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Deciphering of Popcorn (*Zea mays* var. *everta*) Heterosis for Early Maturity, Yield and Popping Expansion Volume Across Different Environments

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ABSTRACT: Maize (*Zea mays* L., 2n = 20), a valuable crop, comes from Mexico to Central Africa and is a cross-pollinated, monoecious, annual plant in the family Poaceae. According to modern concepts, heterosis is the bringing of favourable genes from two different parents into the progeny to overcome barriers and obtain a better genotype with better yield. WINPOP-3×HKIPC-7 cross can be used in developing early maturing lines and WINPOP-8×HKIPC-7, WINPOP-8×HKIPC-5 for heterotic combination of yield per plant, is useful in developing high-yield superior lines with good popping quality. The best heterotic combination of yield per plant was WINPOP-8×HKIPC-7, WINPOP-8×HKIPC-5 over standard checks, which can be further exploited in developing high yielding and popping quality.

Keywords: Heterosis, Popcorn, Popping Volume, Early Maturity.

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. India's maize cultivation surpassed 9.2 million hectares in 2018-19. (DACNET, 2020). 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).

Popcornis 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 *et al.,* 2006). Popcorn swells and puffs up when heated and is a popular recreational snack with a high nutritional content (Rakshit *et al.,* 2003). 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.,* 2008). 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) 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; Dofing *et al.,* 1990) due to narrow genetic background because most of the popcorn lines are descended from flint germplasm (Kantety *et al.,* 1995). However, it has relatively poor agronomic, yield and popping quality and also more susceptible and prone to disease and pests.

In Indian popcorn breeding programmes, improvement of popcorn genotypes are almost untouched. As of now, very few single-cross hybrids (DMRHP-1402, BPCH-6, Pant popcorn-1) as well as a few composites (Amber popcorn, VL Almora popcorn) are available in the public domain with low popping volume and yield potential. As a consequence, there is a critical and urgent demand for the creation of optimal hybrids with high yielding gain and high popping volume. In this research, we 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" Deciphering of popcorn (*zea mays* var. *Everta*) heterosis for early maturity, yield and popping volume across different environments

MATERIALS AND METHODS

The experimental genetic material was comprised of all the available popcorn inbred lines. The selected promising 9 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 36 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 WindostatV.8.5.: Heterosis (or hybrid vigour) is the superiority of the F_1 generation in relation to their parents (Fehr, 1987; Darwin, 1976) which was first coined by Shull (1908). The magnitude of heterobeltiosis (BH), and standard heterosis (SH) have been estimated with better parent and standard local checks *i.e.,* check1(Amberpopcorn)

Better parent Heterosis $(\text{BPH})\% = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$, Standerd Heterosis $(\text{SH})\% = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$, respectively under three sowing environments (Table) given below

RESULT AND DISCUSSION

In most traits, positive significant traits are preferable in breeding programs, except traits like negative heterosis, which are preferred over positive heterosis like plant height, days to 50% anthesis, days to 50% silking, physiological maturity, and popping rate.

Leaves per plant: The range of heterobeltiosis for number of leaves per plant ranged from 25.95 to-11.86 in E1, 30.30 to-9.33 in E2 and 23.58 to-4.91 in E3. WINPOP-47×HKIPC-5, WINPOP-47×HKIPC-7, HKIPC-5×HKIPC-8-3, and HKIPC-7×HKIPC-8-3 crosses have the highest positive significant heterobeltiosis and standard heterosis in all E1 and E2 environments and can be used in breeding programs.

Leaf area: The range of heterobeltiosis for leaf area ranged from 50.29 to -15.99 in E1, 52.8 to-16.26 in E2 and 50.85 to -15.25 in E3. The range of standard heterosis for leaf area ranged from 30.92 to-30.66 in E1, 30.03 to-33.74 in E2 and 36.79 to-26.67 in E3. WINPOP-29× HKIPC-8-3 and WINPOP-13×WINPOP-29 crosses can be utilised for leaf area traits in breeding programmes as these crosses showed the highest positive significant heterobeltiosis and standard heterosis in all three environments.

