International Journal of Bio-resource and Stress Management 2017, 8(1):012-019

Full Research

Doi: HTTPS://DOI.ORG/10.23910/IJBSM/2017.8.1.1748

Exploitation of Heterosis in Single Cross Hybrids of Quality Protein Maize (*Zea maize* L.) for Yield and Quality Traits

Prashant Bisen*, Amit Dadheech, Namrata, Omprakash Nagar and Ram Kunwar Meena

Dept. of Plant Breeding and Genetics, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur (313 001), India

Corresponding Author

Prashant Bisen
e-mail: prashant.bgt@gmail.com

Article History

Manuscript No. AR1748
Received in 12th Dec, 2016
Received in revised form 28th Jan, 2017
Accepted in final form 6th Feb, 2017

Abstract

Forty-five single-cross hybrids developed from ten inbred lines of quality protein maize through diallel mating design along with four checks viz., Pratap QPM Hybrid-1, Vivek QPM-9, HQPM-1 and HQPM-5 were evaluated in randomized block design with three replications for seventeen traits during *kharif*-2014, to identify the heterotic superiority of the New cross combinations over the parents and best check. Out of 45 crosses, 42 crosses over mid parent, 37 crosses over better parent and 6 crosses over standard check (HQPM-5) significantly out yielded for grain yield plant^{-1}. Hybrid $P_6 \times P_8$ showed maximum *per se* performance for grain yield plant^{-1}, stover yield plant^{-1}, ear length, ear girth and tryptophan content also showed good *per se* performance for oil content (6.13%), starch content (69.83%), protein content (10.52%) and for lysine content (4.19%) with maximum positive significant economic heterosis (19.63%) for grain yield plant^{-1}, over the best check HQPM-5. Hybrid $P_5 \times P_8$ showed highest *per se* performance along with maximum positive significant economic heterosis for lysine content and protein content over the best check Vivek QPM-9 and HQPM-5, respectively. Another hybrid $P_3 \times P_5$ and $P_5 \times P_7$ exhibited highest *per se* performance for oil content and starch content, respectively, along with maximum positive significant economic heterosis over the best check HQPM-5 and HQPM-1, respectively.

Keywords: Heterosis, heterobeltiosis, QPM, grain yield, lysine, tryptophan

1. Introduction

Maize (*Zea mays* L.) occupies a prestigious place in the world agriculture. It is a miracle crop in view of its widespread usage as food and nonfood items (Lone et al., 2016). It is also considered as the third important cereal crop in the world after rice and wheat (Devi et al., 2016). Globally, maize has gained tremendous importance as a source of basic raw material for a no. of industries due to rising demand from diversified sectors like human food, animal feed and also serves. Maize grains contain about 9.9% protein, 4% oil, 70% starch and 2.7% crude fiber. Maize oil has high calorific value and is highly suitable especially for heart patients. Maize contains a high percentage of unsaturated fatty acids like oleic acid and linoleic acid and has a very low content of cholesterol. Maize has low protein content with low nutritional quality due to presence of limited amount of essential amino acids, such as lysine, tryptophan and methionine (Bantte and Prasanna, 2003; Huang et al., 2006; Mbuya et al., 2011) and an excess of leucine and isoleucine, leading to a poor growth in children and pellagra in adults.

Quality protein maize (QPM) is bio fortified maize with increased lysine and tryptophan levels. QPM contains higher amount of lysine and tryptophan in the endosperm ensuring higher biological value and availability of protein to human and animal so it can help to get rid of human malnourishment (Hussain et al., 2015). The biological value of common maize is 45% whereas that of QPM is about 80% (Rajendran et al., 2014). Substituting normal maize with high lysine maize on an equal weight basis can maintain proper amino acid balance (Wilson, 1991).

Maize is a highly cross pollinated crop and the scope for the exploitation of hybrid vigour depend on the direction and magnitude of heterosis (Reddy et al., 2015). Hybrids are preferred over varieties in maize for their yield potential. The breeding method to be adopted for maize improvement depends on the nature of the gene action involved in the expression of quantitative traits of economic importance, and its strength depends on the genetic variability in the base populations and development of superior inbreds (Rajendran et al., 2014). Especially, in heterosis breeding the choice of good combiners play a vital role (Singh et al., 2012). The breeding strategy for exploitation of heterosis in maize (*Zea* *mays* L.) through the cultivation of single cross hybrids is primarily dependent on the development and identification of high per se performing diverse, vigorous and productive inbred lines with good seed quality.

