Journal of Agroecology and Natural Resource Management
p-ISSN: 2394-0786, e-ISSN: 2394-0794, Volume 9, Issue 1; January-March, 2022, pg 1-8

http://www.krishisanskriti.org/Publication.html

Estimation of Heterosis in Single Cross Hybrids of Maize (*Zea mays* L.) for Higher Yield in Response to Optimum and High Plant Density

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Abstract: Maize (Zea mays L.) is the third most important cereal crop worldwide consumed equally as human food and animal feed. Its higher productivity is achieved through the development of single cross hybrid by exploiting its hybrid vigour over a double, three-way cross hybrid to meet higher production status. Due to the lack of tillering ability in maize, its production depends on planting density whereas selection of proper plant density is important for achieving higher production. In the present study, field experiments were conducted to estimate heterosis for yield and yield associated traits across optimum and high plant density. For this 8 inbred and 3 testers of diverse genetic backgrounds were used to develop 24 single cross hybrids in randomized block design using line x tester mating design. Hybrids were evaluated along with two checks PSM1 and Rashi 4214 for 12 characters during the Kharif season to identify the best heterotic combination over the parents and checks. Resulted hybrids appear to be promising genotypes to be used for future testing and contributing to improving the maize breeding programme.

Keywords: Maize, Hybrids, Heterosis, Grain Yield, Inbreds, Heterobeltiosis

1. INTRODUCTION

Maize (Zea mays L.) occupies a high status in the agriculture and is widely used for food as well as for non-food products worldwide (Lone et al., 2016). It is the third most consumed cereal crop after rice and wheat (Devi *et al*., 2016). It is used as a staple food in several parts of the world due to its high nutritive value therefore it makes maize more demanding globally not only as a food and feed source (Tanumihardjo *et al*., 2019) but also as a raw material. Thus, it is helping to achieve food security and the economic development of a country (Prasanna *et al.,* 2020). Besides that, maize kernel is rich in several nutrients like vitamins, protein (especially zein), starch and fibre. The oil extracted from maize has a high calorific value. Also, it contains high oleic and linoleic acid content and low cholesterol content which makes maize suitable for cardiovascular patients (Bisen *et al*., 2017).

Further, the concentration of nutrients present in maize is also influenced by the genotypes of the parents as well as interaction of genotype with the environment (Ekpa *et al.,* 2019). The presence of higher genetic variability in maize germplasm allows the possibility of the development of superior cultivar both in yield, quality and adaptability. The reason for the low productivity of maize in our country is improper genotype selection and plant density (Jogdand *et al*., 2008, Singh, 2010, Bisht *et al*., 2012). Plant density is associated with determining yield contributing traits in maize. It has been reported that under an appropriate environment selection of optimum plant population helps in increasing grain yield as it is able to utilize the available resources while low plant density increases weed population (Khan, 1972). Additionally, hybrids are preferred for higher yield over varieties in maize.

Especially, development of single cross hybrid over the double-cross and three-way cross hybrids is preferred for higher yield due to their hybrid vigour. The exploitation of hybrid vigour in maize depends not only on magnitude but also on the direction of heterosis (Reddy *et al.,* 2015). By the end of 2050 it is estimated that 90% of the total land area would be occupied by hybrids which would accelerate maize production (Kumar *et al.,*2015). The successful maize breeding programme depends on nature of the gene involved in the quantitative expression of economically important traits and its strength depends on the broad genetic base of the population (Ciampitti and Vyn, 2012, Rajendran *et al.,* 2014). For exploiting heterosis selection of parents with good combining ability is important for the development of superior hybrids (Singh et al., 2012) and grain yield is the primary target for maize genetic improvement (Ulaganathan *et al.*, 2015). Therefore, breeding strategies for maize improvement primarily depend on the identification and selection of vigorous, diverse inbred lines with the good combining ability for hybrid development. In the view of above facts, the present study was undertaken to develop and identify superior single cross hybrid for grain yield and associated traits in response to optimum and high plant population density.

2. MATERIALS AND METHODS

The study was undertaken with 24 single cross hybrid produced by using line × tester mating design that involved 8 inbred lines and 3 testers of diverse origin (Table 1). The experiment was conducted at N.E. B. Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand during the Kharif season. These hybrids were evaluated with two check varieties PSM1 and Rashi 4214 in randomized block design with three replications in one-row plots of 4 m in length and 75 cm apart across optimum plant densities (53,333 plants/ha) and high planting densities (88,866.7 plants/ha).

3. DATA COLLECTION AND ANALYSIS

Five competitive plants were selected randomly to record data on the following yield associated parameters: plant height, ear height, ear length, ear diameter, no. of grain rows ear-1, no of kernels/ row, 100-grain weight, grain yield plant-1, days to 50 % silking, days to 50 % taselling, number of nodes at first ear emerged, anthesis-silking interval were recorded and subjected to statistical analysis.