Number of primary branches per tassel: The range of heterobeltiosis for the number of primary branches per tassel ranged from 55.13 to -0.5 in E1, 64.06 to -10.53 in E2 and 55.77 to -1.68 in E3. The range of standard heterosis for the number of primary branches tassel ranged from 55.34 to -5.19 in E1, 36.96 to-26.09 in E2 and 39.93 to-13.43 in E3. WINPOP-8×WINPOP-47and WINPOP-20×HKIPC-5 crosses can be utilised for the number of primary branches per tassel trait in breeding programmes as these crosses showed the highest positive significant heterobeltiosis and standard heterosis in E1 and E3 environments.

Plant height: The range of heterobeltiosis for plant height ranged from 88.59 to-1.15 in E1, 58.49 to-5.88 in E2 and 97.49 to 13.67 in E3. The range of standard heterosis for plant height ranged from 35.18 to-17.78 in E1, 32.42 to-27.27 in E2 and 35.05 to-17.78 in E3. WINPOP-3×WINPOP-13 crosses can be utilised for plant height traits in breeding programmes as these crosses showed the highest negative significant heterobeltiosis and standard heterosis in all three environments.

Ear height: The range of heterobeltiosis for ear height ranged from 65.71 to -8.83 in E1, 56.25 to-13.75 in E2 and 100.79 to-4.93 in E3. The range of standard heterosis for ear height ranged from 60.01 to-12.41 in E1, 24.51 to-31.95 in E2 and 100.79 to-9.2 in E3. WINPOP-8× WINPOP-29 crosses can be utilised for ear height traits in breeding programmes as these crosses showed the highest negative significant heterobeltiosis and standard heterosis in all E1and E3 environments.

Days to 50% anthesis: Most the crosses recorded negative heterobeltiosis and standard heterosis for days to 50% anthesis. WINPOP-3×HKIPC-7 cross can be used in breeding programmes for days to 50% anthesis trait because it had the highest negative significant standard heterosis in all three environments, whereas WINPOP-8×HKIPC-7 and HKIPC-5×HKIPC-7 had the highest negative significant heterobeltiosis and standard heterosis in all E1 and E3 environments.

Days to 50% silking: TheWINPOP-3×HKIPC-7cross can be utilised for days to 50% silking in a breeding programme as it recorded high negative significant standard heterosis in all three environments, whereas WINPOP-8×HKIPC-7 and HKI PC-5×HKIPC-7showed the highest negative significant heterobeltiosis and standard heterosis in all E1 and E3 environments.

Days to 75% maturity: Most of the crosses recorded negative heterobeltiosis and standard heterosis for days to 75% maturity. The WINPOP-3×HKIPC-7 cross can be used in breeding programmes for days to 75% maturity traits because it has high negative significant standard heterosis in all three environments. On the other hand, the WINPOP-8×HKIPC-7 and HKIPC-5×HKIPC-7 crosses have the highest negative significant heterobeltiosis and standard heterosis in all E1 and E3 environments.

Ear per plant: The range of heterobeltiosis for ear per plant ranged from 48 to -48.35 in E1, 25.00 to-45.51 in E2 and 32.35 to -15.15 in E3. The range of standard heterosis for ear per plant ranged from 31.28 to-55.90 in E1, 08.07 to-53.80 in E2 and 28.57 to-20.0 in E3. HKIPC-7×HKIPC-8-3 crosses can be used in breeding programmes for ear per plant traits because they showed the highest positive significant heterobeltiosis in E1 and E2, but standard heterosis in E3**.**

Ear length: Most of the crosses recorded positive heterobeltiosis and standard heterosis for ear length. WINPOP-3×HKIPC-8-3 crosses can be used in breeding programmes for ear length because they showed the highest positive significant heterobeltiosis and standard heterosis in E1 and E3 environments.

Ear diameter: The range of heterobeltiosis for ear diameter ranged from 14.28 to-18.33 in E1, 51.32 to 0.63 in E2 and 14.58 to-23.33 in E3. HKI PC-7×HKI PC-8-3, WINPOP-47×HKI PC-7, and WINPOP-8×HKIPC-5 crosses can be utilised for ear diameter traits in breeding programmes as these crosses showed the highest positive significant heterobeltiosis and standard heterosis in the E2 environment.

