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Over the environment study of yield and yield contributing traits for exploitation of heterosis in maize (*Zea mays* L.)

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Abstract

Present study was carried out with 10 parents, their 45 hybrids mated in diallel fashion without reciprocals and 4 checks *viz*., Pratap QPM Hybrid- 1, Vivek QPM- 9, HQPM- 1 and HQPM- 5 in RBD for estimation of heterosis in two environments (*Kharif* 2014 and *Rabi* 2014-15) at the Instructional farm, Rajasthan College of Agriculture, MPUAT, Udaipur. Analysis of variance in individual environment revealed that mean squares due to genotypes were significant for all the characters in both the environments. By further partitioning of genotypic variance the mean square due to parents were significant for all the characters except for grain yield per plant which was non-significant in E_2 environment. Mean squares due to crosses and mean sum of square due to parents v/s crosses were significant for all the characters in both the environments. Bartlett test shown homogeneity of error variance for ear girth, number of grain rows per ear and harvest index out of six characters under study. Pooled analysis revealed significant differences between the environments for these three characters. The mean squares due to genotypes including parents, crosses and parents vs. crosses were also significant for all the three characters. Mean squares due to genotypes x environment interactions were significant for ear girth and harvest index but for number of grain rows per ear it was non-significant, indicating influence of environment on the expression of this character. The partitioning of mean squares due to parents x environments were significant for all the three characters and due to crosses x environments interaction were significant for ear girth and harvest index while non-significant for number of grain rows per ear. Study of economic heterosis showed that for ear length four hybrids (P_2 x P_{10}, P_3 x P_5, P_5 x P_8 and P_2 x P_8) in E_1 while none of the hybrids in E_2, for ear girth six hybrids (P_1 x P_8, P_3 x P_5, P_6 x P_8, P_5 x P_8, P_2 x P_5 and P_2 x P_8) in E_1 and none of the hybrids in E_2, for 100 grain weight two hybrids (P_6 x P_8 and P_7 x P_{10}) in E_1 only and for grain yield per plant six hybrids (P_6 x P_8, P_5 x P_8, P_3 x P_5, P_5 x P_7, P_1 x P_8 and P_2 x P_8) in E_1 while none of the hybrid in E_2 exhibited positive significant economic heterosis over the best check. Over the environment study of harvest index indicated that only one hybrid P_1 x P_9 exhibited positive significant economic heterosis in E_1, E_2 and pooled environment over the best check Vivek QPM-9 in E_1 and on pooled basis while over Pratap QPM Hybrid-1 in E_2. None of the hybrid exhibited positive significant Economic heterosis for ear girth and number of grain rows per ear.

Keywords: Over the environment, relative heterosis, heterobeltiosis, economic heterosis, grain yield, maize

1. Introduction

Maize (*Zea mays* L.) is the world's most widely grown cereal and is the primary staple food in many developing countries (Morris *et al*., 1999) [23]. Maize is an important food, feed and industrial crop in India as well as other countries of the world which is believed to be originated in Southern Mexico or Northern Guatemala (Weatherwax, 1955) [40]. Maize is the third most widely distributed crop of the world after Rice and Wheat (Poehlman, 2006), being grown in diverse seasons and ecologies with highest production and productivity among food cereals. Globally, maize is cultivated on an area of 184 mha, with production of 872 million tonnes and a productivity of 5519 kg/ha (FAO STAT, 2013) [11]. In India, maize is cultivated on an area of 9.23 million ha with a production of 23.67 million tonnes and productivity of 2564 kg/ha (Annual progress report, AICRP on Maize 2015: Indian Institute of Maize Research, New Delhi). Maize consumption in India has grown up to 19 million tonnes (USDA, 2013-14) and with the exploitation of heterosis in development of improved hybrid varieties India became self-sufficient in the maize production. Maize improvement program is under technological transition from open pollinated varieties (OPVs) and multi-parent hybrids (MHs) to single cross hybrids especially in those countries where OPVs or MHs were common in maize production system. The single cross hybrids have potential to exploit maximum heterosis and also ease in maintenance as well as in seed production (Kumar *et al*., 2015) [18]. Nowadays, corn breeders do their best to explore the genetic material in order to develop new maize genotypes which characterized by high yielding potentiality and better quality. For this, they need enough knowledge about the type and relative amount of genetic variance components and their interaction by environments as well as heterosis for yield and its component. One of the most informative methodology in this concern is diallel analysis system which is widely and extensively used for estimating the types of gene action (Abdel-Moneam *et al.*, 2015) [1]. The degree of heterotic effect of F_1 populations is correlated with genetic diversity of the parental lines, as parents are more divergent, the heterosis is higher and vice-versa (Prasad and Singh 1986; Duvick 1999) [25, 9]. However, environment can differentially affect the performance of inbred lines and hybrids and distort the relationship (Kumar *et al*., 2015) [18]. Keeping in view the above fact this study was designed with the objective of determining relationship between grain yield and magnitude of heterosis over the environments.

2. Material and Methods

2.1 Experimental site and design

The experimental material consisted of ten diverse inbred lines (Table 1) which were crossed in all possible combinations using diallel mating design (excluding reciprocals) to obtain 45 single cross hybrids, during *rabi* season (March) of 2014 under irrigated, normal soil condition at the Instructional farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, India. These 45 hybrids, 10 parents along with four standard checks (Table 1) were evaluated in randomized block design with three replications during *Kharif* 2014 and *Rabi* 2014-15. The materials were grown in a single row plot of 4 m length, maintaining crop geometry of 60x25cm. The Recommended packages of practices of Zone IVA of Rajasthan were adopted to raise a healthy crop.