4. STATISTICAL ANALYSIS

Analysis of variance of the recorded data across different plant densities was calculated using the statistical method given by Fischer (1946). Heterosis which is expressed as per cent increase or decrease in the performance of F1 hybrid over the mid-parent (average or relative) heterosis, better parent (heterobeltiosis) and check parent (standard heterosis) for each character was calculated as per procedure given by (Turner, 1953 and Hayes et al., 1955).

$$\text{Relative heterosis} = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Standard heterosis} = \frac{\overline{F}_1 - \overline{CP}}{\overline{CP}} \times 100$$

$\overline{F}_1$ = Mean performance of F_1 hybrid

$\overline{P}_1$ = Mean performance of parent one

$\overline{P}_2$ = Mean performance of parent two

$\overline{BP}$ = Mean performance of better parent

5. RESULT AND DISCUSSION

Table 2, indicated range of per cent relative heterosis from -24.14 to 9.80, -4.42 to 6.13 and -12.07 to 2.63 in E1, E2 and across environments, respectively. Twenty-two hybrids showed significant negative heterosis for early tasselling in E1, the hybrids that showed maximum negative heterosis was L4×T1 (-24.14). While in E2 crosses L8×T1(-4.42), L3×T3 (-4.14) and L8×T2 (-3.81) showed maximum negative heterosis. Similarly, in pooled analysis, maximum significant negative heterotic hybrids were L1×T1(-11.37), L7×T1 (-11.34), L3×T1 (-10.72). The estimates of per cent heterobeltiosis ranged from -26.67 to 1.82, -6.90 to 5.49 and -14.53 to -0.30 in E1, E2 and across environments, respectively. In case of heterobeltiosis, hybrids L4×T1 (-26.67), L7×T1 (-26.67) and L6×T1 (-25.00) showed maximum negative heterosis and cross L7×T3(-17.28) showed maximum negative in E2. Significantly maximum negative heterobeltiosis was shown by the crosses L4×T1 (-14.53), L7×T1 (-14.25), and L1×T1(-13.39) in the pooled environment.

The estimate of per cent heterosis over check parent (PSM1) ranged from -8.33 to 16.67, -1.82 to 5.45 and -3.56 to 7.44 in E1, E2 and pooled environments respectively. Among hybrids thirteen crosses in E1, exhibited significant negative heterosis, some of the crosses were L1×T2(-8.33), L4×T1 (-8.33), L7×T1 (-8.33), and L6×T3 (-1.82), L3×T3 (-1.82), L8×T1(-1.82) showed maximum significant negative heterosis in E2, and crosses L1×T1(-1.62), L1×T2(-2.27), L1×T3 (-3.56), L4×T1(-2.91), L7×T1 (-2.59), L7×T3 (-2.27) show negative significant heterosis in pooled environment over check parent (PSM1).

Table 3 The range of estimates for heterobeltiosis varied from -27.18 to 3.45, -4.92 to 6.78 and -13.44 to – 2.48 in E1, E2 and pooled environments, respectively. The hybrids L7 × T1 (-27.18), L4 × T1 (-23.08), L6 × T1 (-23.08), L1 × T1 (-21.54), L2 × T1(-21.54), L4 × T2 (-21.31), L3 × T1 (-21.03) in E1 and L7 × T3 (-4.92), L1 × T1 (-4.84) and L2 × T2 (-4.76) in E2 environment showed maximum significant negative heterosis over better parent for days to 50 per cent silking. In the pooled analysis, cross L7 × T1 (-13.44) observed maximum significant negative better parent heterosis for early 50 per cent silking.

The estimate of per cent heterobeltiosis ranged from -26.67 to 1.82, -6.90 to 5.49 and -14.53 to -0.30 in E1, E2 and across environments, respectively. In the case of heterobeltiosis, hybrids L7×T1 (-26.67), L4×T1 (-26.67), L6×T1 (-25.00), L3×T1 (-25.00), L1×T1(-23.33),L2×T1 (-23.33) were tested maximum significant negative heterosis in E1 and crossL7×T3(-17.28)showed maximum negative heterosis in E2 . Significantly maximum negative heterobeltiosis was shown by the crosses L4×T1 (-14.53) andL7×T1 (-14.25**).

The estimate of per cent heterosis over check parent(PSM1) ranged from -10.69 to13.21, -3.34 to 4.99 and -5.02 to 7.08 in E1, E2 and pooled environments respectively. Among hybrids crosses L7×T1 (-10.69), L4×T2 (-9.43) and L1×T2(-7.55) display maximum significant negative heterosis in E1, while crosses L3×T3(-3.34), L3×T3(-3.34), L6×T2(-3.34), and

L7×T3(-3.33) in E2 and L7×T3 (-4.42) show negative and maximum significant heterosis in the pooled environment over check parent (PSM1).