Kernel rows per ear: The range of heterobeltiosis for kernel row per ear ranged from 27.91 to -11.76 in E1, 29.41 to -11.76 in E2 and 27.91 to -11.76 in E3. Most of the crosses recorded negative standard heterosis. WINPOP-3×HKIPC-7, HKIPC-5×HKI PC-7, and WINPOP-20×HKIPC-7crosses can be used in breeding programmes for kernel row per ear trait because they showed the highest positive significant standard heterosis in the E2 environment.

Kernels per row: Most the crosses recorded positive heterobeltiosis and standard heterosis for kernels per row. WINPOP-3×HKIPC-8-3 and WINPOP-3×WINPOP-20 crosses can be used in breeding programmes for the kernels per row trait because they showed the highest positive significant heterobeltiosis in E1 and standard heterosis in E1 and E3 environments.

Yield per plant: Most the crosses recorded positive heterobeltiosis and standard heterosis for yield per plant. The range of heterobeltiosis for yield per plant ranged from 241.98 to 13.96 in E1, 401.73 to 11.39 in E2 and 348.62 to 37.69 in E3. The range of standard heterosis for yield per plant ranged from 169.72 to-9.29 in E1, 232.36 to-10.42 in E2 and 151.28 to-9.95 in E3. these HKIPC-7×HKIPC-8-3, WINPOP-8×HKIPC-7 and WINPOP-8×HKIPC-5, crosses can be utilised for yield per plant trait in breeding programmes as these crosses showed the highest positive significant heterobeltiosis and standard heterosis in the E2 environment. In E1 and E3 environments, the WINPOP-8×HKIPC-8-3 cross had the highest positive significant heterobeltiosis and standard heterosis.

Hundred seed weight: The range of heterobeltiosis for hundred seed weight ranged from 51.45 to-2.75 in E1, 6.91 to-13.98 in E2 and 58.70 to 2.49 in E3. The range of standard heterosis for hundred seed weight ranged from 43.27 to-7.58 in E1, 6.91 to-13.98 in E2 and 41.11 to-4.85 in E3. WINPOP-13×HKIPC-7, WINPOP-13×HKIPC-8-3, and WINPOP-3×HKIPC-8-3 crosses can be used in breeding programmes for the hundred seed weight trait because they showed the highest positive significant heterobeltiosis and standard heterosis in the E2 environment. In E1 and E3 environments, the WINPOP-8×HKIPC-7 and WINPOP-3×HKIPC-7crosses had the highest positive significant heterobeltiosis and standard heterosis.

Moisture content: The range of heterobeltiosis for moisture content ranged from 6.94 to-13.54 in E1, 19.72 to-17.07 in E2 and 5.33 to-19.42 in E3. The range of standard heterosis for moisture content ranged from 2.76 to-16.32 in E1, 4.51 to-19.39 in E2 and -9.19 to-4.85 in E3. WINPOP-8×WINPOP-47 crosses can be utilised for moisture content traits in breeding programmes as this cross showed the highest positive significant heterobeltiosis and standard heterosis in the E1 environment.

Popping expansion volume: The range of heterobeltiosis for popping expansion volume ranged from 47.06 to-36.03 in E1, 65.52 to-33.07 in E2 and 56.70 to-20.94 in E3. The range of standard heterosis for popping expansion volume ranged from 32.60 to-41.86 in E1, 13.82 to-40.69 in E2 and 23.38 to-37.14 in E3. WINPOP-8×HKIPC-5 crosses can be utilised for the popping expansion volume trait in breeding programmes as this cross showed the highest positive significant heterobeltiosis and standard heterosis in E1 and E3 environments.