2.2. Recording of data

The data were recorded for yield and yield contributing traits *viz.*, ear length, ear girth, no. of grain rows per ear, 100 grain weight, grain yield per plant and harvest index in both environments on five randomly selected competitive plants of each entry in each replication. The recorded data for above mentioned traits were subjected for statistical analysis.

2.3. Statistical analysis

The mean value of the recorded data was subjected to analysis of variance (ANOVA) using the statistical analysis procedures of Panse and Sukhatme, 1985. Heterosis (over mid parent), heterobeltiosis (over better parent) and economic heterosis (standard heterosis) was calculated as per procedure suggested by Shull (1909), Fonesca and Patterson (1968) [13] and Meredith and Bridge (1972) [21] respectively for individual as well as over the environments. The test of homogeneity of error variance for pooled analysis of variance was carried out by procedure given by Bartlett (1937) [6].

Table 1: List of Parental Inbred Lines and Checks

S. No	Inbred line Symbol/Code	Source
Details of parents		
1.	EIQ-105 (P_1)	AICRP on Maize, Udaipur
2.	EIQ-106 (P_2)	AICRP on Maize, Udaipur
3.	EIQ-107 (P_3)	AICRP on Maize, Udaipur
4.	EIQ-108 (P_4)	AICRP on Maize, Udaipur
5.	EIQ-109 (P_5)	AICRP on Maize, Udaipur
6.	EIQ-110 (P_6)	AICRP on Maize, Udaipur
7.	EIQ-111 (P_7)	AICRP on Maize, Udaipur
8.	EIQ-112 (P_8)	AICRP on Maize, Udaipur
9.	EIQ-113 (P_9)	AICRP on Maize, Udaipur
10.	EIQ-114 (P_{10})	AICRP on Maize, Udaipur
Details of checks		
1.	Pratap QPM Hybrid- 1 (Check-1)	AICRP on Maize, Udaipur
2.	Vivek QPM- 9 (Check-2)	VPKAS. Almora
3.	HQPM- 1 (Check-3)	CCSHAU, Karnal
4.	HQPM- 5 (Check-4)	CCSHAU, Karnal

Where,
AICRP- All India Coordinated Research Project
VPKAS- Vivekanand Parvatiya Krishi Anusandhan Shala
CCSHAU-Choudhary Charan Singh Haryana Agricutural University

3. Results and Discussion

Analysis of variance in individual environment revealed that mean squares due to genotypes were significant for all the characters in both the environments. By further partitioning of genotypic variance the mean square due to parents were significant for all the characters except for grain yield per plant which was non-significant in E_2 environment. Mean squares due to crosses and mean sum of square due to parents v/s crosses were significant for all the characters in both the environments (Table 2). These results were in confirmation with Saidaiah *et al.* (2008) [32], Sundarajan and Shenthil (2011) [37], Premalatha *et al*. (2011) [26], Lal and Kumar (2012) [19], Avinashe *et al*. (2013) [5] and Rajesh *et al*. (2014) [27]. This suggested the presence of heterosis for most of the traits.

The Bartlett test revealed that error variance was homogenous for ear girth, number of grain rows per ear and harvest index (Table 2). Therefore, pooled analysis was carried out for these characters only. The pooled analysis revealed significant differences between the environments for the three characters. The mean squares due to genotypes including parents, crosses and parents vs. crosses were also significant for all the three characters. Mean squares due to genotypes x environment interactions were significant for ear girth and harvest index but for number of grain rows per ear it was non-significant, indicating influence of environments on the expression of this character. The partitioning of mean squares due to parents x environments were significant for all the three characters and due to crosses x environments interaction were significant for ear girth and harvest index while non-significant for number of grain rows per ear (Table 3).