The grain yield is the primary trait targeted for improvement of maize productivity through exploitation of heterosis (Ulaganathan et al., 2015). To overcome the problems associated with multi-parent hybrids, a shift was made from multi-parent to two-parent hybrids. One of the ways to break the productivity barrier is to develop and popularize high yielding single cross hybrids (Kanagarasu et al., 2010; Farhan et al., 2012). In the view of above facts and in order to develop and identify productive, nutritionally superior and industrially important single cross hybrids, the present investigation for yield and quality traits was undertaken.

2. Materials and Methods

2.1. Experimental site and design

The experimental material consisted of ten diverse inbred lines (Table 1) of quality protein maize 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% along with four standard checks were evaluated in randomized block design with three replications, in a single row plot of 4 m length, maintaining crop geometry of 60×25 cm^2 in *kharif*-2014. The Recommended package of practices of zone IVA of Rajasthan were adopted to raise a healthy crop.

2.2. Recording of data

The data were recorded from five randomly selected competitive plants on seventeen distinct morphological and quality characters, except days to 50% tasseling, days to 50% silking and days to 75% brown husk, where it was observed on complete plot basis. The data on plant height, ear height, ear length, ear girth, no. of grain rows ear^{-1}, 100-grain weight, grain yield plant^{-1}, stover yield plant^{-1}, Harvest index, grain oil content, starch content, protein content, tryptophan content and lysine content were recorded for statistical analysis.

2.3. Biochemical analysis

The total grain oil content was determined by Soxhlet Method (A.O.A.C., 1965), starch content by Anthrone reagent method (Morris, 1948), protein content by Micro-Kjeldahl's Method (Kalyana Babu et al., 2009).), tryptophan content by Papain Hydrolysis Method (Huang et al., 2006) and lysine content by using Colorimetric Method (Kalyana Babu et al., 2009).

2.4. 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. Relative heterosis/mid parent heterosis was calculated as per procedure suggested by Shull (1908). Heterobeltiosis/better parent heterosis was calculated as per procedure suggested by Fonesca and Patterson (1968). And Economic heterosis/standard heterosis were calculated as per procedure suggested by Briggle (1963).

Table 1: List of parental inbred lines and checks

Sl. No.	Inbred line symbol/code	Pedigree	Source
Details of parents			
1.	EIQ-105 (P_1)	CATCEYQ-72-5-4-2-2	AICRP on maize, Udaipur
2.	EIQ-106 (P_2)	CATCEYQ-72-2-1-1	AICRP on maize, Udaipur
3.	EIQ-107 (P_3)	CATCEYQ-72-9-1-2-2	AICRP on maize, Udaipur
4.	EIQ-108 (P_4)	CATCEYQ-72-10-3-4-2-1	AICRP on maize, Udaipur
5.	EIQ-109 (P_5)	CATCEYQ-72-11-7-1-1-2	AICRP on maize, Udaipur
6.	EIQ-110 (P_6)	CATCEYQ-72-9-3-6-1	AICRP on maize, Udaipur
7.	EIQ-111 (P_7)	CATCEYQ-72-13-1-1-4	AICRP on maize, Udaipur
8.	EIQ-112 (P_8)	CATCEYQ-72-8-2-3-2-2	AICRP on maize, Udaipur
9.	EIQ-113 (P_9)	CATCEYQ-72-5-2-3-1	AICRP on maize, Udaipur
10.	EIQ-114 (P_{10})	CATCEYQ-72 -3	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

The analysis of variance for experimental design (Table 2) revealed that the mean squares due to genotypes, parents, crosses and parents v/s crosses were significant for all the traits. Significant mean squares due to parents and crosses suggested that the parental lines selected were diverse and with a different genetic background. Similarly, significant mean squares due to parents vs. crosses indicated presence

Table 2: Analysis of variance for seventeen traits in quality protein maize

SV	df	Mean squares								
		DT 50% T	DT 50% S	DT 75% BH	PH	EH	EL	EG	N GRE	100 GW
Replication	2	13.82**	6.56*	3.33*	177.19*	290.04**	1.39	1.17	0.17	1.57
Genotype	54	25.46**	32.49**	36.06**	1211.56**	275.03**	11.6**	4.17**	2.70**	27.58**
Parent	9	31.87**	31.90**	36.70**	574.60**	330.60**	11.72**	3.78**	3.70**	8.11**
Crosses	44	19.55**	29.10**	32.75**	673.23**	192.82**	10.05**	2.98**	2.24**	28.08**
Parent vs. crosses	1	227.50**	186.88**	176.00**	30630.8**	339201**	97.82**	60.10**	14.30**	180.51**
Error	108	0.85	0.80	0.95	56.08	27.30	0.54	0.56	1.13	0.83

Table 2: Continue...