Flake size: Most the crosses recorded positive heterobeltiosis for flake size. The range of standard heterosis for flake size ranged from 60.65 to-4.18 in E1, 42.82 to-25.19 in E2 and 89.54 to-9.23 in E3. WINPOP-3×WINPOP-20 and WINPOP-29×HKIPC-7 crosses can be used in breeding programmes for flake size trait because they showed the highest positive significant heterobeltiosis and standard heterosis in E1 and E3 environments. Popping rate: The range of heterobeltiosis for popping rate volume ranged from 22.73 to 0.59 in E1, 22.73 to 0.59 in E2 and 23.94 to-4.27 in E3. The range of standard heterosis for popping rate volume ranged from 11.83 to -5.65 in E1, 11.83 to -5.65 in E2 and 12.07 to -9.66 in E3. WINPOP-29×HKIPC-8-3, WINPOP-20×HKIPC-8-3, and WINPOP-13×HKIPC-8-3 can be used in breeding programmes for the popping rate trait because this cross had the highest negative significant standard heterosis in both E1 and E2 environments.

The cross WINPOP-13×WINPOP-20 can also be included in the breeding programme as it recorded negative heterobeltiosis and standard heterosis in the E3 environment. Among the 36 crosses, WINPOP-8×WINPOP-47 recorded heterbleitosis and standard heterossis of primary branchers per tassel (E1andE3) and moisture content (E1). WINPOP-3×HKIPC-7 recorded heterbleitosis and standard heterossis of physiological maturity (E1 and E3), days to 50% anthesis (E1 and E3), days to 50% silking (E1 and E3), number of kernel rows per ear (E2), and hundred seed weight (E1 and E3). HKI PC-7×HKI PC-8-3 recorded heterbleitosis and standard heterossis of the number of leaves per plant (E1andE2), the number of ears per plant (E1 and E3), and ear diameter (E2). WINPOP-3×HKIPC-8-3 recorded heterbleitosis and standard heterossis of ear length (E1andE3) and the number of kernels per row (E1&E3). WINPOP-8×HKIPC-5 recorded heterbleitosis and standard heterossis of ear diameter (E2), yield per plant (E2), and popping expansion volume (E1andE3). WINPOP-8×HKIPC-7 found both heterbleitosis and standard heterosis in the yield per plant (E2) and the weight of a hundred seeds (E1 and E3). These findings are in congruity with Solalinde *et al.* (2014) reported heterotic combinations for yield per plant, popping expansion volume, plant height and ear height. Saleh *et al.* (2002) reported high heterosis for plant height, ear height, kernel rows per ear, kernels per row, and hundred grain weight.

Table 1: Estimation of heterobeltiosis (%) and standard heterosis (%) for agro-morphological and phenological traits.