The estimates of heterosis for ear length revealed that out of forty five hybrids, thirty one hybrids with range varied from 10.94 (P_8 x P_9) to 91.01 per cent (P_2 x P_{10}) in E_1 and thirty four hybrids with range 12.94 (P_4 x P_8) to 65.94 per cent (P_2 x P_6) in E_2 depicted positive significant relative heterosis. In E_1 the positive significant heterobeltiosis was expressed by nineteen hybrids with the range varied from 11.59 (P_2 x P_3) to 77.08 per cent (P_2 x P_{10}). In E_2, twenty hybrids exhibited positive significant heterobeltiosis with a range varied from 13.50 (P_6 x P_7) to 52.80 (P_2 x P_6). The positive significant economic heterosis was expressed by only four hybrids in E_1 with magnitude ranged from 11.90 (P_2 x P_8) to 15.48 per cent (P_6 x P_8) while, in E_2 none of the hybrids exhibited positive significant economic heterosis for this trait over the best check (Table 4). These results were in accordance with Saidaiah *et al.* (2008) [32], Bhavana *et al.* (2011) [7], Ram Reddy *et al.* (2011) [28], Rajesh *et al.* (2014) [27] and Ruswandi *et al.* (2015) [31], Reddy *et al.* (2015) [29]. Mid parent heterosis for ear girth indicated that twenty eight hybrids in E_1 with the range 12.90 (P_4 x P_9) to 41.59 per cent (P_3 x P_5) while, thirty two hybrids in E_2 with the range varied from 9.12 (P_3 x P_{10}) to 34.21 per cent (P_2 x P_6) depicted positive significant relative heterosis. In E_1 nineteen hybrids with magnitude varied from 11.76 (P_2 x P_8) to 40.38 per cent (P_2 x P_{10}) and in E_2, eleven hybrids with magnitude varied from 9.52 (P_4 x P_5) to 30.77 per cent (P_2 x P_6) expressed positive significant heterobeltiosis. The positive significant economic heterosis was expressed by six hybrids with magnitude varied from 11.76 (P_2 x P_8 and P_2 x P_5) to 17.65 per cent (P_1 x P_8, P_3 x P_5 and P_6 x P_8) in E_1 while none of the hybrids exhibited positive significant economic heterosis in E_2 for this trait over the best check (Table 5). The pattern of heterosis for ear girth was also observed by Saidaiah *et al.* (2008) [32], Bhavana *et al.* (2011) [7], Ram Reddy *et al.* (2011) [28], Farhan *et al.* (2012) [12], Abdel *et al*. (2014) [2] and Reddy *et al.* (2015) [29]. The estimates of Number of grain rows per ear highlighted that fourteen hybrids in E_1 with the range 13.51 (P_5 x P_8) to 27.27 per cent (P_2 x P_{10}) while, sixteen hybrids in E_2 exhibited positive significant relative heterosis with range varied from 12.82 (P_8 x P_{10}) to 37.14 per cent (P_2 x P_{10}). The positive significant heterobeltiosis was expressed by six hybrids with range varied from 17.65 (P_1 x P_{10} and P_5 x P_{10}) to 25 per cent (P_1 x P_2) in E_1 while, in E_2 seven hybrids showed positive significant heterobeltiosis with a range from 15.00 (P_5 x P_{10}) to 20.00 per cent (P_2 x P_{10}). None of the hybrid exhibited positive significant economic heterosis for this trait over the best check in both the environments (Table 5). The present results were comparable with findings of Singh *et al.* (2010) [34], Bhavana *et al.* (2011) [7], Ram Reddy *et al.* (2011) [28], Melkamu *et al.* (2013) [22] and Abdel *et al.* (2014) [2]. The perusal of 100 Grain weight indicated that thirty hybrids in E_1 exhibited positive significant mid parent heterosis for this trait. It ranged from 6.61 (P_3 x P_{10}) to 50.39 per cent (P_7 x P_{10}). In E_2, twenty three hybrids showed positive significant mid parent heterosis with magnitude varied from 9.24 (P_1 x P_9) to 51.86 per cent (P_2 x P_8). The positive significant heterobeltiosis was observed in twenty three and thirteen hybrids in E_1 and E_2, respectively. The magnitude ranged from 7.87 (P_5 x P_9) to 39.42 per cent (P_7 x P_{10}) in E_1 and in E_2, the range was 11.48 (P_5 x P_9) to 48.48 per cent (P_2 x P_8). Only two hybrids, P_6 x P_8 (5.59%) and P_7 x P_{10} (6.70%) in E_1 and none of the hybrids in E_2 exhibited positive significant economic heterosis over the best check (Table 4). These results are in comparable with findings of Singh *et al.* (2010) [34], Bhavana *et al.* (2011) [7], Ram Reddy *et al.* (2011) [28], Sumalini and Shobha Rani (2011) [36], Farhan *et al.* (2012) [12] and Abdel *et al.* (2014) [2], Reddy *et al.* (2015) [29]. The estimates of Grain Yield per Plant indicated that forty two hybrids with the range 10.16 (P_7 x P_8) to 152.10 per cent (P_3 x P_5) in E_1 while, forty three hybrids in E_2 which ranged from 23.70 (P7xP8) to 124.76 per cent (P1xP8) exhibited positive significant mid parent heterosis. In case of heterobeltiosis, thirty seven hybrids exhibited positive significant better parent heterosis in E_1 with the magnitude ranged from 12.16 (P3xP7) to 128.44 per cent (P1xP9). In case of E_2, thirty six hybrids showed positive significant better parent heterosis with range 24.67 (P4xP7) to 108.14 per cent (P7xP8). Six hybrids viz., P2 x P8 (7.22%), P1xP8 (8.89%), P5 x P7 (10.00%), P3 x P5 (11.11%), P5 x P8 (15.56%) and P6 x P8 (19.63%) in E_1 and none of the hybrid in E_2 exhibited positive significant economic heterosis over the best check (Table 4). These results are in comparable with findings of Devi and Prodhan (2004) [10], Premalatha and Kalamani (2010), Singh *et al.* (2010) [34], Sultan *et al.* (2010) [35], Bhavana *et al.* (2011) [7], Ram Reddy *et al.* (2011) [28], Farhan *et al.* (2012) [12], Melkamu *et al.* (2013) [22], Abdel *et al.* (2014) [2], Asif *et al.* (2014) [4], Imdad *et al.* (2014) [15], Rajesh *et al.* (2014) [27] and Ruswandi *et al.* (2015) [31]. The perusal of data for harvest index indicated that the estimates of positive significant relative heterosis were manifested by twenty-six hybrids with the magnitude ranged from 6.64 (P_3 x P_7) to 39.23 per cent (P_1 x P_9) in E_1 while in E_2, thirty one hybrids exhibited positive significant relative heterosis with the magnitude ranged from 7.58 (P_6 x P_{10}) to 36.54 per cent (P_1 x P_9). Twenty-one hybrids in E_1 with the magnitude ranged from 8.08 (P_8 x P_{10}) to 34.38 per cent (P_1 x P_9) and twenty six hybrids in E_2 with the magnitude ranged from 6.01 (P_4 x P_7) to 28.10 per cent (P_2 x P_3) showed significant positive heterobeltiosis (Table 5). Ravikant *et al.* (2006) [30], Dubey *et al.* (2009), Lal *et al.* (2011) [20], Khanorkar *et al.* (2012) [17], Avinashe *et al.* (2013) [5], Khan *et al.* (2014) [16] and Verma *et al.* (2014) [39] also reported economic heterosis in maize for yield and its contributing traits.

