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Heterosis for grain yield and its attributes in maize under heat stress

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Abstract
In this changing climatic scenario, heat stress is playing a significant role in reducing the grain yield of many important crop plants. Being an allogamous crop, the major breeding approach for increasing the productivity of maize is development of superior hybrids. Hence, 45 F_1s generated by crossing 15 heat tolerant double haploid lines with 3 double haploid testers were evaluated along with the parents in a randomized block design with two replications during *Summer* 2018 at EB II Section, Department of Plant Breeding & Genetics, College of Agriculture, OUAT, Bhubaneswar to estimate the relative heterosis and heterobeltiosis under heat stress. The crosses; ZL155246 × ZL155828, ZL155219 × ZL155828, ZL155235 × ZL154230 and ZL155235 × ZL155828 exhibited highly significant negative relative heterosis as well as heterobeltiosis for days to 50% tasselling and days to 50 % silking. Two crosses *viz.*, ZL155181 × CML451 and ZL155181 × ZL154230 exhibited highly significant negative heterobeltiosis for ASI accompanied with significant positive relative heterosis and heterobeltosis for plant height, ear height, cob length, cob diameter, number of grains per row, 100 grain weight and yield per plant. Most of the crosses exhibited both relative heterosis and heterobeltosis in positive direction for yield and its attributing descriptors signifying the genes controlling these traits with positive effect were dominant. Nine crosses *viz.*, ZL155115 × ZL155828, ZL155115 × CML 451, ZL155122 × ZL155828, ZL155132 × ZL155828, ZL155181 × ZL155828, ZL155181 × CML451, ZL155187 × ZL155828, ZL155201 × ZL155828 and ZL155247 × ZL155828 possessed highly significant positive relative heterosis as well as heterobeltiosis for yield per plant and its attributing traits; plant height, ear height, cob length, cob diameter, number of grain rows per cob, number of grains per row and 100 seed weight.

Keywords: Maize, Double haploid, Heat Stress, Yield, Heterobeltiosis and Relative Heterosis

Introduction
The present day maize (*Zea mays* L.) is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions making it an all season crop in India. It is a tropical crop but has adapted magnificently to temperate environments with much higher productivity. In India, it is the third most important cereal crop next to rice and wheat that contributes 8 % in national food basket and has highest growth rate among the cereals (Bisen *et al*., 2017) [8]. However, each year an average of 15% to 20% of the potential world maize production is lost due to various abiotic stresses like heat and drought (Lobell *et al*., 2011) [17]. The effect of heat stress on yield is highly complex and influences processes as diverse as nutrient assimilation and supply to reproductive organs, stem reserve accumulation, gametogenesis, fertilization, embryogenesis, and endosperm and grain development.

The major breeding approach for increasing productivity in cross pollinated crops like maize is development of superior hybrids using heterosis breeding. However, the success from this method depends on development and identification of suitable inbred lines. Around one century ago, an observation was made by Shull (1909) that when two inbred lines are crossed, both vigour and grain yield of the F_1 hybrid often exceeds the mean of the two parents. This phenomenon was termed as heterosis that gave rise to the modern maize industry (Crow, 1998) [10]. Heterosis has been extensively studied in maize because of (i) its large expression for grain yield (ii) its intensive exploitation in hybrid breeding of maize, and (iii) the favourable biological prerequisites such as large multiplication coefficient and ease of both self and controlled cross fertilization. Heterosis has also been reported to be helpful for maize cultivation by improving its adaption under diverse stress conditions (Tollenaar and Lee, 2006; Tollenaar *et al*., 2004) [28, 29]. Ribaut *et al*. (2003) [22] found the expression of heterosis to be greater under drought stress and smaller under low N environments in comparison to non-stress environments. Betran *et al*. (2003a) reported an average mid parent heterosis and heterobeltiosis of 22-25% and 12.25% respectively for grain yield under severe stress conditions. Betran *et al*. (2003b) also found that the differences in grain yield between hybrids and inbreds increased with the intensity of drought stress. Hence, in the present investigation 45 F_1s were grown along with parents during *Summer* 2018 to study the relative heterosis and heterobeltiosis under heat stress.

Materials and Methods

Experimental details

The experimental material for the present study comprised of forty five maize F_1s (Table 1) generated by crossing previously identified 15 heat tolerant double haploid lines with 3 double haploid testers collected from International Maize and Wheat Improvement Center (CIMMYT), Hyderabad, India. The F_1s and the parents were evaluated in a randomized block design with two replications during *Summer*, 2018 at EB-II section of the Department of Plant Breeding and Genetics, College of Agriculture, OUAT, Bhubaneswar. Each entry was sown in two rows of 4 meter length spaced at 60cm with a plant to plant spacing of 30 cm. Two seeds per hill were sown followed by thinning to maintain single plant per hill. In order to avoid the influence of moisture stress on the plants, proper care was taken by mulching the soil with paddy straw along with need based irrigation. Fertilizers were applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O per hectare in the form of Urea, SSP and MOP respectively along with FYM; 12 cart loads/ha and Zinc Sulphate; 25kg/ha. Normal agronomic practices and plant protection measures were followed to raise a successful crop.

