ** | 243.67 | 7.569 *** | 250.17 | 6.777 | 235.50 | 10.299 *** |
| 7 Parent | 13.55 | 0.404 *** | 10.63 | -0.377 ** | 13.57 | 0.368 * | 155.47 | -22.183 *** | 155.50 | -25.307 *** | 158.13 | -18.783 *** |
| 8 Parent | 13.45 | 0.610 *** | 12.67 | 0.512 *** | 13.47 | 0.641 *** | 222.53 | 16.751 *** | 232.00 | 18.231 ** | 220.23 | 12.123 *** |
| 9 Parent | 12.90 | 0.333 ** | 10.67 | 0.212 | 12.87 | 0.305 * | 195.27 | 3.079 ** | 195.00 | 2.005 | 203.87 | 4.150 |
| Gi <> 0 at 95% | 0.254 *** | | 0.284 *** | | 0.326 *** | | 2.355 *** | | 13.727 *** | | 4.922 *** | |
| Gi--Gj at 95% | 0.380 *** | | 0.426 *** | | 0.489 *** | | 3.533 *** | | 20.591 *** | | 7.383 *** | |
| GCA/SCA Ratio | 0.213 | | 0.110 | | 0.238 | | 0.107 | | 0.132 | | 0.070 | |
| Predictability Ratio | 0.299 | | 0.180 | | 0.322 | | 0.177 | | 0.208 | | 0.123 | |

**Table 4:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Number of Primary branches per tassel | | | | | | Plant height | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 15.17 | -0.231 | 11.67 | 0.265 | 14.10 | -0.624 | 89.67 | 0.153 | 83.33 | -3.465 * | 78.90 | -1.323 |
| 2 Parent | 14.62 | -0.654 *** | 12.80 | 0.744 * | 14.90 | -0.757 | 94.00 | -3.288 * | 96.67 | 3.232 * | 82.00 | -4.687 ** |
| 3 Parent | 15.30 | -1.302 *** | 15.33 | 0.144 | 13.00 | -1.727 *** | 72.00 | -8.905 *** | 108.33 | 0.263 | 62.00 | -9.935 *** |
| 4 Parent | 13.92 | 0.118 | 10.07 | 0.935 ** | 13.90 | 0.152 | 69.82 | -4.370 ** | 88.33 | 1.505 | 66.70 | -4.156 * |
| 5 Parent | 14.68 | -0.370 * | 11.00 | -0.856 ** | 14.20 | -0.487 | 65.67 | -8.502 *** | 85.00 | -6.253 *** | 65.67 | -7.696 *** |
| 6 Parent | 16.05 | 0.599 *** | 12.67 | -0.129 | 15.90 | 0.858 * | 84.11 | 3.968 ** | 95.00 | -0.859 | 84.10 | 4.589 ** |
| 7 Parent | 15.94 | 1.339 *** | 9.67 | -0.977 *** | 16.00 | 1.349 *** | 94.05 | 5.697 *** | 75.00 | -7.525 *** | 94.07 | 6.353 *** |
| 8 Parent | 15.67 | 0.255 | 15.33 | 0.387 | 15.67 | 0.246 | 113.02 | 12.263 *** | 110.00 | 9.202 *** | 113.03 | 13.247 *** |
| 9 Parent | 15.41 | 0.244 | 13.00 | 1.356 *** | 17.87 | 0.989 * | 92.17 | 2.984 * | 91.67 | 3.899 * | 92.17 | 3.607 * |
| Gi <> 0 at 95% | 0.381 *** | | 0.657 *** | | 0.894 *** | | 3.217 *** | | 3.611 *** | | 3.836 *** | |
| Gi--Gj at 95% | 0.571 *** | | 0.985 *** | | 1.341 *** | | 4.825 *** | | 5.416 *** | | 5.754 *** | |
| GCA/SCA Ratio | 0.072 | | 0.115 | | 0.122 | | 0.107 | | 0.081 | | 0.110 | |
| Predictability Ratio | 0.125 | | 0.187 | | 0.196 | | 0.176 | | 0.139 | | 0.180 | |