Over the environment study of Ear girth, Number of grain rows per ear and Harvest index showed that the positive significant relative heterosis were exhibited by thirty seven, twenty one and thirty three hybrids respectively. Their magnitude varied from 7.06 (P1 x P4) to 32.82 (P2 x P6) for Ear girth, from 10.81 (P1 x P10 and P3 x P5) to 32.35 per cent (P2 x P10) for Number of grain rows per ear and from 5.84 (P4 x P9) to 37.83 per cent (P1 x P9) for Harvest index. Similarly, positive significant heterobeltiosis was exhibited by twenty four, eleven and twenty eight hybrids respectively for the above mentioned characters. The range of heterobeltiosis was 7.49 (P5 x P7) to 29.83 per cent (P2 x P6) for Ear girth, from 10.81 (P1 x P2, P1 x P6, P1 x P10 and P6 x P10) to 21.62 per cent (P2 x P10) for Number of grain rows per ear and from 6.01 (P4 x P7) to 30.92 (P1 x P9) for Harvest Index. None of the hybrid exhibited positive significant Economic heterosis for ear girth and number of grain row per ear. For Harvest index only one hybrid (P1 x P9) exhibited positive significant economic heterosis in E1, E2 and pooled environments with magnitude 13.40, 10.96 and 13.23 per cent respectively, over the best check Vivek QPM-9 in E1 and pooled basis while over Pratap QPM Hybrid-1 in E2 (Table 5).

Table 2: Mean squares for different characters environment wise

SN	Characters	Env	Source						Bartlett
			Rep	Genotype	Parent	Crosses	Parents vs crosses	Error	
			[2]	[54]	[9]	[44]	[1]	[108]	[1]
1	Ear length (cm)	1	1.38788	11.9556**	11.7185**	10.0526**	97.8185**	0.536027	14.87**
		2	4.22769*	8.46996**	7.18967**	5.75756**	139.338**	1.13552	
2	Ear girth (cm)	1	1.16515	4.16818**	3.7787**	2.9766**	60.1031**	0.55867	2.37689
		2	0.878571	1.68896**	2.97052**	0.675731*	34.7372**	0.415013	
3	Number of grain rows per ear	1	0.169697	2.70438**	3.68889**	2.23973**	14.2882**	1.13266	0.0252574
		2	0.678788	3.03659**	4.74074**	2.04983**	31.1165**	1.09854	
4	100-Grain weight (g)	1	1.57276	27.5754**	8.11111**	28.0809**	180.511**	0.82675	16.8673**
		2	6.65486*	17.2658**	11.2576**	17.2588**	71.6491**	1.84128	
5	Grain yield per plant (g)	1	15.8061	982.046**	127.482**	853.212**	14341.8**	10.411	65.9651**
		2	69.1869	665.872**	56.3824	447.078**	15778.2**	53.8692	
6	Harvest index (%)	1	1.3373	30.8761**	18.3143**	27.902**	274.792**	2.55375	0.484708
		2	7.05377*	31.5175**	19.7769**	23.4901**	490.392**	2.23341	

*,** Significant at 5 and 1 percent respectively (Model I)

Table 3: Pooled mean squares for Ear girth, Number of grain rows per ear and Harvest index

SN	Characters	Source											Bartlett
		Env	Rep/Env	Genotype	Parents	Crosses	Parents vs crosses	GxE	Parent x Env	Crosses x E	Parents vs Crosses x E	Pool Error	
		[1]	[4]	[54]	[9]	[44]	[1]	[54]	[9]	[44]	[1]	[216]	[1]
1	Ear girth (cm)	22.5688**	1.02186	4.17592**	4.67498**	2.05255**	93.1128**	1.68123**	2.07424**	1.59979**	1.72755	0.486842	2.37689
2	Number of grain rows per ear	87.5758**	0.424242	4.23928**	5.25185**	3.13333**	43.7879**	1.50168	3.17778**	1.15623	1.61684	1.1156	0.0252574
3	Harvest index (%)	178.118**	4.19554	52.7503**	28.8107**	41.8076**	749.683**	9.64332**	9.28043**	9.58442**	15.501*	2.39358	0.484708

*,** Significant at 5 and 1 percent respectively (Model I)

Table 4: Extent of heterosis for Ear length (cm), 100-grain weight (g) and Grain yield per plant (g)