Table 4, revealed the range of estimates for relative heterosis is varied from -25.43 to 33.68, -21.81 to 26.69 and -12.38 to 28.43 in E1, E2 and across environments, respectively. Hybrids with the maximum heterotic expression were L4 × T2 (33.68) and L6 × T2 (21.85) in E1 environment. Whereas, L4 × T3 (26.69) and L4 × T2 (22.50) exhibited maximum positive and significant relative heterosis in E2 environments. Similarly, in the pooled analysis, hybrids with maximum significantly heterotic expression were L4 × T2 (28.43).

The range of heterobeltiosis in E1 andE2 and across environments was -26.88 to30.19, -22.39 to 10.50 and -13.91to18.68 respectively. Hybrids with significant heterotic expression were L4 × T2 (30.19) exhibited positive and significant relative heterosis in E1, hybrids L1 × T1 (2.22), L3 × T2 (5.96), L3× T3 (5.96), L4× T2(1.62), L4× T3(3.14), L5× T1(1.48), L5× T2(10.50), L7× T2(5.49), L8× T2(8.21) and L8 × T3 (7.83) in E2 and L4 × T2 (18.68), L5 × T2 (7.22), L7× T2(8.77), L8 × T2 (7.61) and L8 × T3 (12.01) in the pooled environment.

The estimate of per cent heterosis over check parent (PSM1) ranged from -35.83 to 9.97, -17.48 to 12.67 and -18.80 to 5.67 in E1, E2 and pooled environments respectively. Significant positive heterotic hybrids over check parent (PSM1) were L1×T1(9.52), L3×T2 (12.67), L3×T3(12.67), L4×T3(4.76), L5×T1(7.90), L5×T2(8.71), L7×T1(2.38), L7×T2(7.14), L7×T3(2.38), L8×T1(4.76), L8×T2(4.76) andL8×T3(9.52) in E2 environment over check parent (PSM1). No positive significant difference was found among hybrids in E1 and pooled environments.

Table 5 indicated the range of relative heterosis in E1, E2 and across environments was -4.96 to 41.80, -4.98 to 28.78 and -1.14 to 23.57, respectively. Hybrids with the maximum significant heterotic expression were L5 × T2 (41.80) in E, and L2 × T3 (28.78) in E2. Hybrids, L5 × T2 (23.57) and L3 × T2 (20.90), in the pooled environment.

The range of estimates for heterobeltiosis varied from -4.80 to 39.58, -11.02 to 17.86 and -5.24 to 22.06 in E1, E2 and across environments, respectively. Hybrids with the maximum heterotic expression were L5 × T2 (39.58) andL3 × T2 (21.78) in E1, L2 × T3 (17.86), L3 × T2 (16.50) and L7 × T3(15.18) in E2, L5 × T2 (22.66) and L3× T2 (19.70) in pooled environment showed positive significant heterosis over the better parent. The estimate of per cent heterosis over check parent (PSM1) ranged from -23.53 to -1.47, -27.74 -3.65 and -21.98 to -8.79 in E1, E2 and pooled environments respectively. None of the hybrids exhibited positive significant heterosis over the checks in the given environments.

Table 6, indicate the range of relative heterosis in E1, E2 and across environments was -37.98 to134.32, -38.93 to 139.25 and -25.30 to 93.03, respectively. Hybrids with the significant and maximum heterotic expression was L3 × T2 (134.32) in E1. Whereas, L8 × T1 (139.25) in E2 and L1 × T2 (42.85) in pooled environment showed maximum significant positive heterosis.

The range of heterobeltiosis in E1, E2 and across environments was -55.55 to 132.49, -31.21 to 132.26 and -39.28 to79.89, respectively. Hybrid with the maximum significant heterotic expression was L3 × T2 (132.49) in E1, L8 × T1(132.26) in E2. Similarly, in pooled analysis, hybrids with maximum significant heterosis was L5 × T1 (79.89).

The range of per cent standard heterosis for grain yield E1, E2 and across environments was -54.48 to 35.12, -68.99 to -20.43 and -50.03 to 2.23 for PSM1, respectively. Hybrids with significant heterosis were L3 × T2 (9.65), L4 × T3(6.25), L5× T1 (9.39), L5 × T3 (25.37), L6 × T2 (35.12) and L7 × T1 (7.56) in E1, and L6 × T2 (2.23) in the pooled environment, respectively. No positive significant heterosis was exhibited by hybrids in E2 environments.