**Table 5:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Ear height | | | | | | Days to 50% anthesis | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 51.40 | -1.691 *** | 53.33 | -2.111 | 51.57 | -2.337 ** | 106.67 | -0.502 | 49.67 | -1.175 *** | 102.67 | -0.434 |
| 2 Parent | 58.11 | -2.168 *** | 57.83 | 1.343 | 56.10 | -2.992 *** | 111.00 | 1.074 *** | 49.33 | 0.704 ** | 107.00 | 1.141 *** |
| 3 Parent | 49.33 | -4.411 *** | 63.77 | -0.457 | 44.67 | -5.361 *** | 109.67 | 0.771 ** | 49.33 | 0.401 | 103.67 | 0.475 |
| 4 Parent | 45.00 | -3.046 *** | 48.33 | 0.919 | 38.67 | -4.176 *** | 109.67 | 0.620 * | 49.67 | -0.024 | 105.67 | 0.687 * |
| 5 Parent | 43.11 | -2.619 *** | 51.67 | -3.884 ** | 39.20 | -3.179 *** | 106.33 | -0.168 | 48.67 | -0.024 | 102.33 | -0.101 |
| 6 Parent | 58.00 | 2.846 *** | 53.33 | -0.505 | 55.67 | 4.563 *** | 107.33 | 0.377 | 48.00 | 0.158 | 103.33 | 0.444 |
| 7 Parent | 56.67 | 2.727 *** | 43.33 | -4.248 ** | 54.33 | 2.793 *** | 111.00 | -0.077 | 49.33 | 0.582 * | 105.67 | -0.253 |
| 8 Parent | 58.40 | 6.748 *** | 68.33 | 5.229 *** | 58.77 | 8.969 *** | 106.33 | -2.108 *** | 48.67 | -0.933 *** | 102.33 | -2.040 *** |
| 9 Parent | 60.48 | 1.613 *** | 51.67 | 3.714 ** | 58.57 | 1.721 * | 107.00 | 0.013 | 48.67 | 0.310 | 103.00 | 0.081 |
| Gi <> 0 at 95% | 0.861 *** | | 3.038 *** | | 1.882 *** | | 0.599 *** | | 0.603 *** | | 0.636 *** | |
| Gi--Gj at 95% | 1.292 *** | | 4.557 *** | | 2.823 *** | | 0.899 *** | | 0.904 *** | | 0.954 *** | |
| GCA/SCA Ratio | 0.113 | | 0.101 | | 0.133 | | 0.091 | | 0.172 | | 0.096 | |
| Predictability Ratio | 0.185 | | 0.169 | | 0.210 | | 0.153 | | 0.256 | | 0.161 | |

**Table 6:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Days to 50% silking | | | | | | Physiological maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 109.00 | -0.448 | 53.00 | -1.135 *** | 106.33 | -0.253 | 141.00 | -0.455 | 82.33 | 0.290 | 141.33 | -0.273 |
| 2 Parent | 113.67 | 1.007 *** | 50.67 | 0.744 ** | 110.33 | 1.141 *** | 145.67 | 1.000 *** | 81.33 | -0.013 | 145.33 | 1.061 *** |
| 3 Parent | 111.67 | 0.582 * | 50.00 | 0.259 | 106.00 | 0.263 | 144.00 | 0.636 * | 81.00 | 0.350 | 142.33 | 0.455 |
| 4 Parent | 112.00 | 0.522 * | 52.33 | -0.347 | 108.33 | 0.596 * | 144.00 | 0.515 * | 81.67 | -0.438 | 144.00 | 0.636 * |
| 5 Parent | 109.33 | -0.266 | 52.00 | 0.077 | 105.00 | -0.313 | 141.33 | -0.273 | 80.67 | 0.168 | 140.33 | -0.333 |
| 6 Parent | 110.67 | 0.522 * | 50.00 | -0.044 | 107.33 | 0.657 * | 142.67 | 0.515 * | 82.67 | 0.138 | 142.33 | 0.576 * |
| 7 Parent | 114.33 | 0.067 | 51.67 | 0.956 *** | 109.00 | -0.101 | 146.33 | 0.061 | 80.67 | 0.320 | 145.33 | 0.000 |
| 8 Parent | 109.00 | -2.024 *** | 50.33 | -1.044 *** | 105.00 | -2.010 *** | 141.00 | -2.030 *** | 81.00 | -0.135 | 140.00 | -2.091 *** |
| 9 Parent | 110.67 | 0.037 | 51.00 | 0.532 * | 106.67 | 0.020 | 142.67 | 0.030 | 80.33 | -0.680 * | 141.67 | -0.030 |
| Gi <> 0 at 95% | 0.576 *** | | 0.507 *** | | 0.632 *** | | 0.573 *** | | 0.632 *** | | 0.627 *** | |
| Gi--Gj at 95% | 0.864 *** | | 0.760 *** | | 0.948 *** | | 0.860 *** | | 0.948 *** | | 0.941 *** | |
| GCA/SCA Ratio | 0.075 | | 0.143 | | 0.077 | | 0.075 | | 0.057 | | 0.073 | |
| Predictability Ratio | 0.130 | | 0.223 | | 0.133 | | 0.131 | | 0.102 | | 0.127 | |