The flowering occurred during the month of May, wherein the maximum and minimum temperature ranged between 35–39ºC and 20-28ºC respectively, while the mean relative humidity during the flowering period was 74%. Data was recorded on five randomly selected plants from each genotypes for twelve traits *viz.*, days to 50% tasseling (DT), days to 50 % silking (DS), anthesis to silking interval (ASI), days to 75 % dry husk (DDH), plant height (PH), ear height (EH), cob length (CL), cob diameter (CD), number of grain rows per cob (R/C), Number of grains per row (G/R), 100 seed weight (SW) and grain yield per plant (GY/P).

Statistical analysis

Heterosis is expressed as per cent increase or decrease of F_1 over the mid parent and better parent. The heterosis in negative direction is considered to be desirable for days to 50 % tasseling, days to 50 % silking, anthesis to silking interval and days to 75 % dry husk, whereas for rest of the traits positive heterosis is considered as desirable. Relative heterosis and heterobeltiosis were estimated according to the method suggested by Shull (1908), Fonseca and Patterson (1968) respectively. It was calculated as lined below.

$$Relative\ heterosis = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$Heterobeltosis = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where,

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

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

$\overline{MP}$ = Mean mid-parental value i.e., $(\overline{P_1}+\overline{P_2})/2$

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

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

The significance of heterosis was tested with 't' test as given below:

a) For relative heterosis

$$t = \frac{\overline{F_1} - \overline{MP}}{SE_d}$$

For heterobeltiosis

$$t = \frac{\overline{F_1} - \overline{BP}}{SE_d}$$

SE_d was calculated as follows.

i) For relative heterosis

$$SE_d = \sqrt{3MSe/2r}$$

ii) For heterobeltiosis

$$SE_d = \sqrt{2MSe/r}$$

Where,

MSe = Error mean square

SE_d = Standard error of difference

r = Number of replications

The calculated value of t (t_{cal}) is compared with tabulated value (t_{tab}) of t at 5% or 1% level of significance. When t_{cal} value is greater than t_{tab}, it is considered significant and vice versa.

Table 1: Forty five hybrids generated from crossing programme

1	ZL155069 × ZL155828	16	ZL155132 × ZL155828	31	ZL155201 × ZL155828
2	ZL155069 × ZL154230	17	ZL155132 × ZL154230	32	ZL155201 × ZL154230
3	ZL155069 × CML 451	18	ZL155132 × CML 451	33	ZL155201 × CML 451
4	ZL155085 × ZL155828	19	ZL155136 × ZL155828	34	ZL155219 × ZL155828
5	ZL155085 × ZL154230	20	ZL155136 × ZL154230	35	ZL155219 × ZL154230
6	ZL155085 × CML 451	21	ZL155136 × CML 451	36	ZL155219 × CML 451
7	ZL155110 × ZL155828	22	ZL155181 × ZL155828	37	ZL155235 × ZL155828
8	ZL155110 × ZL154230	23	ZL155181 × ZL154230	38	ZL155235 × ZL154230
9	ZL155110 × CML 451	24	ZL155181 × CML451	39	ZL155235 × CML451
10	ZL155115 × ZL155828	25	ZL155187 × ZL155828	40	ZL155246 × ZL155828
11	ZL155115 × ZL154230	26	ZL155187 × ZL154230	41	ZL155246 × ZL154230
12	ZL155115 × CML 451	27	ZL155187 × CML 451	42	ZL155246 × CML 451
13	ZL155122 × ZL155828	28	ZL155199 × ZL155828	43	ZL155247 × ZL155828
14	ZL155122 × ZL154230	29	ZL155199 × ZL154230	44	ZL155247 × ZL154230
15	ZL155122 × CML 451	30	ZL155199 × CML 451	45	ZL155247 × CML 451

Results and Discussion

In cross pollinated crops, heterosis is the way to achieve the desirable cross combinations over the mid-parent, better parent and any commercial variety. Heterosis breeding in maize has made tremendous impact resulting in release of greater number of high yielding hybrids for general cultivation. The single cross hybrid technology in maize is the key to realize desired success that has the potential to open up the new vistas. Heterobeltiosis and relative heterosis are important parameters as they provide information about the presence of dominance and over-dominance type of gene actions in the expression of various traits. According to Kiani *et al*. (2015) [16] greater success should be expected when inbred lines are developed from populations which show substantial heterosis in crosses. The extent of heterotic response of the F_1 hybrids largely depends on the breeding value and genetic diversity of the parents included in crosses, and on the environmental conditions under which the hybrids are grown (Hallauer and Miranda, 1988) [12]. In this present investigation percent relative heterosis (Hr) and heterobeltiosis (Hb) were estimated and presented in table 2.

