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Quality Protein Maize: An Investigation for Identification of Heterotic Hybrids for Grain Yield and Important yield Component Traits

Arjun Kumar Agarwal[1], Devraj Lenka[2], Digbijaya Swain[3], Barsha Rani Barik[1], Ankita Mishra[4] and SwapanKumar Tripathy[5]

[1]P.G. Scholar, Department of Plant Breeding & Genetics,
College of Agriculture, OUAT, Bhubaneswar-751003 Bhubaneswar, (Odisha), India.
[2]Professor, Department of Plant Breeding & Genetics,
College of Agriculture, OUAT, Bhubaneswar-751003, (Odisha), India.
[3]Maize Breeder, All India Co-ordinated Research Project on Maize,
Directorate of Research, OUAT, Bhubaneswar, (Odisha), India.
[4]Ph. D. Scholar, Department of Plant Breeding & Genetics, College of Agriculture,
OUAT, Bhubaneswar-751003, (Odisha), India.
[5]Professor, Department of Agricultural Biotechnology, College of Agriculture,
OUAT, Bhubaneswar-751003, (Odisha), India.

(Corresponding author: Swapan Kumar Tripathy)*
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ABSTRACT: Maize is a highly cross pollinated crop. Heterosis breeding is the most widely accepted breeding method for enhancing yield potential in the crop. But, development of a truly potential heterotic hybrid requires identification of a specific cross combination that exhibits maximum hybrid vigour. Therefore, a study was conducted on F_1 population of 28 crosses generated by half diallel mating of 8 QPM inbred lines during *Kharif* -2020. These crosses were evaluated in a Randomised Block Design with three replications to estimate average heterosis, heterobeltiosis and standard heterosis for twelve morpho-agronomic traits including grain yield. For all the characters, analysis of variance revealed that the mean sum of squares owing to genotype is highly significant. The most significant positive average heterosis and heterobeltiosis for grain yield were recorded in the cross DQL 2159 (Q3) × 70160 (Q5), followed by the crosses DQL 2221-1-1(Q4) × 70160 (Q5) and DQL 2099 (Q2) × 70160 (Q5). The crosses DQL 2261(Q1) × 70160 (Q5), followed by DQL 2099 (Q2) × 72154 (Q7) and DQL 2261 (Q1) × 71266 (Q6) emerged as superior maize hybrids based on standard heterosis for grain yield over the best check HQPM-7. These crosses can be disseminated for cultivation as high yielding QPM hybrids.

Keywords: Average heterosis, heterobeltiosis, standard heterosis, quality protein maize (QPM)

INTRODUCTION

Maize (*Zea mays* L.) is one of the world's most widely grown crop. In India, maize is the third most important food grains next to rice and wheat (Aziz *et al.,* 2021). It has the highest genetic yield potential among the cereals (Dass *et al.*, 2012). However, the grain yield realized is very low due to the cultivation of landraces and composite varieties. Maize can be used as fodder, feed for animals and in feed preparation (Shafiq *et al.*, 2019). Maize is used as a simple raw material in several agricultural good industries e.g., sugar, oil, alcoholic drinks, dietary sweeteners, food supplement, pharmaceuticals, textiles, gum and paper industries. It is used as a poultry ration (49%), human food (25%), animal feed (12%), synthetic starch goods (12%), drinks (1%) and crop seed (1%) (Yadav *et al.*, 2016). Due to a deficiency of tryptophan and lysine, the normal maize protein quality is low (Prasanna *et al.*, 2001). However, the discovery of *opaque-2* (o-2) mutant gene has brought up endless possibilities for enhancing protein expression in maize kernel, ultimately leading to the development of Quality Protein Maize (QPM). In conventional breeding approaches, yield potential of maize has been tremendously increased by development of hybrid varieties. The chief measure for determination of hybrid vigour of a cross is to estimate the heterosis.

Heterosis refers to the superiority of F_1 hybrids over their parents in one or more characteristics. Heterosis breeding has made one of the most significant achievements in plant breeding for increasing global food security (Naveena *et al.*, 2021). There are different measures of heterosis *i.e,* average heterosis, heterobeltiosis and standard heterosis which determine the superiority of F_1 over mid-parent, a better parent, and standard check respectively. The estimates of heterosis in experimental hybrids serve as the most important parameter for choosing suitable cross combinations. Crosses between genetically diverse parents are expected to reveal better performance than either of the parents. The merit of experimental hybrids are often finally assessed over the popular widely adaptable standard varieties (standard heterosis) based on their ability to produce improved features and higher yield. Single-cross hybrids with high production capacity and heterotic potential can be established to address productivity barriers in maize. Knowledge on heterotic pattern can help increasing the effectiveness of hybrid development. Therefore, the present investigation was undertaken to estimate average heterosis, heterobeltiosis, and standard heterosis for yield and component traits in a set of 8×8 half-diallel crosses.