Sr. No.	Trait / Crosses	Days to 75% maturity								
		rabi, 2017-18			*kharif*-2018			*rabi*, 2018-19		
		MEAN	BP	SH1	MEAN	BP	SH1	MEAN	BP	SH1
1.	$P_1 \times P_2$	140.00	-3.89 **	-4.33 **	80.33	-2.43	-2.82	139.00	-4.36 **	-4.36 **
2.	$P_1 \times P_3$	140.67	-2.31 **	-3.87 **	81.33	-1.21	-1.61	139.67	-1.87	-3.90 **
3.	$P_1 \times P_4$	136.00	-5.56 **	-7.06 **	79.33	-3.64 *	-4.03 *	135.00	-6.25 **	-7.11 **
4.	$P_1 \times P_5$	135.33	-4.25 **	-7.52 **	85.33	3.64 *	3.23	134.33	-4.95 **	-7.57 **
5.	$P_1 \times P_6$	137.00	-3.97 **	-6.38 **	80.67	-2.42	-2.42	136.00	-4.45 **	-6.42 **
6.	$P_1 \times P_7$	137.00	-6.38 **	-6.38 **	80.00	-2.83	-3.23	136.00	-6.42 **	-6.42 **
7.	$P_1 \times P_8$	133.67	-5.20 **	-8.66 **	78.67	-4.45 **	-4.84 **	132.67	-6.13 **	-8.72 **
8.	$P_1 \times P_9$	135.33	-5.14 **	-7.52 **	81.00	-1.62	-2.02	134.33	-5.18 **	-7.57 **
9.	$P_2 \times P_3$	139.67	-4.12 **	-4.56 **	82.00	0.82	-0.81	138.67	-4.59 **	-4.59 **
10.	$P_2 \times P_4$	138.67	-4.81 **	-5.24 **	79.67	-2.45	-3.63 *	137.67	-5.28 **	-5.28 **
11.	$P_2 \times P_5$	139.67	-4.12 **	-4.56 **	79.00	-2.87	-4.44 **	138.67	-4.59 **	-4.59 **
12.	$P_2 \times P_6$	140.00	-3.89 **	-4.33 **	81.33	-1.61	-1.61	139.00	-4.36 **	-4.36 **
13.	$P_2 \times P_7$	135.67	-7.29 **	-7.29 **	82.33	1.23	-0.40	134.67	-7.34 **	-7.34 **
14.	$P_2 \times P_8$	131.67	-9.61 **	-10.02 **	80.67	-0.82	-2.42	130.67	-10.09 **	-10.09 **
15.	$P_2 \times P_9$	136.33	-6.41 **	-6.83 **	80.00	-1.64	-3.23	135.33	-6.88 **	-6.88 **
16.	$P_3 \times P_4$	136.67	-5.09 **	-6.61 **	81.00	-0.82	-2.02	135.67	-5.79 **	-6.65 **
17.	$P_3 \times P_5$	136.67	-5.09 **	-6.61 **	81.33	0.41	-1.61	135.67	-4.68 **	-6.65 **
18.	$P_3 \times P_6$	138.33	-3.94 **	-5.47 **	80.00	-3.23	-3.23	137.33	-3.51 **	-5.50 **
19.	$P_3 \times P_7$	136.00	-7.06 **	-7.06 **	82.00	1.23	-0.81	135.00	-7.11 **	-7.11 **
20.	$P_3 \times P_8$	135.00	-6.25 **	-7.74 **	81.00	0.00	-2.02	134.00	-5.85 **	-7.80 **
21.	$P_3 \times P_9$	138.00	-4.17 **	-5.69 **	81.33	0.41	-1.61	137.00	-3.75 **	-5.73 **
22.	$P_4 \times P_5$	138.00	-4.17 **	-5.69 **	81.00	-0.82	-2.02	137.00	-4.86 **	-5.73 **
23.	$P_4 \times P_6$	138.67	-3.70 **	-5.24 **	79.33	-4.03 *	-4.03 *	137.67	-4.40 **	-5.28 **
24.	$P_4 \times P_7$	137.33	-6.15 **	-6.15 **	81.67	0.00	-1.21	136.33	-6.19 **	-6.19 **
25.	$P_4 \times P_8$	136.67	-5.09 **	-6.61 **	79.33	-2.86	-4.03 *	135.67	-5.79 **	-6.65 **
26.	$P_4 \times P_9$	137.67	-4.40 **	-5.92 **	78.67	-3.67 *	-4.84 **	136.67	-5.09 **	-5.96 **
27.	$P_5 \times P_6$	138.00	-3.27 **	-5.69 **	82.00	-0.81	-0.81	137.00	-3.75 **	-5.73 **
28.	$P_5 \times P_7$	137.00	-6.38 **	-6.38 **	79.67	-1.24	-3.63 *	136.00	-6.42 **	-6.42 **
29.	$P_5 \times P_8$	134.33	-4.95 **	-8.20 **	81.67	0.82	-1.21	133.33	-4.99 **	-8.26 **
30.	$P_5 \times P_9$	137.33	-3.74 **	-6.15 **	78.67	-2.48	-4.84 **	136.33	-3.76 **	-6.19 **
31.	$P_6 \times P_7$	135.33	-7.52 **	-7.52 **	81.33	-1.61	-1.61	134.33	-7.57 **	-7.57 **
32.	$P_6 \times P_8$	136.33	-4.44 **	-6.83 **	80.00	-3.23	-3.23	135.33	-4.92 **	-6.88 **
33.	$P_6 \times P_9$	138.67	-2.80 **	-5.24 **	79.67	-3.63 *	-3.63 *	137.67	-3.28 **	-5.28 **
34.	$P_7 \times P_8$	134.00	-8.43 **	-8.43 **	83.00	2.47	0.40	133.00	-8.49 **	-8.49 **
35.	$P_7 \times P_9$	137.67	-5.92 **	-5.92 **	80.33	-0.41	-2.82	136.67	-5.96 **	-5.96 **
36.	$P_8 \times P_9$	136.00	-4.67 **	-7.06 **	80.33	-0.82	-2.82	135.00	-4.71 **	-7.11 **

Table 2: Estimation of heterobeltiosis (%) and standard heterosis (%) for yield and its attributing traits.