**Table 7:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Ears per plant | | | | | | Ear length | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 1.30 | 0.049 * | 1.23 | 0.055 ** | 1.17 | 0.014 | 14.09 | -0.025 | 13.33 | 0.006 | 14.10 | -0.100 |
| 2 Parent | 1.11 | -0.064 ** | 0.96 | -0.028 | 1.10 | -0.007 | 13.77 | -0.356 | 11.42 | -0.328 | 13.77 | -0.342 |
| 3 Parent | 1.12 | -0.016 | 1.04 | -0.072 *** | 1.07 | -0.016 | 13.27 | -0.376 | 15.33 | 0.157 | 13.27 | -0.360 |
| 4 Parent | 1.10 | -0.005 | 1.00 | -0.002 | 1.07 | -0.035 | 13.48 | 0.252 | 12.77 | 0.063 | 13.70 | 0.306 |
| 5 Parent | 1.08 | 0.027 | 1.08 | -0.022 | 1.03 | -0.029 | 14.93 | -0.166 | 12.87 | -0.140 | 14.93 | -0.151 |
| 6 Parent | 0.92 | 0.000 | 1.14 | 0.030 | 1.07 | -0.010 | 12.17 | -0.096 | 14.17 | -0.064 | 12.20 | -0.075 |
| 7 Parent | 0.90 | -0.067 ** | 1.10 | -0.004 | 1.10 | 0.017 | 11.67 | -0.289 | 13.50 | 0.427 | 11.67 | -0.275 |
| 8 Parent | 1.04 | 0.075 ** | 1.07 | 0.047 ** | 1.10 | 0.017 | 14.17 | 0.466 * | 11.07 | -0.146 | 14.17 | 0.391 |
| 9 Parent | 0.89 | 0.001 | 1.08 | -0.004 | 1.13 | 0.050 * | 13.93 | 0.591 ** | 12.87 | 0.024 | 13.93 | 0.606 ** |
| Gi <> 0 at 95% | 0.053 *** | | 0.038 *** | | 0.056 *** | | 0.462 *** | | 0.762 *** | | 0.456 *** | |
| Gi--Gj at 95% | 0.079 *** | | 0.056 *** | | 0.084 *** | | 0.692 *** | | 1.143 *** | | 0.683 *** | |
| GCA/SCA Ratio | 0.043 | | 0.115 | | 0.007 | | 0.023 | | -0.019 | | 0.023 | |
| Predictability Ratio | 0.079 | | 0.187 | | 0.015 | | 0.044 | | -0.040 | | 0.043 | |