SV	df	Mean squares							
		GYP	SYP	HI	OC	SC	PC	TC	LC
Replication	2	15.81	54.89	1.34	0.0004	1.13*	0.004	1.8	0.001
Genotype	54	982.0**	934.73**	30.88**	1.55**	21.33**	3.004**	0.03**	1.30**
Parent	9	127.49**	256.08**	18.31**	1.55*	4.02**	2.09**	0.01**	0.18**
Crosses	44	853.21**	734.79**	27.90**	1.32**	18.70**	2.30**	0.024**	0.99**
Parent vs. crosses	1	14341.8**	15840.4**	274.80**	11.80**	293.05**	42.39**	0.47**	25.22**
Error	108	10.41	19.09	2.55	0.001	0.323	0.004	4.13	0.0003

SV: Source of variance; DT50% T: Days to 50% tasseling; DT50% S: Days to 50% silking; DT75% BH: Days to 75% brown husk; PH: Plant height; EH: Ear height; EL: Ear length; EG: Ear girth; NGRE: No. of grain rows ear^{-1}; 100 GW: 100 grain weight; GYP^{-1}: Grain yield plant^{-1}; SYP^{-1}: Stover yield plant^{-1}; HI: Harvest index; OC: Oil content; SC: Starch content; PC: Protein content; TC: Tryptophan content; LC: Lysine content; *, **Significant at (p=0.05) and (p=0.01) level of significance respectively

of considerable amount of variability and overall heterosis for all the traits under study. These results were in confirmation with Avinashe et al. (2013); Sundarajan and Kumar (2011).

3.1. *Per se performance*

The *per se* performance was advocated by Genter and Alexander (1962) as one of the method useful in evaluating parents for heterosis breeding in maize. The mean values of seventeen characters studied are presented in (Table 3).

A perusal of mean values of hybrids revealed that grain yield plant^{-1} ranged from 50.00 (P_1×P_3) to 107.67 g (P_6×P_8). The hybrid P_6×P_8 showed maximum mean values for ear length (16.17 cm.), ear girth (13.33 cm.), grain yield plant^{-1} (107.67 g plant^{-1}) and stover yield plant^{-1} (137.33 g plant^{-1}). Hybrid P_7×P_{10} exhibited maximum mean value for 100-grain weight (31.83 g). Hybrids P_2×P_{10}, P_4×P_5, P_5×P_8 and P_7×P_{10} exhibited maximum mean value for no. of grain rows ear^{-1} (14.00). Three hybrids P_1×P_8, P_3×P_5 and P_6×P_8 showed maximum mean values for ear girth (13.33 cm.). Hybrid P_1×P_9 exhibited maximum mean value for harvest index (47.86%).

A perusal of data on mean values of maturity traits revealed that hybrid P_2×P_4 exhibited minimum mean values for days to 50% silking (49.67 days), so we conclude that this hybrid comes under early maturity group.

The data on quality traits viz., oil, starch, protein, tryptophan and lysine content revealed that the hybrid P_3×P_5 exhibited maximum mean values for oil content (6.23%). The maximum mean value for starch content (70.02%) was depicted by hybrid P_5×P_7 whereas; hybrid P_5×P_8 exhibited maximum mean value for protein content (10.58%) and lysine content (4.25). The maximum mean value for tryptophan content (0.94%) was depicted by hybrid P_6×P_8.

3.2. *Magnitude of heterosis and heterobeltiosis*

A perusal of estimates of economic heterosis for grain yield plant^{-1} revealed that six hybrids P_6×P_8 (19.63%), P_5×P_8 (15.56%), P_3×P_5 (11.11%), P_5×P_7 (10.00%), P_1×P_8 (8.89%) and P_2×P_8 (7.22%) depicted positive significant economic heterosis for grain yield plant^{-1} over the best check HQPM- 5 (Table 4). Hybrid P_6×P_8 showed maximum economic heterosis (19.63%) for grain yield plant^{-1}.

A perusal of estimates of economic heterosis for ear length revealed that only four hybrids P_6×P_8 (15.48%), P_3×P_5 (14.29%), P_5×P_8 (13.10%) and P_2×P_8 (11.90%) depicted positive significant economic heterosis for ear length over the best check HQPM-1. Six hybrids P_6×P_8 (17.65%), P_3×P_5 (17.65%), P_1×P_8 (17.65%), P_5×P_8 (14.71%), P_2×P_5 (11.76%) and P_2×P_8 (11.76%) exhibited significant economic heterosis for ear girth over the best check Vivek QPM- 9 and HQPM-5. Only two hybrids P_7×P_{10} (6.70%) and P_6×P_8 (5.59%) exhibited significant economic heterosis for