6. CONCLUSION

In the present study, significant heterosis for grain yield at all plant density were observed. Under optimum plant density (E1) parents L5, L6, T2 and T3 and parents L4, L7, L8, T1 and T3 in high plant population density (E2) and under pooled environment parents L5, L6, L8, T1, T2 and T3 were selected as good combiners for yield and associated characters. Based on per performance, specific combining ability of hybrids and heterosis crosses combination L6 × T2 and L5 × T3 in optimum plant population (E1) were selected as superior hybrids for yield. It may be concluded that for these hybrids optimal plant population density (53,333 plants/ha) has allowed them to intercept and use available resources more efficiently which contributed in remarkable increase of their grain yield, while, cross L7 × T3, L4 × T3 and L8 × T1 in high plant population (E2) were selected as superior hybrids. Results show that these hybrids may require a greater number of plants per area to generate the leaf area index that provides maximum interception of solar radiation, an essential step to maximize grain yield, while, L6 × T2, L5 × T3 and L8 × T1 in the pooled environment were selected as superior hybrids. Hence, these hybrids appear to be promising genotypes to be used for future testing and contributing to improve the maize breeding programmes.

7. STATEMENTS & DECLARATIONS

- **Ethical Approval:** This research work did not involve the use of animal or humans therefore ethical approval is not required
- **Consent to Participate**: Not required
- **Consent to Publish**: Not required
- **Authors Contributions**: "All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Himanki Dabral], [Ramesh Kumar Singh] and [Dinesh Chandra

Baskheti]. The first draft of the manuscript was written by [Himanki Dabral] and [Anu Singh], and all authors commented on previous versions of the manuscript, later the final edited draft was prepared by [Anu Singh] and [Rajeev Singh]. All authors read and approved the final manuscript."

- **Funding**: HD acknowledges Govind Ballabh Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India, for providing 'University Ph.D. Fellowship'. AS acknowledges the funding received from Union Grant Commission of India ie. UGC (F.15-1/2016-17/PDFWM-2015-17-UTT-33566(SA-II)).

- **Competing Interests:** "The authors have no relevant financial or non-financial interests to disclose."
- **Availability of data and materials**: All the required details are incorporated in the Manuscript.

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TABLE 1. Maize genotypes used in the development of single cross hybrids.

S.No.	Genotypes	Pedigree
1	L1	Tarun ⊗ 83-1-3-2-3-2-1
2	L2	Pob 445⊗ -74-2-2-BBB
3	L3	Pop 45- C_8 -72-2-1-1-2⊗
4	L4	Pob 31 ⊗ 23-1-1-1-1-2-1/2 # ⊗ 2-2 to6 ⊗
5	L5	YHP B⊗ 45-1-2-3-1-6-2-4 ⊗ 4
6	L6	POB 31⊗ 18-2-1-1-1-1-3-1 to 6 # 1-1 to 5
7	L7	POB 445⊗-58-6-3-BBB
8	L8	POB 446⊗-74-2-2-BBB C_8
9	T1	DBR N 21
10	T2	Tarun ⊗ 6-5-3-1-2-1-1-1
11	T3	V 116-1

Table 2. Estimation of heterosis (%) over MP, BP and SC in E1, E2 and pooled environments for days to 50% tasselling in maize