Days to 50% tasselling, days to 50% silking, anthesis to silking interval and days to 75 % dry husk are the traits related to maturity which should be earlier in order to overcome the heat stress. So, the low scoring parent was considered as better parent for estimation of heterobeltiosis for these traits. Earliness is also looked for multiple cropping and better land water use efficiency (Hundera *et al*., 2017) [14]. Out of forty five crosses, thirty two crosses exhibited significant relative heterosis and seventeen crosses possessed significant heterobeltiosis estimates in desirable direction for days to 50% tasseling. The range of relative heterosis was from -12.33 % (ZL155246 × ZL155828) to 1.87% (ZL155187 × ZL154230) and heterobeltiosis was from -11.93% (ZL155246 × ZL155828) to 6.00% (ZL155110 × ZL155828). A perusal of estimates of relative heterosis of days to 50 % silking indicated that thirty six crosses depicted significant negative value and the magnitude of relative heterosis varied from -11.61 % (ZL155219 × ZL155828 and ZL155235 × ZL154230) to 0.47 % (ZL155110 × ZL154230). Negative and significant heterobeltiosis for days to 50 % silking was expressed by twenty seven crosses and the range of heterobeltiosis was from -11.61 % (ZL155235 × ZL155230) to 4.85 % (ZL155110 × ZL154230). The crosses *viz*., ZL155246 × ZL155828, ZL155219 × ZL155828 and ZL155235 × ZL154230, ZL155235 × ZL155828 showed highly significant negative relative heterosis as well as heterobeltiosis for days to 50% tasselling and days 50 % silking. So, these cross combinations attained earlier reproductive phase in order to escape the heat stress than their mid parents and better parents. Similar findings were reported by Prasanna Kumar and Ratna Babu (2016) [20]; Patil *et al*. (2017) [19]. The estimates of relative heterosis of ASI indicated that eight crosses exhibited negative significant value with magnitude ranged from -77.78 % (ZL155181 × CML451) to 42.86 % (ZL155246 × ZL155828). Two crosses exhibited significant negative heterobeltiosis for ASI, ranged from -75.00 % (ZL155181 × CML451 and ZL155181 × ZL154230) to 66.67 % (ZL155246 × ZL155828). Two crosses *viz.*, ZL155181 × CML451 and ZL155181 × ZL154230 exhibited highly significant negative heterobeltiosis for ASI accompanied with significant positive relative heterosis and heterobeltosis for plant height, ear height, cob length, cob diameter, number of grains per row, 100 grain weight and yield per plant. Negative relative heterosis and heterobeltosis for days to 50 % tasseling, days to 50 % silking and ASI were also reported by Umar *et al*. (2014) [30] under drought stress suggesting negative high value heterosis for ASI in order to tolerate drought stress. Thirty one crosses depicted negative significant relative heterosis and four crosses attained significant positive relative heterosis for days to 75% dry husk. The magnitude varied from -9.04 % (ZL155122 × ZL155828) to 8.02 % (ZL155187 × ZL154230). The estimates of significant negative heterobeltiosis were expressed by 17 crosses and 5 crosses showed significant positive value. The range of heterobeltiosis was from -6.17 % (ZL155219 × ZL155828) to 8.70 % (ZL155187 × ZL154230). Heterosis in earliness over mid parent and better parent were also observed by Sharma *et al*. (2017) [23]; Jawaharlal *et al*. (2012) [15] and Zeleke (2015) [32].

All the crosses attributed significant positive relative heterosis and heterobeltiosis for plant height. The estimates of relative heterosis ranged from 23.34 % (ZL155136 × CML451) to 92.47 % (ZL155115 × ZL155828) while for heterobeltiosis from 6.70% (ZL155235 × CML451) to 90.75% (ZL155115 × ZL155828). The cross ZL155115 × ZL155828 exhibited greater relative heterosis and heterobeltosis for plant height along with number of grain rows per cob, 100 seed weight and grain yield per plant. Similarly, Patil *et al*. (2017) [19]; Prasanna Kumar and Ratna Babu (2016) [20] identified crosses with significant positive heterosis over mid parent and better patent for plant height. All the crosses exhibited significant positive relative heterosis for ear height which ranged from 28.94 % (ZL155136 × ZL155828) to 111.33 % (ZL155122 × CML451). Forty four crosses were observed to have significant positive heterobeltiosis for ear height that ranged from 0.98 % (ZL155235 × ZL155828) to 95.80 % (ZL155122 × CML451). Similar results for significant positive heterosis over mid parent and better parent for ear height were reported by Xiaocong *et al*. (2017) [31] and Patil *et al*. (2017) [19]. However, Hundera *et al*. (2017) [14] emphasized the role of negative heterosis for ear height in escaping drought.

All the F_1s exhibited significant positive relative heterosis and heterobeltiosis for cob length and cob diameter. Ali *et al*. (2012) [2], Rajitha (2013) [21] and Brahmbhatt *et al*. (2018) [9] also reported positive significant heterosis over better and mid parents for ear length. The range was from 17.14 % (ZL155085 × CML451) to 79.52 % (ZL155235 × ZL155828) for relative heterosis and was from 15.10 % (ZL155085 × CML451) to 78.83% (ZL155235 × ZL155828) for heterobeltiosis for cob length. For cob diameter, magnitude of relative heterosis varied from 11.68 % (ZL155246 × CML451) to 44.07% (ZL155181 × ZL155828). The maximum estimates of heterobeltiosis were expressed by the cross ZL155110 × ZL155828 (41.51 %) and minimum value was exhibited by the cross ZL155246 × ZL155828 (6.50 %). ZL155181 × ZL155828 exhibited highly significant positive relative heterosis along with heterobeltiosis for cob diameter, number of grain rows per cob, number of grains per row and yield per plant. The positive heterosis for ear circumference was also reported previously by Brahmbhatt *et al*. (2018) [9]