Table 3: *per se* performance of five best hybrids along with parents for all seventeen traits in quality protein maize

Sl. No.	Genotype	Days to 50% silking	Ear length (cm)	Ear girth (cm)	No. of grain rows ear^{-1}	100-grain weight (g)	Grain yield plant^{-1} (g)	Stover yield plant^{-1} (g)
Parents								
1.	P_1	63.33	10.67	8.50	10.67	19.67	35.33	71.33
2.	P_2	62.00	6.83	8.67	10.67	20.33	48.67	80.00
3.	P_3	59.67	11.50	9.67	12.67	18.33	34.67	72.67
4.	P_4	64.67	11.33	10.17	12.67	18.33	45.67	80.00
5.	P_5	64.33	8.33	9.17	10.67	20.00	44.67	80.67
6.	P_6	61.33	11.67	8.33	12.00	23.17	50.17	73.33
7.	P_7	60.67	13.33	11.17	12.67	22.83	49.33	80.00
8.	P_8	55.33	10.67	11.33	14.00	20.00	52.33	100.33
9.	P_9	63.00	10.67	10.50	12.00	21.17	36.33	65.67
10.	P_{10}	67.33	8.00	8.67	11.33	19.50	45.00	80.33
Hybrids								
1.	$P_1 \times P_8$	55.67	14.83	13.33	13.33	25.33	98.00	132.33
2.	$P_3 \times P_5$	57.33	16.00	13.33	14.00	26.83	100.00	136.00
3.	$P_5 \times P_7$	58.67	12.67	12.50	12.00	23.17	99.00	128.67
4.	$P_5 \times P_8$	56.67	15.83	13.00	14.00	22.67	104.00	135.00
5.	$P_6 \times P_8$	55.67	16.17	13.33	12.00	31.50	107.67	137.33
Checks								
1.	Pratap QPM- 1	55.33	10.67	10.00	12.00	27.00	77.00	111.67
2.	Vivek QPM- 9	51.00	12.83	11.33	14.00	29.83	80.33	110.00
3.	HQPM- 1	61.67	14.00	11.00	12.67	25.67	86.00	120.00
4.	HQPM- 5	61.67	12.50	11.33	14.00	26.33	90.00	131.67
	PM	62.17	10.30	9.62	11.93	20.33	44.22	78.43
	FM	59.41	12.30	11.18	12.70	23.05	68.39	103.84
	CM	57.42	12.50	10.92	13.17	27.21	83.33	118.33
	GM	58.60	11.84	10.75	12.41	22.54	64.54	99.15
	SEm±	0.51	0.42	0.44	0.62	0.51	1.93	2.74
	CD (p=0.05)	1.43	1.18	1.24	1.73	1.44	5.40	7.69
	CD (p=0.01)	1.89	1.56	1.64	2.29	1.90	7.15	10.16

Table 3: Continue...

Sl. No.	Genotype	Harvest index (%)	Grain oil content (%)	Starch content (%)	Grain protein content (%)	Tryptophan content (%)	Lysine content (%)
Parents							
1.	P_1	33.13	3.24	59.72	8.00	0.47	1.78
2.	P_2	37.82	3.29	61.15	7.15	0.51	1.81
3.	P_3	32.39	3.14	62.96	8.45	0.60	1.81
4.	P_4	36.29	4.21	62.44	8.10	0.53	2.20
5.	P_5	35.61	3.02	60.29	7.92	0.58	2.11
6.	P_6	40.63	4.96	62.04	6.07	0.56	1.61
7.	P_7	38.36	5.01	60.70	7.02	0.56	1.99

Continue...

Sl. No.	Genotype	Harvest index (%)	Grain oil content (%)	Starch content (%)	Grain protein content (%)	Tryptophan content (%)	Lysine content (%)
8.	P_8	34.28	3.85	62.29	7.24	0.41	1.46
9.	P_9	35.61	3.77	61.08	6.12	0.50	2.12
10.	P_{10}	35.88	3.59	63.13	8.00	0.53	1.61
Hybrids							
1.	P_1×P_8	42.55	5.82	69.44	10.29	0.93	4.02
2.	P_3×P_5	42.38	6.23	66.31	10.34	0.84	3.26
3.	P_5×P_7	43.48	4.71	70.02	9.75	0.67	2.92
4.	P_5×P_8	43.52	5.53	69.13	10.58	0.92	4.25
5.	P_6×P_8	43.95	6.13	69.83	10.52	0.94	4.19
1.	Pratap QPM- 1	40.86	4.68	64.84	9.49	0.70	3.23
2.	Vivek QPM- 9	42.20	4.17	67.79	8.65	0.81	4.16
3.	HQPM- 1	41.79	4.93	68.12	10.05	0.91	3.73
4.	HQPM- 5	40.61	5.77	68.00	10.16	0.75	3.49
	PM	36.00	3.81	61.58	7.41	0.53	1.85
	FM	39.35	4.50	65.04	8.72	0.66	2.86
	CM	41.36	4.89	67.19	9.59	0.79	3.65
	GM	38.31	4.35	63.53	8.42	0.64	2.72
	SEm±	0.94	0.02	0.33	0.04	0.00	0.01
	CD (*p*=0.05)	2.64	0.06	0.93	0.10	0.01	0.03
	CD (*p*=0.01)	3.49	0.07	1.24	0.13	0.01	0.04