SN.	Crosses	Env	Ear length (cm)			100-grain weight (g)			Grain yield per plant (g)		
			RH	Hb	EH	RH	Hb	EH	RH	Hb	EH
1	P1 x P2	E1	42.86**	17.19**		3.33	1.64		47.62**	27.40**	
2	P1 x P2	E2	21.43**			17.70**	4.72		61.42**	47.48**	
3	P1 x P3	E1	14.29**	10.14		26.32**	22.03**		42.86**	41.51**	
4	P1 x P3	E2	14.83*	5.59		-4.42			47.50**	41.60**	
5	P1 x P4	E1	15.15**	11.76*		-0.88			26.75**	12.41*	
6	P1 x P4	E2	19.90**	12.35		-3.72			37.40**	29.01*	
7	P1 x P5	E1	0.00			2.52	1.67		44.17**	29.10**	
8	P1 x P5	E2	29.02**	20.75**		0.00			35.77**	16.98	
9	P1 x P6	E1	1.49			-27.63**			52.05**	29.57**	
10	P1 x P6	E2	22.24**	6.99		7.94	7.09		68.58**	50.68**	
11	P1 x P7	E1	4.17			5.10			22.05**	4.73	
12	P1 x P7	E2	4.46	0.93		3.50	2.31		35.09**	19.33	
13	P1 x P8	E1	39.06**	39.06**	5.95	27.73**	26.67**		123.57**	87.26**	8.89**
14	P1 x P8	E2	8.31	6.29		21.84**	6.30		124.76**	100.00**	
15	P1 x P9	E1	18.75**	18.75**		24.90**	20.47**		131.63**	128.44**	
16	P1 x P9	E2	19.37**	6.29		9.24*	7.09		107.20**	91.85**	
17	P1 x P10	E1	16.07**	1.56		25.11**	24.58**		113.28**	90.37**	
18	P1 x P10	E2	8.20	0.00		11.11*	6.30		88.95**	69.75**	
19	P2 x P3	E1	40.00**	11.59*		33.62**	27.05**		66.40**	42.47**	
20	P2 x P3	E2	44.22**	26.39**		27.60**	15.57**		70.45**	61.87**	
21	P2 x P4	E1	24.77**	0.00		6.90*	1.64		22.26**	18.49**	
22	P2 x P4	E2	37.15**	18.13*		31.78**	22.61**		62.96**	58.27**	
23	P2 x P5	E1	64.84**	50.00**		30.58**	29.51**		95.00**	86.99**	1.11
24	P2 x P5	E2	42.95**	23.26**		35.51**	26.09**		67.79**	57.23**	
25	P2 x P6	E1	54.95**	22.86**	2.38	16.48**	9.35**		55.14**	52.82**	
26	P2 x P6	E2	65.94**	52.80**		37.95**	23.60**		78.25**	73.97**	
27	P2 x P7	E1	19.01**			16.60**	10.22**		14.29**	13.51*	
28	P2 x P7	E2	20.42**	1.00		13.10*			34.95**	30.00*	
29	P2 x P8	E1	79.05**	46.87**	11.90**	25.62**	24.59**		91.09**	84.39**	7.22*
30	P2 x P8	E2	37.72**	14.04*		51.86**	48.48**		74.52**	69.49**	
31	P2 x P9	E1	27.62**	4.69		8.43**	6.30		76.47**	54.11**	
32	P2 x P9	E2	30.36**	17.91*		10.41*			62.04**	59.71**	
33	P2 x P10	E1	91.01**	77.08**	1.19	5.44	3.28		25.98**	21.23**	
34	P2 x P10	E2	37.64**	20.05**		14.42**	6.03		39.06**	36.49**	
35	P3 x P4	E1	10.95*	10.14		14.55**	14.55**		31.12**	15.33*	
36	P3 x P4	E2	15.65*	13.33		-10.55*			25.78*	22.90	