**Table 8:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits Parents | Ear diameter | | | | | | Number of kernels rows per ear | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 3.00 | -0.053 | 2.70 | -0.048 | 3.00 | -0.108 * | 10.73 | -0.170 | 11.33 | -0.377 | 10.73 | -0.217 |
| 2 Parent | 2.80 | -0.091 | 2.53 | -0.070 | 2.80 | -0.084 | 10.67 | -0.261 | 12.00 | -0.013 | 10.67 | -0.275 |
| 3 Parent | 2.82 | -0.170 *** | 2.63 | -0.085 | 3.00 | -0.120 ** | 11.33 | -0.023 | 11.33 | -0.013 | 11.33 | -0.038 |
| 4 Parent | 3.00 | -0.037 | 2.53 | -0.070 | 3.00 | -0.029 | 11.33 | -0.196 | 11.33 | 0.471 | 11.33 | -0.105 |
| 5 Parent | 3.00 | -0.067 | 2.60 | -0.073 | 3.00 | -0.059 | 11.33 | -0.086 | 11.33 | -0.074 | 11.33 | -0.105 |
| 6 Parent | 3.07 | -0.062 | 2.40 | -0.003 | 3.07 | -0.044 | 9.33 | -0.485 * | 10.67 | -0.559 * | 9.33 | -0.502 * |
| 7 Parent | 2.87 | -0.061 | 2.57 | 0.017 | 2.87 | -0.053 | 11.78 | -0.092 | 11.33 | -0.013 | 11.77 | -0.005 |
| 8 Parent | 4.00 | 0.413 *** | 2.53 | 0.257 *** | 4.00 | 0.359 *** | 14.73 | 0.909 *** | 10.67 | 0.229 | 14.73 | 0.862 *** |
| 9 Parent | 3.20 | 0.129 ** | 2.70 | 0.076 | 3.20 | 0.138 ** | 11.47 | 0.403 * | 12.67 | 0.350 | 11.47 | 0.386 * |
| Gi <> 0 at 95% | 0.108 *** | | 0.122 *** | | 0.105 *** | | 0.438 *** | | 0.593 *** | | 0.447 *** | |
| Gi--Gj at 95% | 0.162 *** | | 0.183 *** | | 0.157 *** | | 0.658 *** | | 0.890 *** | | 0.671 *** | |
| GCA/SCA Ratio | 42.908 | | 0.102 | | 3.888 | | 0.177 | | 0.067 | | 0.152 | |
| Predictability Ratio | 0.988 | | 0.169 | | 0.886 | | 0.261 | | 0.119 | | 0.233 | |

**Table 9:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Number of kernels per row | | | | | | Yield per plant | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 30.33 | 0.598 | 28.67 | -0.537 | 32.33 | 0.570 | 36.33 | -0.122 | 27.11 | -6.045 *** | 39.80 | -2.594 |
| 2 Parent | 26.67 | -1.582 ** | 24.33 | 0.206 | 26.00 | -1.548 ** | 29.76 | -4.045 *** | 22.84 | 4.965 *** | 29.23 | -0.542 |
| 3 Parent | 31.33 | -0.244 | 28.00 | 0.479 | 29.73 | -0.381 | 32.95 | -9.432 *** | 21.73 | -6.451 *** | 40.93 | -5.742 *** |
| 4 Parent | 30.17 | 0.695 | 24.00 | 0.085 | 30.17 | 0.846 | 37.70 | -3.483 ** | 32.50 | -1.752 * | 32.50 | -3.706 ** |
| 5 Parent | 29.73 | -0.813 | 28.15 | 0.854 * | 29.73 | -0.660 | 42.00 | -6.886 *** | 21.65 | -6.855 *** | 38.10 | -9.954 *** |
| 6 Parent | 28.33 | -0.329 | 25.67 | -1.340 ** | 28.33 | -0.175 | 38.51 | -0.044 | 34.07 | 0.262 | 30.13 | -1.615 |
| 7 Parent | 24.33 | -0.923 | 26.33 | -0.461 | 24.33 | -0.769 | 33.15 | -1.810 | 17.32 | -0.749 | 29.53 | -3.503 * |
| 8 Parent | 34.07 | 1.774 ** | 30.33 | 1.418 ** | 32.73 | 1.140 * | 52.33 | 22.439 *** | 22.57 | 15.559 *** | 58.63 | 21.646 *** |
| 9 Parent | 30.33 | 0.824 | 25.33 | -0.703 | 30.33 | 0.979 | 36.44 | 3.382 ** | 19.95 | 1.067 | 32.70 | 6.009 *** |
| Gi <> 0 at 95% | 1.318 *** | | 0.974 *** | | 1.322 *** | | 2.452 *** | | 1.998 *** | | 3.209 *** | |
| Gi--Gj at 95% | 1.977 *** | | 1.461 *** | | 1.984 *** | | 3.677 *** | | 2.997 *** | | 4.813 *** | |

| | | | | | | |
|---|---|---|---|---|---|---|
| GCA/SCA Ratio | 0.031 | 0.061 | 0.020 | 0.118 | 0.080 | 0.115 |
| Predictability Ratio | 0.059 | 0.109 | 0.038 | 0.191 | 0.138 | 0.187 |