Table 4: Five best hybrids identified on the basis of *per se* performance and economic heterosis for grain yield plant^{-1} along with their economic heterosis for quality traits

Sl. No.	Hybrids	PPGYP (g)	EHGY (%)	DS	EHG (%)	EHS (%)	EH (%)	EHT (%)	EHL (%)
1.	(P_6×P_8)	107.67	19.63**	55.67	6.36**	2.51**	3.58**	3.66**	0.80**
2.	(P_5×P_8)	104.00	15.56**	56.67	-	1.48**	4.14**	1.10	2.08**
3.	(P_3×P_5)	100.00	11.11**	57.33	8.09**	-	1.81**	-	-
4.	(P_5×P_7)	99.00	10.00**	58.67	-	2.78**	-	-	-
5.	(P_1×P_8)	98.00	8.89**	55.67	0.98**	1.93**	1.31**	2.26**	-
6.	HQPM- 5	90.00	-	61.67	-	-	-	-	-
7.	HQPM- 1	86.00	-	61.67	-	-	-	-	-
8.	Vivek QPM-9	80.33	-	51.00	-	-	-	-	-
9.	Pratap QPM hybrid- 1	77.00	-	55.33	-	-	-	-	-

PPGYP: *Per se* performance for grain yield plant^{-1}; EHGY: Economic heterosis (%) for grain yield plant^{-1} over the best check HQPM-5; DS: Days to 50% silking; EHG: Economic heterosis (%) for grain oil content over best check HQPM-5; EHS: Economic heterosis (%) for starch content over best check HQPM-5; EH: Economic heterosis (%) for grain protein content HQPM-5; EHT: Economic heterosis (%) for tryptophan content over best check HQPM-1; EHL: Economic heterosis (%) for lysine content over best check Vivek QPM-9

100 grain weight over the best check Vivek QPM-9. Only one hybrid namely P_1×P_9 exhibited positive significant economic heterosis for harvest index (13.40%) over the best check Vivek QPM-9. Kumar et al. (2013); Netravati et al. (2013); Khan et al. (2014); Verma et al. (2014) also reported economic heterosis in maize for yield and its contributing traits.

A perusal of quality traits revealed that only three hybrids depicted positive significant economic heterosis for grain oil content. The hybrid P_3×P_5 exhibited maximum positive significant economic heterosis (8.09%) for grain oil content over the best check HQPM-5. Five hybrids depicted positive significant economic heterosis for starch content. The hybrid P_5×P_7 exhibited maximum positive significant economic heterosis for starch content (2.78%) over the best check HQPM-1. In case of protein content five hybrids exhibited positive significant economic heterosis for this trait. The maximum positive significant economic heterosis for this trait was exhibited by hybrid P_5×P_8 (4.14%) over the best check HQPM-5. For tryptophan contant only two hybrids exhibited positive significant economic heterosis. The maximum positive significant economic heterosis for this trait was exhibited by hybrid P_6×P_8 (3.66%) over the best check HQPM-1. In case of lysine content four hybrids exhibited positive significant economic heterosis. Out of them the maximum positive significant economic heterosis was exhibited by hybrid P_5×P_8 (2.08%) over the best check Vivek QPM-9 (Table 4). Singh et al. (2013), Chahar et al. (2014), Lahane et al. (2014) reported economic heterosis for quality traits in maize. Only one hybrid namely P_2×P_4 (-2.46%) exhibited negative significant economic heterosis for days to 75% brown husk. Five best identified hybrids having highest estimates of significant positive economic heterosis for grain yield plant^{-1} were viz., P_6×P_8, P_5×P_8, P_3×P_5, P_5×P_7, P_1×P_8 (Table 5). Of these hybrids, few hybrids also showed higher estimates of significant positive economic heterosis for oil content (P_6×P_8 and P_1×P_8), starch content (P_5×P_7, P_6×P_8 and P_5×P_8), protein content (P_5×P_8, P_6×P_8,