37	P3 x P5	E1	61.34**	39.13**	14.29**	40.00**	34.17**		152.10**	123.88**	11.11**
38	P3 x P5	E2	22.34**	20.05**		-8.86			97.18**	76.10**	
39	P3 x P6	E1	-2.16			15.02**	3.02		22.59**	3.65	
40	P3 x P6	E2	12.32	6.39		0.40			43.91**	33.56**	
41	P3 x P7	E1	-10.07*			19.84**	8.03*		31.75**	12.16*	
42	P3 x P7	E2	13.68*	8.00		-13.49**			31.64**	20.67	
43	P3 x P8	E1	17.29**	13.04*		33.91**	28.33**		76.25**	46.50**	
44	P3 x P8	E2	20.05**	12.35		-1.20			59.27**	47.12**	
45	P3 x P9	E1	-2.26			1.27			93.43**	88.99**	
46	P3 x P9	E2	14.24*	10.28		14.75**	14.75**		67.69**	61.48**	
47	P3 x P10	E1	26.50**	7.25		6.61*	3.42		52.30**	34.81**	
48	P3 x P10	E2	21.55**	20.88**		-9.24			63.37**	52.43**	
49	P4 x P5	E1	35.59**	17.65**		24.35**	19.17**		38.01**	36.50**	
50	P4 x P5	E2	20.43**	20.27**		-6.09			62.07**	47.80**	
51	P4 x P6	E1	15.94**	14.29**		2.81			24.52**	18.94**	
52	P4 x P6	E2	41.75**	31.73**		-11.67*			50.18**	42.47**	
53	P4 x P7	E1	-35.14**			0.40			9.47	5.41	
54	P4 x P7	E2	-0.39			-2.86			30.25**	22.00	
55	P4 x P8	E1	12.12*	8.82		13.91**	9.17*		14.97**	7.64	
56	P4 x P8	E2	12.94*	7.75		28.82**	17.39**		42.19**	34.24**	
57	P4 x P9	E1	27.27**	23.53**	0.00	13.08**	5.51		28.46**	15.33*	
58	P4 x P9	E2	21.97**	15.47*		20.25**	16.80**		25.56*	23.70	
59	P4 x P10	E1	-17.24**			2.20			6.62	5.84	
60	P4 x P10	E2	26.12**	24.27**		-7.79			34.38**	28.18*	
61	P5 x P6	E1	21.67**	4.29		-8.88**			1.23		
62	P5 x P6	E2	30.17**	21.12**		37.50**	32.00**		14.10	9.43	
63	P5 x P7	E1	16.92**			8.17**	1.46		110.64**	100.68**	10.00**
64	P5 x P7	E2	6.20	2.75		-1.22			82.52**	77.36**	
65	P5 x P8	E1	66.67**	48.44**	13.10**	13.33**	13.33**		114.43**	98.73**	15.56**
66	P5 x P8	E2	25.03**	19.13**		23.09**	12.17*		74.88**	68.55**	
67	P5 x P9	E1	38.60**	23.44**		10.93**	7.87*		117.28**	97.01**	
68	P5 x P9	E2	14.53*	8.56		14.77**	11.48*		78.23**	64.78**	
69	P5 x P10	E1	42.86**	40.00**		23.21**	21.67**		59.11**	58.52**	
70	P5 x P10	E2	18.16**	16.58*		3.90	3.45		35.17**	28.93*	
71	P6 x P7	E1	-9.33*			-0.72			16.58**	15.61**	
72	P6 x P7	E2	25.76**	13.50*		-7.45			26.35*	24.67*	
73	P6 x P8	E1	44.78**	38.57**	15.48**	45.95**	35.97**	5.59*	110.08**	105.73**	19.63**
74	P6 x P8	E2	25.44**	11.62		14.75**	0.80		109.20**	108.14**	0.66
75	P6 x P9	E1	5.97	1.43		-1.50			54.14**	32.89**	
76	P6 x P9	E2	13.55	11.34		-6.88			60.14**	54.11**	
77	P6 x P10	E1	23.73**	4.29		-11.72**			12.08*	6.31	
78	P6 x P10	E2	28.57**	21.15**		-3.73			36.40**	35.62**	
79	P7 x P8	E1	-1.39			19.84**	12.41**		10.16*	7.01	
80	P7 x P8	E2	14.39*	12.59		19.32**	3.08		23.70*	22.67	
81	P7 x P9	E1	-8.33			7.58**	3.65		50.19**	30.41**	
82	P7 x P9	E2	-16.19*			15.08**	11.54*		17.89	12.00	
83	P7 x P10	E1	-1.56			50.39**	39.42**	6.70**	73.14**	65.54**	
84	P7 x P10	E2	1.57			-1.63			52.89**	50.00**	
85	P8 x P9	E1	10.94*	10.94		0.40			39.10**	17.83**	
86	P8 x P9	E2	5.08			24.65**	10.66		38.76**	32.88**	
87	P8 x P10	E1	33.93**	17.19**		18.99**	17.50**		39.73**	29.94**	
88	P8 x P10	E2	20.98**	13.80*		27.26**	15.52**		52.14**	50.51**	
89	P9 x P10	E1	-5.36			14.75**	10.24**		64.75**	48.89**	
90	P9 x P10	E2	-7.01			-11.76*			33.89**	29.56*	

Table 5: Extent of heterosis for Ear girth (cm), Number of grain rows per ear and Harvest index (%)

SN.	Crosses	Env	Ear girth (cm)			Number of grain rows per ear			Harvest index (%)		
			RH	Hb	EH	RH	Hb	EH	RH	Hb	EH
1	P1 x P2	E1	28.16**	26.92**		25.00**	25.00**		12.28**	5.31	
2	P1 x P2	E2	13.06**	0.00		16.67**	0.00		14.95**	12.59**	
3	P1 x P2	Pool	19.86**	12.30**		20.59**	10.81*		13.61**	8.87**	
4	P1 x P3	E1	19.27**	12.07		2.86			12.49**	11.24**	
5	P1 x P3	E2	13.77**	5.92		7.32	4.76		21.36**	21.11**	
6	P1 x P3	Pool	16.25**	14.92**		5.26	2.56		17.05**	16.28**	
7	P1 x P4	E1	14.29*	4.92		8.57			-2.12		
8	P1 x P4	E2	1.04			2.44	0.00		3.53	2.50	
9	P1 x P4	Pool	7.06*	5.94		5.26	2.56		0.72		
10	P1 x P5	E1	11.32	7.27		18.75**	18.75*		2.74		