The estimates of relative heterosis and heterobeltiosis revealed that all the crosses depicted significant positive value for number of grain rows per cob, number of grains per row, 100 seed weight and yield per plant. In case of number of grain rows per cob, the range of relative heterosis varied from 8.06 % (ZL155201 × ZL154230) to 51.35 % (ZL155181 × ZL155828) whereas maximum estimates of heterobeltiosis was exhibited by ZL155199 × ZL155828 (39.34 %) and minimum by ZL155132 × CML451 (5.97 %). Similarly Sundarajan and Senthil Kumar (2011); Brahmbhatt *et al*. (2018) [9] reported positive heterosis for number of grain rows per cob. The range of relative heterosis and heterobeltiosis varied from 20.51% (ZL155136 × ZL154230) to 97.71 % (ZL155201 × ZL155828) and from 10.89 % (ZL155136 × ZL154230) to 86.22 % (ZL155181× ZL155828) respectively for number of grains per row. The range of relative heterosis and heterobeltiosis in 100 seed weight varied from 12.42% (ZL155219 × ZL154230) to 51.47% (ZL155132× ZL155828) and from 8.86% (ZL155219 × ZL154230) to 36.76% (ZL155132× ZL155828) respectively. Sharma *et al*. (2017) [23] observed range of 100 grain weight from -24.25 % to 48.74 % over the better parent.

Grain yield is a complex character that is conditioned on plant and environment interaction starting from the day of planting to harvest. Furthermore, being quantitative character, it is controlled by many genes with individual contributing little additional effect on the total expression. Moreover, heterosis expressed by the hybrids mainly dependent on the genetic diversity of the parental genotypes used (Telebi, 2010). The magnitude of relative heterosis varied from 78.27 % (ZL155069 × ZL154230) to 275.67 % (ZL155181 × ZL155828) for yield per plant. Cross ZL155181 × ZL155828 also exhibited maximum heterobeltiosis (247.35 %) and minimum heterobeltiosis was attained by ZL155187 × ZL154230 (59.62 %). High heterotic values for grain yield was also reported in maize by Aminu and Izge (2013) and Aminu *et al*. (2014) under drought stress. The crosses *viz*., ZL155115 × ZL155828, ZL155115 × CML 451, ZL155122 × ZL155828, ZL155132 × ZL155828, ZL155181 × ZL155828, ZL155181 × CML451, ZL155187 × ZL155828, ZL155201 × ZL155828 and ZL155247 × ZL155828 possessed highly significant positive relative heterosis and heterobeltiosis for yield per plant and its attributing traits *viz.*, plant height, ear height, cob length, cob diameter, number of grain rows per cob, number of grains per row and 100 seed weight. Similar results were also recorded by Patel *et al*. (2009) [18], Abuali *et al*. (2017), Aminu *et al*. (2014) [4], Patil *et al*. (2017) [19], Hassan *et al*. (2019) for grain yield and its attributing traits. In the present study the results showed that, relative heterosis and heterobeltosis estimates for most of the hybrids had positive value for grain yield and its attributing descriptors which was also reported by Abuali *et al*. (2012); Patil *et al*. (2017) [19] and Hassan *et al*. (2019) [13].

Conclusion

The majority of the crosses exhibited positive significant relative heterosis and heterobeltiosis for yield and yield related traits, thereby indicating that for these traits the genes with positive effect were dominant. While for maturity related traits, majority of the crosses exhibited negative significant relative heterosis and heterobeltiosis, thereby indicating that for these traits the genes with negative effect were dominant. However, large number of hybrids showed superiority over their parents for various traits indicating the existence of substantial heterosis in the hybrids. The desirable crosses may be tested in various agroclimatic zones or can be used to raise synthetic varieties.

Table 2.1: Per cent relative heterosis (Hr) and heterobeltiosis (Hb) for yield and yield attributing characters