**Table 10:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Hundred seed weight | | | | | | Moisture content | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 12.96 | 0.140 | 21.93 | 0.265 | 11.70 | 0.125 | 14.50 | 0.246 * | 13.37 | -0.542 ** | 13.77 | 0.160 |
| 2 Parent | 12.82 | -0.233 | 20.63 | -0.038 | 12.20 | -0.499 * | 13.93 | 0.334 ** | 14.30 | -0.297 | 13.93 | 0.327 * |
| 3 Parent | 13.89 | 0.350 | 20.97 | 0.498 ** | 11.73 | 0.001 | 12.72 | -0.196 | 12.10 | -0.240 | 12.17 | -0.249 |
| 4 Parent | 12.56 | -0.429 * | 20.70 | -0.308 | 11.17 | -0.708 *** | 12.95 | -0.499 *** | 13.35 | -0.101 | 12.37 | -0.558 *** |
| 5 Parent | 10.40 | -0.855 *** | 20.13 | -0.219 | 10.70 | -0.420 * | 13.30 | -0.499 *** | 14.25 | 0.309 | 11.87 | -0.661 *** |
| 6 Parent | 13.20 | -0.942 *** | 21.20 | 0.061 | 13.40 | -0.593 ** | 13.72 | 0.122 | 13.62 | -0.317 | 13.53 | 0.133 |
| 7 Parent | 13.53 | 0.719 *** | 19.53 | -0.550 ** | 14.43 | 0.868 *** | 13.60 | 0.015 | 13.74 | 0.307 | 13.23 | -0.043 |
| 8 Parent | 13.14 | 0.789 *** | 21.47 | 0.272 | 12.83 | 1.043 *** | 14.05 | 0.380 ** | 14.53 | 0.707 *** | 15.97 | 0.691 *** |
| 9 Parent | 13.69 | 0.462 * | 21.13 | 0.020 | 12.13 | 0.183 | 14.03 | 0.096 | 15.33 | 0.174 | 14.60 | 0.200 |
| Gi <> 0 at 95% | 0.421 *** | | 0.412 *** | | 0.455 *** | | 0.275 *** | | 0.371 *** | | 0.349 *** | |
| Gi--Gj at 95% | 0.632 *** | | 0.618 *** | | 0.682 *** | | 0.412 *** | | 0.557 *** | | 0.524 *** | |
| GCA/SCA Ratio | 0.124 | | 0.094 | | 0.075 | | 1.318 | | 0.168 | | -23.498 | |
| Predictability Ratio | 0.199 | | 0.158 | | 0.131 | | 0.725 | | 0.251 | | 1.022 | |

**Table 11:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Popping expansion volume | | | | | | Flake size | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 7.98 | -0.229 | 9.99 | 0.292 * | 7.83 | -0.206 | 1.51 | -0.010 | 1.73 | -0.031 | 1.67 | 0.059 * |
| 2 Parent | 10.81 | 0.458 *** | 11.41 | 0.003 | 10.40 | 0.775 *** | 2.08 | 0.119 *** | 2.03 | -0.087 ** | 2.23 | 0.280 *** |
| 3 Parent | 11.89 | 0.462 *** | 7.83 | -0.260 * | 12.83 | 0.754 *** | 1.91 | -0.102 *** | 2.04 | -0.031 | 1.80 | -0.016 |
| 4 Parent | 8.90 | -0.639 *** | 8.48 | -0.448 *** | 9.70 | -0.591 *** | 1.61 | -0.046 * | 1.96 | -0.110 *** | 1.17 | -0.271 *** |
| 5 Parent | 9.42 | -0.051 | 8.64 | -0.275 * | 9.77 | -0.412 ** | 2.13 | -0.033 | 2.27 | 0.059 * | 2.13 | 0.008 |
| 6 Parent | 9.91 | 0.425 ** | 14.88 | 1.428 *** | 9.87 | 0.551 *** | 1.59 | -0.009 | 2.77 | 0.073 ** | 1.50 | -0.059 * |
| 7 Parent | 9.39 | 0.133 | 6.72 | -1.036 *** | 9.43 | -0.461 *** | 1.65 | 0.012 | 1.77 | 0.050 | 1.77 | 0.065 * |
| 8 Parent | 10.43 | -1.008 *** | 12.52 | 0.490 *** | 11.30 | -0.491 *** | 1.80 | -0.030 | 2.11 | 0.008 | 1.63 | -0.092 ** |
| 9 Parent | 11.67 | 0.449 *** | 9.70 | -0.194 | 11.90 | 0.081 | 2.28 | 0.098 *** | 2.32 | 0.068 * | 2.30 | 0.026 |
| Gi <> 0 at 95% | 0.299 *** | | 0.263 *** | | 0.285 *** | | 0.050 *** | | 0.061 *** | | 0.068 *** | |
| Gi--Gj at 95% | 0.449 *** | | 0.394 *** | | 0.427 *** | | 0.076 *** | | 0.092 *** | | 0.101 *** | |
| GCA/SCA Ratio | 0.062 | | 0.099 | | 0.059 | | 0.022 | | 0.012 | | 0.091 | |
| Predictability Ratio | 0.110 | | 0.165 | | 0.106 | | 0.043 | | 0.023 | | 0.154 | |