So. No	Cross	Days to 50% Taselling								
		Optimum plant population density (E1)			High plant population density (E2)			Pooled (P)		
		MP	BP	SC(PSM1)	MP	BP	SC(PSM1)	MP	BP	SC(PSM1)
1	$L_1×T_1$	-20.00**	-23.33**	-4.17**	-2.64**	-2.92**	0.61	-11.37**	-13.39**	-1.62*
2	$L_1×T_2$	-13.73**	-20.00**	-8.33**	-0.87	-1.73*	3.03**	-6.93**	-9.85**	-2.27**
3	$L_1×T_3$	-10.89**	-18.18**	-6.25**	-2.40**	-4.12**	-1.21	-6.44**	-11.04**	-3.56**
4	$L_2×T_1$	-22.03**	-23.33**	-4.17**	-1.75*	-1.75*	1.82*	-12.07**	-12.82**	-0.97
5	$L_2×T_2$	-10.48**	-18.97**	-2.08**	-2.33**	-2.89**	1.82*	-6.22**	-10.43**	0.00
6	$L_2×T_3$	-7.69**	-17.24**	0.00	-0.30	-2.34**	1.21	-3.86**	-9.86**	0.65
7	$L_3×T_1$	-21.74**	-25.00**	-6.25**	0.29	-0.57	4.85**	-10.72**	-12.25**	-0.32
8	$L_3×T_2$	-9.80**	-16.36**	-4.17**	-2.02**	-2.30**	3.03**	-5.67**	-9.14**	-0.32
9	$L_3×T_3$	-4.95**	-12.73**	0.00	-4.14**	-6.90**	-1.82*	-4.52**	-9.73**	-0.97
10	$L_4×T_1$	-24.14**	-26.67**	-8.33**	0.90	-1.75*	1.82*	-11.89**	-14.53**	-2.91**
11	$L_4×T_2$	-12.62**	-19.64**	-6.25**	2.09**	-1.16	3.64**	-4.97**	-7.27**	-0.97
12	$L_4×T_3$	-11.76**	-19.64**	-6.25**	6.13**	5.49**	4.85**	-2.53**	-6.67**	-0.32
13	$L_5×T_1$	-19.77**	-21.11**	-1.39	2.70**	0.00	3.64**	-8.88**	-10.83**	1.29
14	$L_5×T_2$	-6.67**	-15.52**	2.08*	3.88**	0.58	5.45**	-1.23*	-4.46**	3.88**
15	$L_5×T_3$	-10.90**	-20.11**	-3.47**	4.91**	4.27**	3.64**	-2.82**	-7.74**	0.32
16	$L_6×T_1$	-21.74**	-25.00**	-6.25**	3.64**	0.00	3.64**	-9.33**	-12.82**	-0.97
17	$L_6×T_2$	-9.80**	-16.36**	-4.17**	4.22**	0.00	4.85**	-2.51**	-4.01**	0.65
18	$L_6×T_3$	-4.95**	-12.73**	0.00	0.31	-1.22	-1.82*	-2.24**	-5.56**	-0.97
19	$L_7×T_1$	-22.81**	-26.67**	-8.33**	0.30	-1.17	2.42**	-11.34**	-14.25**	-2.59**
20	$L_7×T_2$	-6.93**	-12.96**	-2.08*	-2.65**	-4.62**	0.00	-4.67**	-6.71**	-0.97
21	$L_7×T_3$	-10.67**	-17.28**	-6.94**	1.82*	1.20	1.82*	-4.13**	-7.93**	-2.27**
22	$L_8×T_1$	-13.04**	-16.67**	4.17**	-4.42**	-5.26**	-1.82*	-8.77**	-11.11**	0.97
23	$L_8×T_2$	9.80**	1.82**	16.67**	-3.81**	-5.20**	-0.61	2.63**	-0.30	7.44**
24	$L_8×T_3$	-0.99	-9.09**	4.17**	0.60	-0.60	1.21	-0.16	-4.80**	2.59**

*,** Significant at 5% and 1% probability levels, respectively MP- mid parent, BP-better parent and SC- Standard check hybrid heterosis .E1- Optimum plant population density, E2- High plant population density, P- Pooled environment

TABLE 3. Estimation of heterosis (%) over-MP, BP and SC in E1, E2 and pooled environments for days to 50% silking in maize.

S.No	Cross	Days to 50% Silking								
		Optimum plant population density (E1)			High plant population density (E2)			Pooled (P)		
		MP	BP	(SC) PSM1	MP	BP	SC (PSM1)	MP	BP	SC (PSM1)
1.	$L_1×T_1$	-17.07**	-21.54**	-3.77**	-2.48**	-4.84**	-1.67	-9.84**	-11.29**	-2.66**
2.	$L_1×T_2$	-13.27**	-15.52**	-7.55**	0.00	-1.61	1.66	-6.38**	-8.33**	-2.66**
3.	$L_1×T_3$	11.11**	3.45**	13.21**	-1.64	-3.23**	-0.01	4.34**	0.00	6.19**
4.	$L_2×T_1$	-20.31**	-21.54**	-3.77**	0.00	-3.17**	1.66	-10.40**	-11.11**	-0.89
5.	$L_2×T_2$	-13.56**	-19.05**	-3.77**	-2.44**	-4.76**	-0.01	-7.88**	-11.90**	-1.77*
6.	$L_2×T_3$	-7.96**	-17.46**	-1.89	-0.81	-3.17**	1.66	-4.24**	-10.32**	0.00
7.	$L_3×T_1$	-17.87**	-21.03**	-3.14**	6.78**	6.77**	4.99**	-5.90**	-7.80**	1.17