Sr. No.	Trait Crosses	Yield per plant								
		rabi, 2017-18			*kharif*-2018			*rabi*, 2018-19		
		MEA	BP	SH1	MEA	BP	SH1	MEA	BP	SH1
1.	$P_1 \times P_2$	62.12	70.97 **	18.70	46.62	71.93 **	36.84 **	61.43	54.36 **	4.78
2.	$P_1 \times P_3$	47.47	30.65 *	-9.29	43.21	59.37 **	26.84 *	63.13	54.23 **	7.67
3.	$P_1 \times P_4$	84.20	123.33	60.89 **	36.20	11.39	6.27	76.60	92.46 **	30.64 *
4.	$P_1 \times P_5$	107.42	155.76	105.26	52.98	95.39 **	55.51 **	88.73	122.95	51.34 **
5.	$P_1 \times P_6$	84.57	119.63	61.61 **	68.37	100.68	100.68	72.03	80.99 **	22.85
6.	$P_1 \times P_7$	67.15	84.83 **	28.32 **	66.20	144.15	94.32 **	66.00	65.83 **	12.56
7.	$P_1 \times P_8$	137.32	162.40	162.40	81.99	202.39	140.67	117.60	100.57	100.57
8.	$P_1 \times P_9$	72.92	100.11	39.34 **	62.11	129.09	82.33 **	72.90	83.17 **	24.33 *
9.	$P_2 \times P_3$	70.53	114.06	34.78 **	30.52	33.61	-10.42	68.37	67.02 **	16.60
10	$P_2 \times P_4$	68.06	80.52 **	30.04 **	65.24	100.75	91.52 **	84.80	160.92	44.63 **
11	$P_2 \times P_5$	56.66	34.90 **	8.26	73.24	220.68	115.00	55.20	44.88 *	-5.86
12	$P_2 \times P_6$	76.76	99.35 **	46.68 **	90.76	166.41	166.41	80.97	168.69	38.09 **
13	$P_2 \times P_7$	69.92	110.92	33.61 **	99.39	335.17	191.76	73.87	150.11	25.98 *
14	$P_2 \times P_8$	104.52	99.71 **	99.71 **	107.22	369.45	214.75	90.80	54.86 **	54.86 **
15	$P_2 \times P_9$	124.62	241.98	138.12	74.33	225.45	118.20	146.70	348.62	150.20
16	$P_3 \times P_4$	64.04	69.86 **	22.36 *	51.32	57.90 **	50.64 **	65.93	61.07 **	12.45
17	$P_3 \times P_5$	58.59	39.51 **	11.96	72.61	234.11	113.15	65.10	59.04 **	11.03
18	$P_3 \times P_6$	61.00	58.41 **	16.56	47.93	40.69 **	40.69 **	63.33	54.72 **	8.02
19	$P_3 \times P_7$	85.26	157.19	62.92 **	69.24	218.57	103.24	82.13	100.65	40.08 **
20	$P_3 \times P_8$	108.00	106.37	106.37	90.25	299.93	164.92	103.73	76.92 **	76.92 **
21	$P_3 \times P_9$	72.65	99.36 **	38.82 **	58.89	170.97	72.87 **	69.80	70.52 **	19.04
22	$P_4 \times P_5$	71.03	69.13 **	35.73 **	66.47	104.53	95.13 **	65.97	73.14 **	12.51
23	$P_4 \times P_6$	62.79	63.06 **	19.98	78.49	130.40	130.40	66.33	104.10	13.13
24	$P_4 \times P_7$	73.20	94.16 **	39.87 **	56.39	73.52 **	65.54 **	76.27	134.67	30.07 *
25	$P_4 \times P_8$	89.37	70.76 **	70.76 **	86.90	167.39	155.10	80.73	37.69 **	37.69 **
26	$P_4 \times P_9$	110.80	193.90	111.72	53.10	63.37 **	55.86 **	104.17	218.55	77.66 **
27	$P_5 \times P_6$	63.67	51.59 **	21.66 *	40.68	19.42	19.42	52.80	38.58 *	-9.95
28	$P_5 \times P_7$	80.00	90.48 **	52.87 **	33.80	56.14 **	-0.78	54.27	42.43 *	-7.45
29	$P_5 \times P_8$	92.21	76.19 **	76.19 **	64.57	186.12	89.53 **	97.60	66.46 **	66.46 **
30	$P_5 \times P_9$	47.86	13.96	-8.54	55.33	155.62	62.43 **	61.20	60.63 **	4.38
31	$P_6 \times P_7$	87.94	128.38	68.04 **	51.95	52.50 **	52.50 **	97.90	224.89	66.97 **
32	$P_6 \times P_8$	141.15	169.72	169.72	74.43	118.47	118.47	147.33	151.28	151.28
33	$P_6 \times P_9$	81.81	112.45	56.32 **	60.53	77.69 **	77.69 **	67.83	107.44	15.69
34	$P_7 \times P_8$	101.72	94.36 **	94.36 **	85.83	280.35	151.96	91.73	56.45 **	56.45 **
35	$P_7 \times P_9$	85.79	135.42	63.92 **	72.71	264.46	113.43	86.80	165.44	48.04 **
36	$P_8 \times P_9$	105.07	100.78	100.78	113.22	401.73	232.36	117.87	101.02	101.02