Sl. No.	Character	DT		DS		ASI		DDH	
	Crosses	Hr	Hb	Hr	Hb	Hr	Hb	Hr	Hb
1	ZL155069 × ZL155828	-3.26 *	-1.89	-2.70 ns	-0.92	14.29 ns	33.33	-4.29 **	-3.70*
2	ZL155069 × ZL154230	-5.61 **	-4.72*	-5.88 **	-4.59*	-14.29 ns	0.00	-3.38 *	-2.48
3	ZL155069 × CML 451	-3.29 *	-2.83	-4.07 **	-2.75	-25.00 ns	0.00	-4.56 **	-4.27**
4	ZL155085 × ZL155828	-1.41 ns	0.96	-2.73 ns	0.00	-42.86 ns	-33.33	-4.91 **	-4.32**
5	ZL155085 × ZL154230	0.00 ns	1.92	-0.46 ns	1.87	-14.29 ns	0.00	4.62 **	5.59**
6	ZL155085 × CML 451	0.47 ns	1.92	-0.46 ns	1.87	-25.00 ns	0.00	3.34 *	3.66*
7	ZL155110 × ZL155828	1.44 ns	6.00**	-0.93 ns	3.88*	-71.43 *	-66.67	0.31 ns	1.91
8	ZL155110 × ZL154230	0.96 ns	5.00*	0.47 ns	4.85*	-14.29 ns	0.00	0.63 ns	1.91
9	ZL155110 × CML 451	-3.38 *	0.00	-4.19 **	0.00	-25.00 ns	0.00	0.62 ns	3.18*
10	ZL155115 × ZL155828	-3.81 *	0.00	-4.15 **	0.00	-14.29 ns	0.00	-1.24 ns	-0.63
11	ZL155115 × ZL154230	-5.26 **	-1.98	-7.41 **	-3.85*	-71.43 *	-66.67	-4.05 **	-3.75*
12	ZL155115 × CML 451	-5.77 **	-2.97	-7.41 **	-3.85*	-50.00 ns	-33.33	-0.92 ns	0.63
13	ZL155122 × ZL155828	-8.11 **	-6.42**	-8.30 **	-7.08**	-14.29 ns	0.00	-9.04 **	-3.70*
14	ZL155122 × ZL154230	-6.79 **	-4.63*	-7.89 **	-6.25**	-42.86 ns	-33.33	-4.09 **	1.86
15	ZL155122 × CML 451	-3.64 *	-0.93	-5.26 **	-3.57*	-50.00 ns	-33.33	-6.36 **	-1.82
16	ZL155132 × ZL155828	-3.23 *	-2.78	-5.36 **	-4.50*	-71.43 *	-66.67	-3.05 *	-1.85
17	ZL155132 × ZL154230	0.00 ns	0.00	-0.45 ns	0.00	-14.29 ns	0.00	6.42 **	8.07**
18	ZL155132 × CML 451	-1.40 ns	-0.93	-4.04 **	-3.60*	-75.00 **	-66.67	-2.11 ns	-1.82
19	ZL155136 × ZL155828	-6.73 **	-2.02	-7.41 **	-2.91	-25.00 ns	-25.00	-2.19 ns	-0.64
20	ZL155136 × ZL154230	-7.25 **	-3.03	-7.91 **	-3.88*	-25.00 ns	-25.00	-3.14 *	-1.91
21	ZL155136 × CML 451	-3.88 *	0.00	-4.19 **	0.00	-11.11 ns	0.00	-4.97 **	-2.55
22	ZL155181 × ZL155828	-5.16 **	-2.88	-5.88 **	-3.70*	-25.00 ns	-25.00	-3.70 **	-3.70*
23	ZL155181 × ZL154230	-5.66 **	-3.85*	-8.18 **	-6.48**	-75.00 **	-75.00*	-4.64 **	-4.35**
24	ZL155181 × CML451	-3.32 *	-1.92	-6.36 **	-4.63*	-77.78 **	-75.00*	-2.14 ns	-1.23