8.	L_3×T_2	-11.30**	-15.00**	-3.77**	5.89**	5.00**	4.99**	-2.56**	-4.20**	0.88
9.	L_3×T_3	-3.64**	-11.67**	0.00	-2.52**	-3.33**	-3.34**	-3.06**	-6.72**	-1.77*
10.	L_4×T_1	-20.63**	-23.08**	-5.66**	2.56**	1.69	-0.01	-9.47**	-11.29**	-2.66**
11.	L_4×T_2	-17.24**	-21.31**	-9.43**	5.08**	3.33**	3.33**	-5.98**	-7.57**	-2.66**
12.	L_4×T_3	-6.91**	-15.30**	-2.52*	5.08**	3.33**	3.33**	-0.73	-4.48**	0.59
13.	L_5×T_1	-17.83**	-18.46**	0.00	7.69**	6.78**	4.99**	-5.69**	-6.45**	2.65**
14.	L_5×T_2	-9.24**	-15.63**	1.89	3.38**	1.66	1.66	-2.96**	-5.74**	1.76*
15.	L_5×T_3	-8.77**	-18.75**	-1.89	5.08**	3.33**	3.33**	-1.72**	-6.56**	0.88
16.	L_6×T_1	-20.00**	-23.08**	-5.66**	4.21**	3.34**	3.33**	-8.19**	-9.67**	-0.88
17.	L_6×T_2	-11.30**	-15.00**	-3.77**	-3.33**	-3.33**	-3.34**	-7.23**	-9.17**	-3.54**
18.	L_6×T_3	-3.64**	-11.67**	0.00	3.33**	3.33**	3.32**	0.00	-4.17**	1.76*
19.	L_7×T_1	-23.66**	-27.18**	-10.69**	0.00	-1.64	-0.01	-12.02**	-13.44**	-5.02**
20.	L_7×T_2	-8.77**	-11.86**	-1.89	0.82	-0.01	1.66	-3.83**	-5.84**	0.00
21.	L_7×T_3	-8.26**	-15.25**	-5.66**	-4.13**	-4.92**	-3.33**	-6.09**	-10.00**	-4.42**
22.	L_8×T_1	-12.00**	-15.38**	3.77**	1.67	0.00	1.66	-5.31**	-6.45**	2.65**
23.	L_8×T_2	4.35**	0.00	13.21**	0.83	0.00	1.66	2.54**	0.00	7.08**
24.	L_8×T_3	1.82*	-6.67**	5.66**	2.48**	1.64	3.33**	2.16**	-2.48**	4.42**

*,** Significant at 5% and 1% probability levels, respectively MP- mid parent, BP-better parent and SP- Standard check hybrid heterosisE1- Optimum plant population density, E2- High plant population density, P- Pooled environment

TABLE 4. Estimation of heterosis (%) over MP, BP and SC in E1, E2 and pooled environments for plant height in maize.

S.No	Cross	Plant height(cm)							
		Optimum plant population density (E1)			High plant population density (E2)			Pooled (P)	
		MP	BP	SC (PSM1)	MP	BP	SC (PSM1)	MP	BP
1.	L_1×T_1	9.32	8.15	-3.21	2.61**	2.22*	9.52**	5.81	5.06
2.	L_1×T_2	15.34*	9.26	-2.21	-5.86**	-10.40**	-4.00**	4.29	-0.97
3.	L_1×T_3	-1.03	-1.99	-12.28	-5.73**	-8.18**	-1.62	-3.45	-5.21
4.	L_2×T_1	4.12	-0.49	-12.84*	-21.81**	-22.39**	-17.48**	-9.71**	-11.96**
5.	L_2×T_2	13.82*	13.65	-9.02	-3.14**	-6.82**	-2.38*	4.77	2.68
6.	L_2×T_3	6.40	1.59	-10.84	-9.99**	-11.36**	-7.14**	-2.24	-3.62
7.	L_3×T_1	4.14	3.50	-8.21	-7.48**	-7.48**	-1.62	-1.93	-2.22
8.	L_3×T_2	7.62	2.38	-9.20	10.92**	5.96**	12.67**	9.34**	4.24
9.	L_3×T_3	6.28	5.72	-6.24	8.38**	5.96**	12.67**	7.36*	5.85
10.	L_4×T_1	8.65	6.72	-6.53	9.15**	-12.67**	-7.14**	8.89*	-3.44
11.	L_4×T_2	33.68**	30.1 9**	9.97	22.50**	1.62	-1.62	28.43**	18.68**
12.	L_4×T_3	9.09	7.05	-6.05	26.69**	3.14**	4.76**	17.28**	5.05
13.	L_5×T_1	-2.59	-5.66	-11.81	5.42**	1.48	7.90**	1.46	1.10
14.	L_5×T_2	12.15	4.09	-2.69	11.39**	10.50**	8.71**	11.77**	7.22*
15.	L_5×T_3	6.27	3.02	-3.70	-7.12	-8.58**	-7.14**	-0.42	-1.20
16.	L_6×T_1	10.94	8.90	-4.62	-10.07**	-13.43**	-7.95**	0.04	-2.80
17.	L_6×T_2	21.85**	18.74*	0.17	-0.81	-1.60	-3.19**	10.11**	8.29*
18.	L_6×T_3	-25.43**	-26.88**	-35.83**	0.02	-1.55	0.00	-12.38**	-13.91**