Table 5: Extent of heterosis for best five hybrids for yield, yield contributing and quality traits

Sl. No.	Crosses	Ear length (cm)			Ear girth (cm)			No. of grain rows ear^{-1}		
		RH	HB	EH	RH	HB	EH	RH	HB	EH
1.	P_1×P_8	39.06**	39.06**	5.95	34.45**	17.65**	17.65**	8.11	-	-
2.	P_3 × P_5	61.34**	39.13**	14.29**	41.59**	37.93**	17.65**	20.00**	10.53	0.00
3.	P_5×P_7	16.92**	-	-	22.95**	11.94*	10.29	2.86	-	-
4.	P_5×P_8	66.67**	48.44**	13.10**	26.83**	14.71**	14.71**	13.51*	0.00	0.0-0
5.	P_6×P_8	44.78**	38.57**	15.48**	35.59**	17.65**	17.65**	-7.69	-	-

Table 5: Continue...

Sl. No.	Crosses	100-Grain weight (g)			Grain yield plant^{-1} (g)			Stover yield plant^{-1} (g)		
		RH	HB	EH	RH	HB	EH	RH	HB	EH
1.	P_1×P_8	27.73**	26.67**	-	123.57**	87.26**	8.89**	54.17**	31.89**	0.51
2.	P_3×P_5	40.00**	34.17**	-	152.10**	123.88**	11.11**	77.39**	68.60**	3.29
3.	P_5×P_7	8.17**	1.46	-	110.64**	100.68**	10.00**	60.17**	59.50**	-
4.	P_5×P_8	13.33**	13.33**	-	114.43**	98.73**	15.56**	49.17**	34.55**	2.53
5.	P_6×P_8	45.95**	35.97**	5.59*	110.08**	105.73**	19.63**	58.16**	36.88**	4.30

Table 5: Continue...

Sl. No.	Crosses	Harvest index (%)			Grain oil content (%)			Starch content (%)		
		RH	HB	EH	RH	HB	EH	RH	HB	EH
1.	P_1×P_8	26.23**	24.12**	0.82	64.11**	51.12**	0.98*	13.82**	11.48**	1.93**
2.	P_3×P_5	24.65**	19.01**	0.43	102.49**	98.51**	8.09**	7.60**	5.32**	-
3.	P_5×P_7	17.56**	13.35**	3.04	17.36**	-	-	15.74**	15.35**	2.78**
4.	P_5×P_8	24.53**	22.20**	3.13	61.09**	43.60**	-	12.79**	10.99**	1.48*
5.	P_6×P_8	17.35**	8.18*	4.15	39.18**	23.66**	6.36**	12.34**	12.11**	2.51**

Table 5: Continue...

Sl. No.	Crosses	Grain protein content (%)			Tryptophan content (%)			Lysine content (%)		
		RH	HB	EH	RH	HB	EH	RH	HB	EH
1.	P_1×P_8	35.01**	28.62**	1.31*	112.12**	97.18**	2.56**	147.43**	125.23**	-
2.	P_3×P_5	26.28**	22.32**	1.81**	41.41**	38.67**	-	66.16**	54.59**	-
3.	P_5×P_7	30.54**	23.10**	-	18.48**	16.09**	-	42.28**	38.45**	-
4.	P_5×P_8	39.47**	33.49**	4.14**	86.49**	58.62**	1.10	137.91**	101.58**	2.08**
5.	P_6×P_8	58.08**	45.24**	3.58**	94.50**	67.46**	3.66**	172.89**	160.46**	0.80*

$P_3 \times P_5$ and $P_1 \times P_8$), tryptophan content ($P_6 \times P_8$ and $P_1 \times P_8$), lysine content ($P_5 \times P_8$ and $P_6 \times P_8$).

Relative heterosis (MP) and heterobeltiosis (BP) 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. Heterobeltiosis for grain yield plant^{-1} was exhibited by 37 hybrids with maximum heterobeltiosis depicted by the hybrid $P_1 \times P_9$. This hybrid also exhibited significant positive heterobeltiosis for no. of yield contributing traits viz., ear length (18.75%), 100 grain weight (20.47%), stover yield plant^{-1} (27.57%) and harvest index (34.38%), whereas for yield and yield contributing traits, the no. of hybrids depicting positive significant heterobeltiosis ranged from 6 (no. of grain rows ear^{-1}) to 37 (grain yield plant^{-1}) and for quality traits it varied from 25 (grain oil content)–44 (lysine content).