25	ZL155187 × ZL155828	-3.26 *	-1.89	-4.46 **	-3.60*	-33.33 ns	-25.00	-2.15 ns	-1.85
26	ZL155187 × ZL154230	1.87 ns	2.83	-0.45 ns	0.00	-55.56 *	-50.00	8.02 **	8.70**
27	ZL155187 × CML 451	1.41 ns	1.89	-0.45 ns	0.00	-40.00 ns	-40.00	-1.22 ns	-0.61
28	ZL155199 × ZL155828	-10.50 **	-10.09**	-10.62 **	-10.62**	-14.29 ns	0.00	-7.19 **	-4.32**
29	ZL155199 × ZL154230	-6.42 **	-5.56**	-6.67 **	-6.25**	-14.29 ns	0.00	-4.50 **	-1.24
30	ZL155199 × CML 451	-5.07 **	-3.74*	-6.67 **	-6.25**	-50.00 ns	-33.33	-3.86 **	-1.82
31	ZL155201 × ZL155828	-4.63 **	-3.74*	-4.93 **	-3.64*	-14.29 ns	0.00	-3.93 **	-1.85
32	ZL155201 × ZL154230	-6.98 **	-6.54**	-8.11 **	-7.27**	-42.86 ns	-33.33	-6.06 **	-3.73*
33	ZL155201 × CML 451	-2.80 ns	-2.80	-3.60 *	-2.73	-25.00 ns	0.00	-2.99 *	-1.82
34	ZL155219 × ZL155828	-11.63 **	-10.38**	-11.61 **	-10.81**	-11.11 ns	0.00	-8.43 **	-6.17**
35	ZL155219 × ZL154230	-9.35 **	-8.49**	-10.31 **	-9.91**	-33.33 ns	-25.00	-6.95 **	-4.35**

36	ZL155219 × CML 451	-2.35 ns	-1.89	-4.04 **	-3.60*	-40.00 ns	-40.00	-5.07 **	-3.64*
37	ZL155235 × ZL155828	-11.01 **	-11.01**	-11.11 **	-10.71**	-14.29 ns	0.00	-5.17 **	-3.70*
38	ZL155235 × ZL154230	-11.52 **	-11.11**	-11.61 **	-11.61**	-14.29 ns	0.00	-5.49 **	-3.73*
39	ZL155235 × CML451	-7.41 **	-6.54**	-9.82 **	-9.82**	-75.00 **	-66.67	-5.42 **	-4.85**
40	ZL155246 × ZL155828	-12.33 **	-11.93**	-10.62 **	-10.62**	42.86 ns	66.67	-4.48 **	-1.23
41	ZL155246 × ZL154230	-7.34 **	-6.48**	-7.56 **	-7.14**	-14.29 ns	0.00	-4.19 **	-0.62
42	ZL155246 × CML 451	-2.30 ns	-0.93	-3.11 *	-2.68	-25.00 ns	0.00	-4.73 **	-2.42
43	ZL155247 × ZL155828	-9.59 **	-9.17**	-10.92 **	-9.73**	-40.00 ns	-25.00	-5.95 **	-2.47
44	ZL155247 × ZL154230	-2.75 ns	-1.85	-3.51 *	-1.79	-20.00 ns	0.00	-4.48 **	-0.62
45	ZL155247 × CML 451	-3.23 *	-1.87	-3.51 *	-1.79	-9.09 ns	0.00	-2.65 *	0.00
	Range	-12.33 to 1.87	-11.93 to 6.00	-11.61 to 0.47	-11.61 to 4.85	-77.78 to 42.86	-75.00 to 66.67	-9.04 to 8.02	-6..17 to 8.70
	SE(d)	0.848	0.980	0.852	0.984	0.532	0.615	1.074	1.240
	CD (0.05)	1.680	1.940	1.686	1.947	1.054	1.217	2.126	2.455