19.	$L_7 \times T_1$	7.87	2.40	-10.31	-1.51	-3.72**	2.38*	2.89	-0.81
20.	$L_7 \times T_2$	11.65	10.71	-11.38	8.02**	5.49**	7.14**	9.72**	8.77*
21.	$L_7 \times T_3$	-6.45	-11.28	-22.13**	0.80	0.80	2.38*	-2.64	-5.10
22.	$L_8 \times T_1$	7.55	6.54	-4.90	5.62**	-1.48	4.76**	6.57*	3.31
23.	$L_8 \times T_2$	7.36	1.82	-9.12	10.94**	8.21**	4.76**	9.16**	7.61*
24.	$L_8 \times T_3$	15.40	14.44*	2.14	13.13**	7.83**	9.52**	14.27**	12.01**

*,** Significant at 5% and 1% probability levels, respectively. MP- mid parent, BP-better parent and SC- Standard check hybrid heterosis E1- Optimum plant population density, E2- High plant population density, P- Pooled environment.

TABLE 5. Estimation of heterosis (%) MP, BP and SC in E1, E2 and pooled environments for ear diameter in maize

S.No	Cross	Ear diameter(cm)								
		Optimum plant population density (E1)			High plant population density (E2)			Pooled (P)		
		MP	BP	SC (PSM1)	MP	BP	SC (PSM1)	MP	BP	SC (PSM1)
1.	$L_1 \times T_1$	9.43	8.41	-14.71*	2.28	-5.08	-18.25**	5.80	2.24	-16.48**
2.	$L_1 \times T_2$	15.42*	10.48	-14.71*	-4.98	-11.02	-23.36**	4.74	-0.90	-19.05**
3.	$L_1 \times T_3$	2.70	-2.56	-16.18**	-2.61	-5.08	-18.25**	0.00	-1.31	-17.22**
4.	$L_2 \times T_1$	0.86	-6.40	-13.97*	13.40*	8.91	-19.71**	6.57	4.13	-16.85**
5.	$L_2 \times T_2$	7.69	-4.80	-12.50*	5.10	0.00	-24.82**	6.47	1.83	-18.68**
6.	$L_2 \times T_3$	-4.96	-8.00	-15.44**	28.78**	17.86**	-3.65	10.51**	7.86	-9.52*
7.	$L_3 \times T_1$	9.62	6.54	-16.18**	-2.46	-2.94	-27.74**	3.65	2.40	-21.98**
8.	$L_3 \times T_2$	24.87**	21.78**	-9.56	17.07**	16.50*	-12.41*	20.90**	19.70**	-10.99**
9.	$L_3 \times T_3$	6.42	-0.85	-14.71*	0.93	-3.57	-21.17**	3.70	-2.18	-17.95**
10.	$L_4 \times T_1$	12.08	8.41	-14.71*	1.42	-2.73	-21.90**	6.70	6.19	-18.32**
11.	$L_4 \times T_2$	19.39**	17.00*	-13.97*	0.47	-2.73	-21.90**	9.54*	6.67	-17.95**
12.	$L_4 \times T_3$	2.30	-5.13	-18.38**	-4.50	-5.36	-22.63**	-1.14	-5.24	-20.51**
13.	$L_5 \times T_1$	11.00	3.74	-18.38**	5.66	0.90	-18.25**	8.25	7.21	-18.32**
14.	$L_5 \times T_2$	41.80**	39.58**	-1.47	7.48	3.60	-16.06**	23.57**	22.06**	-8.79*
15.	$L_5 \times T_3$	21.90**	9.40	-5.88	-3.14	-3.57	-21.17**	9.01*	3.06	-13.55**
16.	$L_6 \times T_1$	-2.80	-2.80	-23.53**	9.17	1.71	-13.14*	3.24	-0.45	-18.32**
17.	$L_6 \times T_2$	13.30*	7.48	-15.44**	0.00	-5.98	-19.71**	6.38	0.45	-17.58**
18.	$L_6 \times T_3$	0.00	-4.27	-17.65**	0.44	-1.71	-16.06**	0.22	-0.87	-16.85**
19.	$L_7 \times T_1$	5.07	3.64	-16.18**	12.62*	10.48	-15.33**	8.75*	6.98	-15.75**
20.	$L_7 \times T_2$	9.71	2.73	-16.91**	6.73	5.71	-18.98**	8.21	4.19	-17.95**
21.	$L_7 \times T_3$	1.32	-1.71	-15.44**	18.89**	15.18*	-5.84	9.91*	6.55	-10.62**
22.	$L_8 \times T_1$	10.38	9.35	-13.97*	5.99	-0.86	-16.06**	8.16*	4.98	-15.02**
23.	$L_8 \times T_2$	13.43*	8.57	-16.18**	3.20	-2.59	-17.52**	8.10	2.71	-16.85**
24.	$L_8 \times T_3$	7.21	1.71	-12.50*	-6.14	-7.76	-21.90**	0.44	-1.31	-17.22**