The presence of heterobeltiosis indicated that over dominance played an important role in the expression of all these traits. However, its magnitude and number of hybrids which exhibited significant heterobeltiosis were variable. Heterosis over better parent for grain yield was also reported by Amiruzzaman et al. (2013), Netravati et al. (2013); Chahar et al., (2014). Amanullah et al. (2011); Silva et al. (2011), Khanorkar et al. (2012) reported heterosis over better parent for maturity traits.

The study of relative heterosis revealed number of hybrids exhibiting positive significant mid parent heterosis for yield and yield contributing traits ranged from 15 (no. of grain rows ear^{-1})–42 (grain yield plant^{-1}). In case of quality traits, the no. of hybrids exhibiting positive significant mid parent heterosis ranged from 32 (grain oil content)–45 (tryptophan content and lysine content). For maturity traits, no. of hybrids exhibiting negative significant mid parent heterosis ranged from 28 (days to 75% brown husk)–34 (days to 50% silking). Similar findings for mid parent heterosis for yield and its contributing traits were also obtained by Khanorkar et al. (2012), Jain and Bhardawaj (2014); Ofori et al. (2015). Amanullah et al. (2011); Amiruzzaman et al. (2013) reported heterosis over better parent for maturity type traits.

4. Conclusion

Hybrid $P_6 \times P_8$ could be identified as the best performing hybrid as it not only exhibited maximum positive economic heterosis (19.63%) along with highest *per se* performance (107.67 g plant^{-1}) for grain yield plant^{-1}, also exhibited positive economic heterosis for many yield contributing traits viz., ear length, ear girth, 100 grain weight, stover yield plant^{-1}, harvest index and for quality traits viz., grain oil content, starch content, grain protein content, tryptophan content and lysine content. Hence these hybrids appear to be very promising combination for actual exploitation and could be recommended for testing in multi-location trials.

5. References

A.O.A.C., 1965. Official methods for oil analysis for association of Official Agricultural Chemists. 10th (Edn.). Washington, D.C.

Amanullah, S.J., Muhammad, M., Muhammad, A.K., 2011. Heterosis studies in diallel crosses of maize. Sarhad Journal of Agriculture 27(2), 207–211.

Amiruzzaman, M., Islam, M.A., Lutful, H., Monjurul, K., Rohman, M.M., 2013. Heterosis and combining ability in a diallel among elite inbred lines of maize (*Zea mays* L.). Emirates Journal of Food and Agriculture 25(2), 132–137.

Avinashe, H.A., Jaiwar, S.S., Girase, V.K., Rawool, S.A., Khanorkar, S.M., 2013. Assessment of heterosis and combining ability for biochemical components in crosses among high quality protein maize (*Zea mays* L.). Journal of Soils and Crops 23(1), 176–184.

Bantte, K., Prasanna, B., 2003. Simple sequence repeat polymorphism in QPM lines. Euphytica 129, 33–344.

Briggle, L.W., 1963. Heterosis in wheat- a review. Crop Science 3, 407–412.

Chahar, S., Vyas, M., Ranwah, B.R., Vadodariya, G., 2014. Heterosis and combining ability analysis for yield and its contributing traits in early maturing maize (*Zea mays* L.) genotypes. Trends in Biosciences 7(14), 1774–1777.

Devi, S., Parimala, K., Sravanthi K., 2016. Gene action and combining ability analysis for yield and its component traits in maize and its component traits in maize (*Zea mays* L.). The Bioscan, 11(2), 1043–1047.

Farhan, A., Irfan, Ahmed, S., Hidayatur, R., Mohammad, N., Durrishahwar, Muhammad Yasir Khan, Ihteram, U., Jianbing, Y., 2012. Heterosis for yield and agronomic attributes in diverse maize germplasm. Australian Journal of Crop Science. 6(3), 455–462.

Fonseca, S., Patterson, F.L., 1968. Hybrid vigour in a seven parent diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Science 8, 85–88.

Genter, G.F., Alexander, M.N., 1962. Comparitive performance of S1 progenies and test crosses of corn. Crop Science 2, 416–419.

Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Sciences 9, 463–493.

Huang, S., Frizzi, A., Florida, C.A., Kruger, D.E., Luethy, M.H., 2006. High lysine and high tryptophan transgenic maize resulting from the reduction of both 19- and 22-kD α-zeins. Plant molecular biology 61(3), 525–535.

Hussain, M., Kiani, T.T., Shah, K.N., Ghafoor, A., Rabbani, A., 2015. Gene action studies for protein quality traits in (*Zea mays* L.) under normal and drought conditions. Pakistan Journal of Botany 47(1), 57–61.

Jain, R., Bharadwaj, D.N., 2014. Heterosis and inbreeding depression for grain yield and yield contributing characters in quality protein maize. Agricultural communications 2(1), 8–16.