Table 2.2: Per cent relative heterosis (Hr) and heterobeltiosis (Hb) for yield and yield attributing characters

Sl. No.	Character	PH		EH		CL		CD	
	Crosses	Hr	Hb	Hr	Hb	Hr	Hb	Hr	Hb
1	ZL155069 × ZL155828	54.91 **	33.62 **	30.73 **	5.55 *	39.95 **	26.08 **	28.04 **	18.34 **
2	ZL155069 × ZL154230	49.93 **	26.24 **	40.61 **	4.35 ns	20.09 **	19.45 **	27.14 **	18.76 **
3	ZL155069 × CML 451	38.72 **	38.51 **	54.03 **	14.54 **	19.75 **	18.50 **	27.81 **	25.48 **
4	ZL155085 × ZL155828	78.05 **	67.39 **	82.63 **	76.02 **	45.15 **	34.15 **	42.19 **	37.60 **
5	ZL155085 × ZL154230	60.35 **	46.75 **	94.25 **	68.10 **	24.65 **	20.60 **	30.06 **	27.26 **
6	ZL155085 × CML 451	41.49 **	29.21 **	99.74 **	73.30 **	17.14 **	15.10 **	19.70 **	16.19 **
7	ZL155110 × ZL155828	67.93 **	61.46 **	76.89 **	76.46 **	48.49 **	45.20 **	42.43 **	41.51 **
8	ZL155110 × ZL154230	64.18 **	53.56 **	75.78 **	56.80 **	25.94 **	15.24 **	30.84 **	30.21 **
9	ZL155110 × CML 451	38.50 **	23.83 **	80.46 **	61.41 **	42.53 **	32.33 **	32.73 **	25.58 **
10	ZL155115 × ZL155828	92.47 **	90.75 **	61.67 **	47.39 **	45.35 **	42.55 **	33.52 **	27.01 **
11	ZL155115 × ZL154230	77.40 **	70.87 **	69.55 **	39.76 **	37.19 **	25.19 **	19.41 **	14.83 **
12	ZL155115 × CML 451	56.96 **	36.60 **	78.13 **	47.19 **	30.29 **	20.63 **	32.35 **	30.75 **
13	ZL155122 × ZL155828	69.27 **	57.16 **	98.23 **	91.22 **	60.58 **	56.61 **	37.00 **	28.88 **
14	ZL155122 × ZL154230	69.36 **	53.12 **	91.76 **	77.17 **	36.98 **	25.65 **	33.27 **	26.72 **
15	ZL155122 × CML 451	47.09 **	35.98 **	111.33 **	95.80 **	51.08 **	40.63 **	29.51 **	29.46 **
16	ZL155132 × ZL155828	41.75 **	25.50 **	68.24 **	47.87 **	56.55 **	48.34 **	35.13 **	30.54 **
17	ZL155132 × ZL154230	45.91 **	25.99 **	87.73 **	49.91 **	33.55 **	25.96 **	23.47 **	20.60 **
18	ZL155132 × CML 451	42.99 **	38.98 **	79.91 **	43.99 **	40.80 **	34.82 **	22.50 **	19.12 **
19	ZL155136 × ZL155828	43.77 **	33.49 **	28.94 **	28.78 **	54.56 **	39.13 **	25.57 **	21.20 **
20	ZL155136 × ZL154230	44.39 **	30.55 **	63.93 **	46.70 **	33.28 **	32.70 **	28.30 **	25.20 **
21	ZL155136 × CML 451	23.34 **	14.02 **	60.49 **	44.01 **	25.65 **	24.22 **	25.84 **	22.48 **
22	ZL155181 × ZL155828	75.76 **	62.23 **	58.64 **	44.49 **	57.37 **	57.34 **	44.07 **	41.26 **
23	ZL155181 × ZL154230	51.64 **	36.32 **	72.75 **	42.28 **	29.75 **	16.31 **	30.71 **	29.61 **
24	ZL155181 × CML451	47.24 **	36.92 **	72.82 **	42.69 **	39.19 **	26.56 **	31.78 **	26.27 **
25	ZL155187 × ZL155828	64.35 **	45.66 **	72.04 **	53.85 **	67.17 **	59.27 **	31.67 **	27.22 **
26	ZL155187 × ZL154230	55.89 **	34.74 **	66.07 **	34.62 **	41.00 **	21.13 **	19.02 **	16.28 **
27	ZL155187 × CML 451	41.84 **	37.69 **	79.41 **	45.77 **	42.17 **	23.79 **	25.18 **	21.71 **
28	ZL155199 × ZL155828	56.65 **	50.54 **	73.22 **	71.36 **	64.86 **	61.20 **	38.65 **	37.95 **
29	ZL155199 × ZL154230	53.22 **	43.24 **	82.48 **	61.58 **	39.37 **	22.51 **	30.93 **	30.11 **
30	ZL155199 × CML 451	33.83 **	19.70 **	88.17 **	67.06 **	44.21 **	28.54 **	23.88 **	17.05 **
31	ZL155201 × ZL155828	73.07 **	52.79 **	68.60 **	48.42 **	49.21 **	36.54 **	29.04 **	22.64 **
32	ZL155201 × ZL154230	65.83 **	42.79 **	83.53 **	46.75 **	27.64 **	24.81 **	16.00 **	11.45 **
33	ZL155201 × CML 451	42.89 **	39.33 **	77.78 **	42.49 **	27.66 **	26.80 **	22.56 **	21.19 **
34	ZL155219 × ZL155828	27.56 **	21.67 **	46.62 **	40.40 **	53.25 **	42.94 **	40.18 **	37.57 **
35	ZL155219 × ZL154230	42.30 **	32.07 **	56.42 **	34.60 **	33.20 **	27.64 **	31.12 **	30.13 **
36	ZL155219 × CML 451	35.58 **	22.12 **	65.07 **	42.41 **	45.33 **	41.42 **	23.62 **	18.35 **
37	ZL155235 × ZL155828	56.91 **	48.93 **	87.23 **	0.98 **	79.52 **	78.83 **	32.14 **	27.26 **
38	ZL155235 × ZL154230	56.63 **	52.89 **	63.43 **	56.35 **	45.53 **	30.93 **	26.60 **	23.28 **
39	ZL155235 × CML451	29.06 **	6.70 **	103.87 **	94.46 **	48.55 **	35.57 **	18.32 **	15.42 **
40	ZL155246 × ZL155828	51.45 **	31.42 **	41.91 **	18.18 **	37.81 **	27.65 **	17.66 **	6.50 *
41	ZL155246 × ZL154230	54.07 **	30.47 **	53.99 **	17.37 **	23.36 **	19.07 **	17.16 **	7.13 **
42	ZL155246 × CML 451	29.44 **	28.74 **	50.90 **	15.26 **	33.79 **	31.15 **	11.68 **	7.21 **
43	ZL155247 × ZL155828	78.23 **	59.71 **	42.26 **	16.00 **	58.21 **	50.30 **	40.49 **	38.26 **
44	ZL155247 × ZL154230	78.06 **	55.56 **	61.15 **	20.62 **	43.83 **	35.30 **	32.35 **	31.72 **
45	ZL155247 × CML 451	48.11 **	42.06 **	62.67 **	22.00 **	40.31 **	33.99 **	28.19 **	22.39 **
	Range	23.34 to 92.47	6.70 to 90.75	28.94 to 111.23	0.98 to 95.80	17.14 to 79.52	15.10 to 78.83	11.68 to 44.07	6.50 to 41.51
	SE(d)	2.773	3.202	1.571	1.814	0.388	0.448	0.285	0.329
	CD (0.05)	5.490	6.339	3.110	3.591	0.767	0.886	0.564	0.652