11	P1 x P5	E2	3.91	1.13		5.00	0.00		3.38		
12	P1 x P5	Pool	7.13*	7.04		11.11*	8.11		3.07		
13	P1 x P6	E1	8.91	7.84		17.65**	11.11		5.70		
14	P1 x P6	E2	12.70**			10.53	0.00		13.63**	6.89*	
15	P1 x P6	Pool	10.99**	1.80		13.89**	10.81*		9.67**	1.33	
16	P1 x P7	E1	-3.39			2.86			4.75		
17	P1 x P7	E2	-3.28			-4.76			13.76**	10.71**	
18	P1 x P7	Pool	-3.33			-1.30			9.25**	4.00	
19	P1 x P8	E1	34.45**	17.65**	17.65**	8.11			26.23**	24.12**	0.82
20	P1 x P8	E2	-1.34			0.00			21.96**	17.80**	
21	P1 x P8	Pool	15.48**	11.43**		3.90	0.00		24.11**	22.99**	
22	P1 x P9	E1	14.04*	3.17		5.88	0.00		39.23**	34.38**	13.40**
23	P1 x P9	E2	5.65	0.00		7.69	0.00		36.54**	27.83**	10.96**
24	P1 x P9	Pool	9.50**	7.59		6.85	5.41		37.83**	30.92**	13.23**
25	P1 x P10	E1	28.16**	26.92**		21.21**	17.65*		20.68**	16.05**	
26	P1 x P10	E2	9.80*	2.54		2.44	0.00		18.00**	14.52**	
27	P1 x P10	Pool	17.83**	13.77**		10.81*	10.81*		19.32**	15.28**	
28	P2 x P3	E1	16.36**	10.34		2.86			22.84**	14.01**	2.19
29	P2 x P3	E2	26.42**	19.61**		20.00**	5.00		31.05**	28.10**	1.15
30	P2 x P3	Pool	21.52**	15.10**		11.43*	0.00		26.95**	20.89**	2.64
31	P2 x P4	E1	4.42			8.57			0.20		
32	P2 x P4	E2	16.75**	8.49		8.57			18.64**	17.37**	
33	P2 x P4	Pool	10.73**	2.73		8.57			9.25**	7.55**	
34	P2 x P5	E1	42.06**	38.18**	11.76*	18.75**	18.75*		14.25**	10.91**	
35	P2 x P5	E2	15.27**	4.46		17.65**	5.26		4.76		
36	P2 x P5	Pool	27.80**	19.64**		18.18**	11.43*		9.41**	8.00**	
37	P2 x P6	E1	31.37**	28.85**		5.88	0.00		5.66	2.02	
38	P2 x P6	E2	34.21**	30.77**		25.00**	17.65*		21.37**	16.46**	0.07
39	P2 x P6	Pool	32.82**	29.83**		15.15**	8.57		13.36**	9.12**	0.15
40	P2 x P7	E1	9.24			14.29*	5.26		-4.18		
41	P2 x P7	E2	10.82*			11.11			4.08	3.39	
42	P2 x P7	Pool	10.05**			12.68**	0.00		-0.15		
43	P2 x P8	E1	26.67**	11.76*	11.76*	-2.70			19.11**	13.53**	1.75
44	P2 x P8	E2	16.47**	8.54		11.76			20.93**	14.49**	
45	P2 x P8	Pool	21.61**	10.21**		4.23			20.00**	14.00**	
46	P2 x P9	E1	14.78*	4.76		17.65**	11.11		16.06**	12.67**	0.99
47	P2 x P9	E2	17.29**	9.15		21.21**	11.11		15.07**	9.87**	
48	P2 x P9	Pool	16.05**	6.96		19.40**	11.11*		15.56**	14.50**	
49	P2 x P10	E1	40.38**	40.38**	7.35	27.27**	23.53**	0.00	4.46	1.78	
50	P2 x P10	E2	23.58**	16.56**		37.14**	20.00**	0.00	11.99**	10.94**	
51	P2 x P10	Pool	31.52**	27.46**		32.35**	21.62**	0.00	8.21**	7.29**	
52	P3 x P4	E1	9.24	6.56		-10.53			0.72		
53	P3 x P4	E2	10.90*	8.81		5.00	5.00		3.75	2.50	
54	P3 x P4	Pool	10.09**	7.70		-2.56			2.25		
55	P3 x P5	E1	41.59**	37.93**	17.65**	20.00**	10.53	0.00	24.65**	19.01**	0.43
56	P3 x P5	E2	13.40**	8.33		2.56	0.00		4.61		
57	P3 x P5	Pool	26.59**	25.04**	3.95	10.81*	5.13		14.16**	7.38**	
58	P3 x P6	E1	22.22**	13.79*		2.70			-5.33		
59	P3 x P6	E2	21.42**	12.09*		8.11	0.00		4.24		
60	P3 x P6	Pool	21.81**	12.92**		5.41	0.00		-0.52		
61	P3 x P7	E1	5.60			-5.26			6.64*		
62	P3 x P7	E2	1.53			-2.44			12.03**	8.80*	
63	P3 x P7	Pool	3.52			-3.80			9.34**	3.45	
64	P3 x P8	E1	1.59			-5.00			21.86**	18.50**	
65	P3 x P8	E2	3.54	1.90		2.56	0.00		17.99**	14.19**	
66	P3 x P8	Pool	2.56			-1.27			19.92**	19.63**	
67	P3 x P9	E1	2.48			8.11	5.26		10.09**	5.11	
68	P3 x P9	E2	13.64**	11.67*		15.79**	10.00		8.12**	1.02	
69	P3 x P9	Pool	8.14*	5.06		12.00**	7.69		9.07**	2.96	
70	P3 x P10	E1	25.45**	18.97**	1.47	11.11	5.26		8.35*	3.08	
71	P3 x P10	E2	9.12*	8.77		5.00	5.00		14.53**	10.92**	
72	P3 x P10	Pool	16.84**	14.09**		7.89	5.13		11.51**	7.05**	
73	P4 x P5	E1	10.34	4.92		20.00**	10.53	0.00	12.08**	11.03**	
74	P4 x P5	E2	12.54**	9.52*		7.69	5.00		14.97**	7.93*	
75	P4 x P5	Pool	11.51**	10.43**		13.51**	7.69		13.56**	10.38**	
76	P4 x P6	E1	17.12**	6.56		-8.11			-6.33*		
77	P4 x P6	E2	20.28**	9.12		2.70			3.21		
78	P4 x P6	Pool	18.73**	7.87*		-2.70			-1.63		
79	P4 x P7	E1	0.00			-5.26			0.98		