Table 3: Estimation of heterobeltiosis (%) and standard heterosis (%) for popping quality traits.

Sr. No.	Trait Crosses	Popping expansion volumes								
		rabi, 2017-18			*kharif*-2018			*rabi*, 2018-19		
		MEAN	BP	SH1	MEAN	BP	SH1	MEAN	BP	SH1
1.	$P_1 \times P_2$	14.96	38.46 **	25.85 **	14.15	24.05 **	-4.88	15.30	47.12 **	19.22 **
2.	$P_1 \times P_3$	13.77	15.78 **	15.78 **	13.79	37.99 **	-7.30	12.70	-1.04	-1.04
3.	$P_1 \times P_4$	13.09	47.08 **	10.09	13.82	38.26 **	-7.13	15.20	56.70 **	18.44 **
4.	$P_1 \times P_5$	11.52	22.34 **	-3.11	14.83	48.43 **	-0.29	10.93	11.95	-14.81 **
5.	$P_1 \times P_6$	14.55	46.90 **	22.40 **	9.96	-33.07 **	-33.07 **	15.40	56.08 **	20.00 **
6.	$P_1 \times P_7$	10.94	16.54 *	-7.96	9.70	-2.94	-34.80 **	8.90	-5.65	-30.65 **
7.	$P_1 \times P_8$	8.93	-14.38 *	-24.87 **	10.98	-12.27 **	-26.17 **	9.43	-16.52 **	-26.49 **
8.	$P_1 \times P_9$	11.27	-3.43	-5.24	13.88	38.89 **	-6.70	11.37	-4.48	-11.43 *
9.	$P_2 \times P_3$	13.23	11.30 *	11.30 *	13.45	17.94 **	-9.57 *	14.17	10.39 *	10.39 *
10.	$P_2 \times P_4$	10.89	0.77	-8.41	9.24	-18.97 **	-37.87 **	9.53	-8.33	-25.71 **
11.	$P_2 \times P_5$	12.04	11.38	1.23	12.56	10.08	-15.59 **	11.30	8.65	-11.95 *
12.	$P_2 \times P_6$	13.35	23.53 **	12.28 *	14.01	-5.83	-5.83	14.03	34.94 **	9.35
13.	$P_2 \times P_7$	14.90	37.88 **	25.32 **	8.82	-22.65 **	-40.69 **	15.40	48.08 **	20.00 **
14.	$P_2 \times P_8$	6.91	-36.03 **	-41.86 **	12.24	-2.24	-17.72 **	11.93	5.60	-7.01
15.	$P_2 \times P_9$	14.65	25.57 **	23.21 **	10.63	-6.84	-28.57 **	13.23	11.20 *	3.12
16.	$P_3 \times P_4$	9.45	-20.55 **	-20.55 **	10.62	25.32 **	-28.59 **	10.60	-17.40 **	-17.40 **
17.	$P_3 \times P_5$	10.16	-14.58 **	-14.58 **	12.90	49.25 **	-13.29 **	10.60	-17.40 **	-17.40 **
18.	$P_3 \times P_6$	11.83	-0.48	-0.48	11.78	-20.82 **	-20.82 **	13.27	3.38	3.38
19.	$P_3 \times P_7$	15.77	32.60 **	32.60 **	12.34	57.49 **	-17.07 **	14.93	16.36 **	16.36 **