Kalyana Babu, B., Agrawal, P.K., Mahajan, V., Gupta, H.S., 2009). Molecular and biochemical characterization of

short duration quality protein maize. Journal of plant biochemistry and biotechnology 18(1), 93–96.
Kanagarasu, S., Nallathambi, G., Ganesan, K.N., 2010. Combining ability analysis for yield and its component traits in maize (*Zea mays* L.). Electronic Journal of Plant Breeding 1(4), 915–920.
Khan, R., Dubey, R.B., Vadodariya, G.D., Patel, A.I., 2014. Heterosis and combining ability for quantitative and quality traits in maize (*Zea mays* L.). Trends in Biosciences 7(6), 422–424.
Khanorkar, S.M., Avinashe, H.A., Jaiwar, S.S., Girase, V.K., 2012. Heterosis in quality protein maize (*Zea mays* L.). Maize Journal 1(1), 30–34.
Kumar, B., Razdan, A.K., Gupta B.B., 2013. Heterosis and character association for grain yield and its component traits in single cross maize hybrids under mid hills of jammu and kashmir, India. Agricultural Science Digest 33(3), 198–202.
Lahane, G.R., Chauhan, R.M., Patel, J.M., 2014. Combining ability and heterosis studies for yield and quality traits in quality protein maize. Journal of AgriSearch 1(3), 135–138.
Lone, A.A., Khan, M.H., Dar, Z.A., Wani, S.H., 2016. Breeding strategies for improving growth and yield under waterlogging conditions in maize: a review. Maydica 61(1), 1–11.
Mbuya, K., Nkongolo, K.K., Kalonji-Mbuyi, A., 2011. Nutritional analysis of quality protein maize varieties selected for agronomic characteristics in a breeding program. International Journal of Plant Breeding and Genetics 5, 317–327.
Morris, D.L., 1948. Quantitative determination of carbohyderate with Derwood's anthrone reagent. Science 107, 254–255.
Netravati, S.G., Adiger, S., Malkannavar, L., Gangashetty, P., 2013. Heterosis breeding for maturity, yield and quality characters in maize (*Zea mays* L.). Molecular Plant Breeding 6(4), 44–49.
Ofori, A.P., Ofori, K., Obeng-Antwi, K., Tengan, K.M.L., Badu-Apraku, B., 2015. Combining ability and heterosis estimate of extra-early quality protein maize (QPM) single cross hybrids. Journal of Plant Breeding and Crop Science 7(4), 87–93.
Panse, V.G., Sukhatme, P.V., 1985. Statistical Methods for Agriculture Workers. ICAR, New Delhi, 14–33.
Reddy, V., Jabeen, F., Sudarshan, M.R., 2015. Heterosis studies in diallel crosses of maize for yield and yield attributing traits in maize (*Zea mays* L.) over locations. International Journal of Agriculture, Environment & Biotechnology 8(2), 271.
Shull, G.H., 1908. What is heterosis. Genetics 33, 439–446.
Silva, V.Q.R., Amaral, J.A.T., Goncalves, L.S.A., Freitas, J.S.P., Candido, L.S., Vittorazzi, C., Moterle, L.M., Vieira, R.A., Scapim, C.A., 2011. Heterotic parameterizations of crosses between tropical and temperate lines of popcorn. Acta Scientiarum. Agronomy 33(2), 243-249.
Singh, P.K., Singh, A.K., Shahi, J.P., Ranjan, R., 2012. Combining ability and heterosis in quality protein maize. The Bioscan 7(2), 337–340.
Singh, P.K., Singh, N., Singh, A.K., Shahi, J.P., Rao, M., 2013. Heterosis in relation to combining ability in quality protein maize (*Zea mays* L.). Biolife 1(2), 65–69.
Sundararajan, R., Kumar, P.S., 2011. Studies on heterosis in maize (*Zea mays* L.). Plant Archives 11, 55–57.
Ulaganathan, V., Vinoth, R., Baghyalakshmi, K., Suvarna Rani, C., Gurusamy, A., 2015. Standard heterosis for grain yield and other agronomic characters in maize (*Zea mays* L.) under normal and moisture stress conditions. The Bioscan 10(3), 1251–1253.
Verma, R., Kumar, S.S., Reddy, V.N., Sankar, A.S., 2014. Heterosis studies for grain yield and its component traits in single cross hybrids of maize (*Zea mays* L.). International Journal of Plant, Animal and Environmental Science 4(1), 304–306.
Wilson, C.M., 1991. Multiple zeins from maize endosperms characterized by reverse phase high performance liquid chromatography. Plant Physiology 95, 777–786.