80	P4 x P7	E2	-5.42			-12.20*			16.13**	14.14**	
81	P4 x P7	Pool	-2.76			-8.86*			8.41**	6.01*	
82	P4 x P8	E1	5.43	0.00	0.00	0.00			5.27	2.35	
83	P4 x P8	E2	3.47	3.14		-2.56			26.04**	20.56**	
84	P4 x P8	Pool	4.46	1.83		-1.27			15.43**	11.34**	
85	P4 x P9	E1	12.90*	11.11	2.94	-2.70			6.33	5.34	
86	P4 x P9	E2	14.02**	13.84**		5.26	0.00		5.37		
87	P4 x P9	Pool	13.47**	12.66**		1.33			5.84**	3.25	
88	P4 x P10	E1	7.96			5.56			8.14*	7.52*	
89	P4 x P10	E2	11.18*	9.43		5.00	5.00		22.59**	20.15**	
90	P4 x P10	Pool	9.66**	4.82		5.26	2.56		15.36**	14.53**	
91	P5 x P6	E1	25.71**	20.00**		5.88	0.00		-6.01*		
92	P5 x P6	E2	22.02**	8.04		16.67**	10.53		3.82	2.57	
93	P5 x P6	Pool	23.75**	13.42**		11.43*	11.43*		-0.99		
94	P5 x P7	E1	22.95**	11.94*	10.29	2.86			17.56**	13.35**	3.04
95	P5 x P7	E2	4.69	3.18		5.00	0.00		8.95**	3.97	
96	P5 x P7	Pool	13.31**	7.49*		4.00			13.17**	12.48**	
97	P5 x P8	E1	26.83**	14.71**	14.71**	13.51*	0.00	0.00	24.53**	22.20**	3.13
98	P5 x P8	E2	12.27**	8.93		15.79**	15.79*		8.65**		
99	P5 x P8	Pool	19.34**	15.24**	2.86	14.67**	7.50		16.44**	9.28**	
100	P5 x P9	E1	20.34**	12.70*	4.41	5.88	0.00		17.29**	17.29**	
101	P5 x P9	E2	15.47**	12.20*		8.11	5.26		10.10**	9.31**	
102	P5 x P9	Pool	17.78**	15.82**		7.04	5.56		13.48**	13.05**	
103	P5 x P10	E1	21.50**	18.18**		21.21**	17.65*		16.00**	15.57**	
104	P5 x P10	E2	15.84**	11.01*		17.95**	15.00*		4.03		
105	P5 x P10	Pool	18.41**	14.24**		19.44**	16.22**		9.79**	7.48**	
106	P6 x P7	E1	14.53*			-2.70			-2.53		
107	P6 x P7	E2	14.05**			15.79**	4.76		10.37**	6.57*	
108	P6 x P7	Pool	14.29**			6.67	0.00		3.79	0.57	
109	P6 x P8	E1	35.59**	17.65**	17.65**	-7.69			17.35**	8.18*	4.15
110	P6 x P8	E2	18.26**	7.59		22.22**	15.79*		22.71**	11.73**	
111	P6 x P8	Pool	27.04**	12.80**	0.68	6.67	0.00		19.97**	9.93**	0.89
112	P6 x P9	E1	15.04*	3.17		11.11	11.11		-4.27		
113	P6 x P9	E2	21.18**	10.09*		20.00**	16.67*		-1.84		
114	P6 x P9	Pool	18.14**	6.65		15.49**	13.89**		-3.03		
115	P6 x P10	E1	25.49**	23.08**		14.29*	11.11		-4.23		
116	P6 x P10	E2	20.28**	10.71*		13.51*	5.00		7.58**	4.17	
117	P6 x P10	Pool	22.75**	16.37**		13.89**	10.81*		1.66		
118	P7 x P8	E1	-8.15			-25.00**			8.53**	2.75	
119	P7 x P8	E2	-1.21			-10.00			20.68**	13.54**	
120	P7 x P8	Pool	-4.71			-17.50**			14.44**	8.02**	
121	P7 x P9	E1	-1.54			8.11	5.26		1.69		
122	P7 x P9	E2	1.96			2.56			-8.86**		
123	P7 x P9	Pool	0.23			5.26	0.00		-3.67		
124	P7 x P10	E1	26.05**	11.94*	10.29	16.67**	10.53	0.00	16.81**	13.02**	2.75
125	P7 x P10	E2	11.31**	5.20		7.32	4.76		15.71**	15.38**	
126	P7 x P10	Pool	18.33**	8.52*	0.54	11.69**	7.50		16.26**	14.50**	
127	P8 x P9	E1	-3.82			-7.69			11.94**	9.85**	
128	P8 x P9	E2	8.06	7.89		8.11	5.26		15.86**	5.01	
129	P8 x P9	Pool	2.02	0.15		-0.00			13.93**	7.30**	
130	P8 x P10	E1	10.00			5.26			10.55**	8.08*	
131	P8 x P10	E2	10.58*	9.18		12.82*	10.00		15.10**	8.00*	
132	P8 x P10	Pool	10.29**	2.90		9.09*	5.00		12.80**	8.04**	
133	P9 x P10	E1	23.48**	12.70*	4.41	14.29*	11.11		9.98**	9.57*	
134	P9 x P10	E2	10.40*	8.83		21.05**	15.00*		-1.51		
135	P9 x P10	Pool	16.67**	10.76**		17.81**	16.22**		4.04	2.23	

4. Conclusion

It is inferred from the above finding that heterotic effects were observed for the important yield and yield contributing traits indicating genetic diversity existing among the parents involved in these crosses. Existence of economic heterosis for grain yield in *Kharif* and non-existence in *Rabi* indicates that the hybrids under study were suitable only for *Kharif* season. So for the actual exploitation of above single cross hybrids in the field it would recommend to carry out their large scale multi location testing in the *Kharif* season to identify the heterotic hybrids.

5. References

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