20.	$P_3 \times P_8$	13.33	12.14 *	12.14 *	11.49	-8.20	-22.74 **	12.03	-6.23	-6.23
21.	$P_3 \times P_9$	11.28	-5.16	-5.16	12.98	33.78 **	-12.77 **	11.50	-10.39 *	-10.39 *
22.	$P_4 \times P_5$	12.28	30.41 **	3.28	14.31	65.52 **	-3.83	8.07	-17.41 **	-37.14 **
23.	$P_4 \times P_6$	11.44	15.44 *	-3.81	10.69	-28.12 **	-28.12 **	11.23	13.85 *	-12.47 *
24.	$P_4 \times P_7$	13.59	44.76 **	14.33 **	10.73	26.62 **	-27.85 **	14.87	53.26 **	15.84 **
25.	$P_4 \times P_8$	10.62	1.76	-10.71	14.34	14.54 **	-3.61	10.37	-8.26	-19.22 **
26.	$P_4 \times P_9$	11.34	-2.83	-4.65	12.25	26.25 **	-17.68 **	11.40	-4.20	-11.17 *
27.	$P_5 \times P_6$	13.97	41.02 **	17.49 **	11.87	-20.21 **	-20.21 **	13.37	35.47 **	4.16
28.	$P_5 \times P_7$	9.54	1.31	-19.76 **	11.57	33.90 **	-22.20 **	8.80	-9.90	-31.43 **
29.	$P_5 \times P_8$	14.20	36.13 **	19.46 **	9.36	-25.21 **	-37.06 **	14.20	25.66 **	10.65 *
30.	$P_5 \times P_9$	14.42	23.57 **	21.25 **	10.16	4.78	-31.68 **	15.83	33.05 **	23.38 **
31.	$P_6 \times P_7$	13.17	32.97 **	10.79	16.29	9.48 *	9.48 *	11.70	18.58 **	-8.83
32.	$P_6 \times P_8$	11.99	14.92 *	0.84	16.93	13.82 **	13.82 **	12.77	12.98 *	-0.52
33.	$P_6 \times P_9$	12.07	3.43	1.49	12.30	-17.30 **	-17.30 **	11.73	-1.40	-8.57
34.	$P_7 \times P_8$	8.87	-14.98 *	-25.40 **	11.16	-10.86 *	-24.98 **	8.93	-20.94 **	-30.39 **
35.	$P_7 \times P_9$	13.41	14.94 **	12.78 *	12.43	28.11 **	-16.47 **	9.70	-18.49 **	-24.42 **
36.	$P_8 \times P_9$	10.70	-8.29	-10.01	11.72	-6.39	-21.22 **	9.50	-20.17 **	-25.97 **

CONCLUSIONS

The WINPOP-3×HKIPC-7 cross can be used in developing early maturing lines as this corss combination showed heterbleitosis and standard heterossis for days to 75% maturity, days to 50% anthesis, and days to 50% silking.

FUTURE SCOPE

These WINPOP-8×HKIPC-7and WINPOP-8×HKIPC-5 heterotic combination use forexploitation of high-yielding superior lines with good popping quality

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