Table 2.3: Per cent relative heterosis (Hr) and heterobeltiosis (Hb) for yield and yield attributing characters

Sl. No.	Character	RC		GR		SW		YP	
	Crosses	Hr	Hb	Hr	Hb	Hr	Hb	Hr	Hb
1	ZL155069 × ZL155828	16.41 **	11.19 **	44.42 **	22.94 **	30.28 **	23.42 **	122.71 **	75.16 **
2	ZL155069 × ZL154230	10.85 **	6.72 *	23.88 **	19.00 **	20.52 **	18.23 **	78.27 **	68.04 **
3	ZL155069 × CML 451	20.90 **	20.90 **	39.73 **	27.96 **	27.53 **	22.50 **	102.89 **	79.11 **
4	ZL155085 × ZL155828	28.57 **	24.62 **	65.56 **	45.91 **	22.16 **	13.00 **	136.55 **	90.31 **
5	ZL155085 × ZL154230	11.81 **	9.23 **	31.52 **	31.52 **	14.97 **	14.25 **	85.87 **	80.38 **
6	ZL155085 × CML 451	13.64 **	11.94 **	48.47 **	41.25 **	18.13 **	10.75 **	102.17 **	83.34 **
7	ZL155110 × ZL155828	27.97 **	25.69 **	57.79 **	44.00 **	29.08 **	24.66 **	161.69 **	127.86 **
8	ZL155110 × ZL154230	13.37 **	12.25 **	27.81 **	22.96 **	22.37 **	17.72 **	85.09 **	73.34 **
9	ZL155110 × CML 451	10.56 **	7.46 *	31.63 **	30.11 **	32.59 **	29.86 **	103.29 **	102.33 **
10	ZL155115 × ZL155828	30.68 **	27.13 **	65.90 **	51.26 **	36.35 **	35.36 **	194.30 **	160.29 **
11	ZL155115 × ZL154230	12.25 **	10.08 **	29.29 **	24.51 **	21.62 **	13.92 **	123.32 **	105.67 **
12	ZL155115 × CML 451	23.19 **	20.90 **	60.43 **	58.40 **	33.81 **	32.86 **	156.29 **	152.90 **
13	ZL155122 × ZL155828	29.03 **	26.98 **	80.30 **	74.29 **	40.00 **	35.88 **	225.54 **	218.94 **
14	ZL155122 × ZL154230	24.80 **	23.81 **	49.04 **	35.41 **	22.24 **	10.63 **	136.80 **	98.28 **
15	ZL155122 × CML 451	27.69 **	23.88 **	67.42 **	59.48 **	36.42 **	30.57 **	172.91 **	142.91 **
16	ZL155132 × ZL155828	27.38 **	24.59 **	60.69 **	44.73 **	51.47 **	36.76 **	213.86 **	207.59 **
17	ZL155132 × ZL154230	14.69 **	11.29 **	35.57 **	32.30 **	33.63 **	13.16 **	110.66 **	70.79 **
18	ZL155132 × CML 451	13.31 **	5.97 *	59.67 **	55.56 **	46.79 **	30.86 **	143.39 **	109.14 **
19	ZL155136 × ZL155828	33.87 **	31.75 **	53.88 **	46.76 **	26.81 **	25.88 **	160.97 **	146.98 **
20	ZL155136 × ZL154230	23.20 **	22.22 **	20.51 **	10.89 *	21.64 **	12.41 **	89.63 **	63.55 **
21	ZL155136 × CML 451	30.77 **	26.87 **	33.93 **	29.31 **	27.59 **	24.86 **	134.67 **	115.70 **
22	ZL155181 × ZL155828	51.35 **	37.70 **	90.85 **	86.22 **	30.14 **	24.86 **	275.67 **	247.35 **
23	ZL155181 × ZL154230	30.36 **	17.74 **	54.23 **	33.07 **	20.26 **	16.46 **	156.30 **	98.59 **
24	ZL155181 × CML451	24.79 **	8.96 **	70.13 **	53.45 **	27.78 **	24.32 **	214.54 **	157.24 **
25	ZL155187 × ZL155828	30.00 **	27.87 **	85.07 **	77.04 **	29.41 **	29.41 **	227.33 **	208.08 **
26	ZL155187 × ZL154230	11.57 **	8.87 **	49.08 **	26.46 **	21.09 **	12.66 **	103.18 **	59.62 **
27	ZL155187 × CML 451	19.05 **	11.94 **	61.56 **	43.10 **	30.43 **	28.57 **	159.29 **	115.27 **
28	ZL155199 × ZL155828	40.50 **	39.34 **	65.38 **	61.73 **	40.00 **	29.71 **	220.22 **	188.35 **
29	ZL155199 × ZL154230	31.15 **	29.03 **	39.08 **	20.23 **	28.76 **	11.65 **	111.53 **	60.60 **
30	ZL155199 × CML 451	27.56 **	20.90 **	54.81 **	39.91 **	38.75 **	26.86 **	170.14 **	116.05 **
31	ZL155201 × ZL155828	15.45 **	14.52 **	97.71 **	76.53 **	30.47 **	23.30 **	218.95 **	202.41 **
32	ZL155201 × ZL154230	8.06 **	8.06 *	51.82 **	21.40 **	18.66 **	16.71 **	135.80 **	86.31 **
33	ZL155201 × CML 451	14.73 **	10.45 **	68.39 **	40.09 **	25.68 **	20.42 **	166.63 **	122.75 **
34	ZL155219 × ZL155828	32.77 **	29.51 **	44.59 **	29.44 **	23.94 **	18.92 **	141.64 **	113.21 **
35	ZL155219 × ZL154230	29.17 **	25.00 **	22.77 **	20.62 **	12.42 **	8.86 **	90.51 **	75.89 **
36	ZL155219 × CML 451	21.60 **	13.43 **	32.08 **	27.82 **	25.00 **	21.62 **	105.25 **	103.08 **
37	ZL155235 × ZL155828	42.49 **	37.77 **	66.75 **	63.78 **	32.46 **	30.57 **	183.83 **	175.55 **
38	ZL155235 × ZL154230	36.66 **	33.18 **	38.12 **	19.84 **	20.54 **	13.67 **	115.89 **	82.15 **
39	ZL155235 × CML451	36.03 **	34.33 **	52.97 **	38.79 **	25.71 **	25.71 **	146.80 **	121.48 **
40	ZL155246 × ZL155828	23.08 **	15.94 **	59.63 **	46.38 **	27.40 **	19.23 **	146.29 **	102.38 **
41	ZL155246 × ZL154230	14.50 **	8.70 **	40.24 **	34.24 **	18.47 **	17.72 **	84.60 **	84.05 **
42	ZL155246 × CML 451	14.34 **	12.68 **	55.89 **	54.89 **	23.24 **	16.92 **	108.93 **	94.27 **
43	ZL155247 × ZL155828	46.79 **	31.15 **	69.88 **	57.64 **	35.06 **	32.02 **	240.55 **	233.75 **
44	ZL155247 × ZL154230	48.18 **	31.45 **	54.73 **	46.30 **	23.04 **	16.96 **	141.33 **	95.65 **
45	ZL155247 × CML 451	40.00 **	20.15 **	51.84 **	50.86 **	32.86 **	31.74 **	176.70 **	137.77 **
	Range	8.06 to 51.35	5.97 to 39.34	20.51 to 97.71	10.89 to 86.22	12.42 to 51.47	8.86 to 36.76	78.27 to 275.67	59.62 to 247.35
	SE(d)	0.346	0.400	0.963	1.112	0.357	0.413	3.410	3.938
	CD (0.05)	0.685	0.792	1.906	2.201	0.707	0.817	6.753	7.797

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