**Table 12:** General Combining Ability of nine parents studied under *rabi*, 2017:18 (E1), *kharif*- 2018 (E2) and rabi, 2018-19 (E3)

| Traits / Parents | Flake volume | | | | | | Popping rate | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | E1 | Mean | E2 | Mean | E3 | Mean | E1 | Mean | E2 | Mean | E3 |
| 1 Parent | 174.33 | 16.509 *** | 174.07 | 10.087 *** | 180.00 | 5.644 * | 86.84 | 2.844 *** | 86.84 | 2.844 *** | 75.33 | 0.468 |
| 2 Parent | 178.67 | -1.622 | 197.53 | -4.002 * | 182.00 | 1.290 | 81.27 | 1.575 * | 81.27 | 1.575 * | 78.93 | 0.932 |
| 3 Parent | 193.33 | -8.119 *** | 178.03 | -17.939 *** | 189.20 | -11.486 *** | 72.68 | -0.248 | 72.68 | -0.248 | 83.30 | -0.123 |
| 4 Parent | 190.17 | -3.022 | 174.80 | -12.258 *** | 208.67 | 0.360 | 76.70 | -0.116 | 76.70 | -0.116 | 84.27 | 0.153 |
| 5 Parent | 191.74 | -6.226 ** | 164.77 | 13.984 *** | 205.17 | 6.144 * | 75.33 | -1.515 * | 75.33 | -1.515 * | 85.70 | 1.171 |
| 6 Parent | 193.33 | -2.783 | 288.47 | 17.413 *** | 181.67 | -7.571 ** | 83.75 | 1.339 * | 83.75 | 1.339 * | 79.40 | -0.377 |
| 7 Parent | 183.50 | 3.078 | 158.43 | -7.120 *** | 181.10 | 0.181 | 75.20 | -1.444 * | 75.20 | -1.444 * | 80.73 | -0.620 |
| 8 Parent | 197.88 | -0.883 | 224.83 | 0.493 | 195.50 | 2.911 | 75.95 | 0.017 | 75.95 | 0.017 | 74.13 | -3.753 *** |
| 9 Parent | 226.67 | 3.069 | 224.43 | -0.657 | 216.67 | 2.526 | 74.03 | -2.453 *** | 74.03 | -2.453 *** | 86.97 | 2.150 * |
| Gi <> 0 at 95% | 5.105 *** | | 4.565 *** | | 6.377 *** | | 1.381 *** | | 1.381 *** | | 2.144 *** | |
| Gi--Gj at 95% | 7.657 *** | | 6.848 *** | | 9.566 *** | | 2.071 *** | | 2.071 *** | | 3.216 *** | |
| GCA/SCA Ratio | 0.022 | | 0.044 | | 0.009 | | 0.073 | | 0.073 | | 0.066 | |
| Predictability Ratio | 0.043 | | 0.080 | | 0.017 | | 0.128 | | 0.128 | | 0.116 | |

## Conclusion

G×E interaction is clearly indicated as narrow sense heritability is less than unity. Selection of parents with dominant alleles in yield attributing characters is desirable in pedigree method or bulk method is to be followed. As all twenty characters studied recorded partial or over dominance selection of inbred lines in early generation is not suggestible, it is to be done in later generation to obtain better inbred line. Two good general combiners are recorded, HKIPC-7 can be exploited for yield per and earliness, WINPOP-29 can be exploited for earliness and dwarfer lines. Specific combiners for yield and popping characters are WINPOP-47×HKIPC-7 cross for yield per plant, WINPOP-8×HKIPC-7 and WINPOP-3×HKIPC-7 cross for earliness and WINPOP-47×HKIPC-5cross for popping expansion

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