*,** Significant at 5% and 1% probability levels, respectively.
MP- mid parent, BP-better parent and SC- Standard check hybridheterosis
E1- Optimum plant population density, E2- High plant population density, P- Pooled environment

TABLE 6: Estimation of heterosis (%) MP, BP and SC in E1, E2 and pooled environments for ear diameter in maize

S.No	Cross	Grain weight(q)								
		Optimum plant population density (E1)			High plant population density (E2)			Pooled (P)		
		MP	BP	SC (PSM1)	MP	BP	SC(PSM1)	MP	BP	SC(PSM1)
1.	$L_1 \times T_1$	-12.58**	-28.21**	-50.37**	72.56**	34.84**	-23.65**	31.56**	26.49**	-34.87**
2.	$L_1 \times T_2$	66.52**	62.90**	-24.38**	25.35**	-1.55	-44.26**	42.85**	24.47**	-35.91**
3.	$L_1 \times T_3$	-37.98**	-55.55**	-54.48**	-14.46**	-21.46**	-46.82**	-25.30**	-39.28**	-50.03**
4.	$L_2 \times T_1$	16.91**	11.71**	-15.23**	1.08	-28.50**	-45.06**	8.85**	-11.74**	-32.54**
5.	$L_2 \times T_2$	35.67**	9.33**	-17.03**	2.52**	-27.18**	-44.05**	17.37	-11.96**	-32.70**
6.	$L_2 \times T_3$	-12.63**	-23.95**	-22.12**	-4.69**	-10.34**	-31.11**	-8.44	-11.69**	-27.34**
7.	$L_3 \times T_1$	54.36**	29.83**	-10.24**	-1.94*	-31.21**	-45.60**	22.35	5.44**	-30.75**
8.	$L_3 \times T_2$	134.32**	132.49**	9.65**	37.25**	-3.33**	-23.55**	73.96	37.63**	-9.61**
9.	$L_3 \times T_3$	13.52**	-17.10**	-15.11**	-16.74**	-22.73**	-38.89**	-3.90	-13.59**	-28.90**
10.	$L_4 \times T_1$	5.01**	-4.32**	-19.55**	3.87**	-26.57**	-43.45**	4.44	-16.75**	-33.41**
11.	$L_4 \times T_2$	21.28**	-5.88**	-20.86**	1.49	-27.96**	-44.51**	10.67	-18.21**	-34.58**
12.	$L_4 \times T_3$	13.95**	3.76**	6.25**	7.86**	1.34	-21.95**	10.80	9.25**	-10.11**
13.	$L_5 \times T_1$	93.73**	58.21**	9.39**	79.96**	40.69**	-20.43**	86.58	79.89**	-7.91**
14.	$L_5 \times T_2$	31.63**	27.89**	-40.63**	75.65**	38.02**	-21.95**	57.01	37.15**	-29.79**
15.	$L_5 \times T_3$	71.53**	22.44**	25.37**	26.39**	15.98**	-21.47**	47.15	19.35**	-1.80**
16.	$L_6 \times T_1$	-13.98**	-21.58**	-34.14**	27.99**	0.49	-43.84**	4.56	-11.01**	-39.77**
17.	$L_6 \times T_2$	107.21**	60.88**	35.12**	77.85**	40.35**	-21.57**	93.03	51.05**	2.23**
18.	$L_6 \times T_3$	-8.07**	-16.33**	-14.33**	-12.94**	-20.55**	-46.20**	-10.40	-18.35**	-32.81**
19.	$L_7 \times T_1$	71.51**	55.57**	7.56**	73.22**	35.36**	-23.36**	72.35	58.68**	-10.38**
20.	$L_7 \times T_2$	41.01**	28.66**	-27.58**	76.37**	38.52**	-21.57**	60.27	34.39**	-24.09**
21.	$L_7 \times T_3$	-2.83**	-24.71**	-22.90**	26.60	16.23**	-21.29**	12.47	-5.17**	-21.97**
22.	$L_8 \times T_1$	10.08**	0.14	-15.51**	139.25**	132.26**	-21.38**	58.08	47.25**	-18.92**
23.	$L_8 \times T_2$	-26.83**	-43.28**	-52.15**	68.13**	64.33**	-44.38**	12.23	-4.91**	-47.64**
24.	$L_8 \times T_3$	-10.93**	-18.77**	-16.82**	-38.93**	-54.20**	-68.99**	-22.94	-35.69**	-47.08**

*,** Significant at 5% and 1% probability levels, respectively.
MP- mid parent, BP-better parent and SC- Standard check hybrid heterosis
E1- Optimum plant population density, E2- High plant population density, P- Pooled environment