MATERIALS AND METHODS

A field experiment on maize was conducted under the All India Co-ordinated Research Project (AICRP) on maize at the EB-II division of the Department of Plant Breeding and Genetics, College of Agriculture, OUAT, Bhubaneswar during *Kharif* - 2020. The materials used for the study comprised eight QPM inbred lines (Q1-DQL 2261, Q2-DQL 2099, Q3-DQL 2159, Q4-DQL 2221-1-1, Q5-70160, Q6-71266, Q7-72154, and Q8-72242) collected from the ICAR-Indian Institute of Maize Research (IIMR) and maintained by AICRP on maize OUAT Bhubaneswar; their twenty-eight hybrid combinations following 8×8 half-diallel mating design and four popular standard maize hybrids used as checks (Vivek QPM 9, HQPM-1, HQPM-5, HQPM-7). The F_1s, parents and standard checks were evaluated in a Randomized Block Design with three replications. Each entry was sown in two rows of 4 m length, with a spacing of 60 × 20 cm. Normal agronomic practices and plant protection measures were followed to raise a successful crop. Data was recorded for twelve traits *viz.*, days to 50% pollen shedding, days to 50% silking, days to 75% dry husk, cob weight (kg), plant height (cm), ear height (cm), cob length (cm), cob diameter (cm), number of kernel (grain) rows per cob, number of grains per row, shelling percentage (%) and grain yield (kg/ha). The data were subjected to statistical analysis for Analysis of Variance as per Panse and Sukhatme (1985). Average heterosis and heterobeltiosis were estimated as per Fonseca and Patterson (1968), whereas the Virmani *et al*., (1982) method was used to calculate standard heterosis. The significance of heterosis was tested according to 't' test to assess the merit of the better performing experimental hybrids.

RESULTS AND DISCUSSION

A. Analysis of variance (ANOVA)

The analysis of variance presented in Table 1 shows significance of mean sum of squares due to genotypes and parents *vs.* crosses for all of the characters. The mean sum of squares due to parents revealed significant for all characters except for cob weight and shelling percentage. Moreover, it also indicated that mean sum of squares owing to crosses was significant for all of the characters except for cob weight indicating a considerable difference between them. Thus, it was clear from the ANOVA that there exists an enough amount of variability in the parental and hybrid populations which suggests validity for study of heterosis. Similar results were reported by Amanullah *et al*., (2011), Patil *et al.*, (2012); Singh *et al.*, (2012) with a significant mean sum of squares due to genotypes for all characters studied.

Table 1: Analysis of variance of parents and crosses for twelve characters in an 8 × 8 half-diallel mating design in QPM.

Source of variation	d.f.	Days to 50% pollen shedding	Days to 50% silking	Days to 75% dry husk	Cob weight (kg)	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	No. of kernel rows per cob	No. of grains per row	Shelling percentage (%)	Grain yield (kg/ ha)
Replication	2	1.0835	0.8425	3.4535	0.1475	64.0235	3.7315	2.444	0.6725	0.293	1.9835	0.434	389926.0
Genotypes	35	17.855**	17.101**	17.431**	2.118**	1453.762**	853.165**	13.009**	9.633**	10.304**	117.646**	15.21**	6160725.9**
Parents	7	3.238**	3.405**	4.423**	0.084	362.280**	475.119**	11.174**	10.050**	13.466**	100.964**	0.095	219755.8**
Crosses	27	11.828**	10.873**	16.728**	1.38	367.898**	393.680**	5.407**	4.350**	2.046**	44.342**	15.88**	4049471.4**
Parents *vs.* Crosses	1	282.8**	281.1**	127.4**	36.2**	38412.4**	15905.5**	231.0**	149.3**	211.1**	2213.6**	102.8**	104751389.3**
Error	70	1.369	1.014	1.311	0.103	89.628	52.008	0.474	0.223	0.379	2.533	0.652	283410.323

* Significant at 5% level of probability ** Significant at 1% level of probability

B. Average Heterosis (AH)

The average heterosis (AH) estimates for grain yield and component traits are presented in Table 2. The AH ranged from -12.579 to 0.935%; -13.07 to 0.606%; and-7.812 to 1.811% for days to 50% pollen shedding, days to 50% silking, and days to 75% dry husk, respectively. Out of 28 crosses, 25 crosses for days to 50% pollen shedding and days to 50% silking showed significant negative AH, while only 14 crosses showed significant negative AH for days to 75% dry husk. For these maturity characters, the crosses Q4 × Q7, Q4 × Q8, and Q7 × Q8 performed the best. The AH ranged from 11.061 to 49.25% for plant height while it ranged from 11.966 to 93.75% for ear height. For yield and component characters, significant positive AH were observed in 24, 25, 27, 27, 26, 19, and 28 crosses with an overall range of 3.077 to 113.223%; 7.105 to 78.543%; 1.280 to 69.610%; -1.596 to 100.866%; 5.579 to 194.118%; -3.476 to 6.891% and 0.058 to 115.705% for cob weight (kg), cob length (cm), cob diameter (cm), number of kernel rows per cob, number of grains per row, shelling percentage (%) and grain yield (kg/ha) respectively. It shows that all crosses reveal significant positive AH for grain yield. Crosses Q2 × Q4, Q2 × Q5, Q3 x Q5, and Q4 x Q5 were among the best for yield and component characters. Similar findings were reported by Reddy *et al*., (2015); Bisen *et al*., (2017); Patil *et al*., (2017); Tafa *et al*., (2020).

C. Heterobeltiosis (HB)

The estimates of heterobeltiosis (HB) for grain yield and component characters are presented in Table 3. The significant negative HB for days to 50% pollen shedding, days to 50% silking, and days to 75% dry husk were observed in 23, 23, and 9 crosses out of 28 crosses with an overall range of -12.025 to 1.887%; -12.805 to 1.220%; and -7.812 to 2.429% respectively.

Table 2: Average heterosis estimates of 28 crosses for twelve characters in an 8 × 8 half-diallel mating design in QPM.

Sr. No.	Crosses	Days to 50% pollen shedding	Days to 50% silking	Days to 75% dry husk	Cob weight (kg)	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	No. of kernel rows per cob	No. of grains per row	Shelling percentage (%)	Grain yield (kg/ ha)
1.	Q1 × Q2	0.935	0.606	-0.587	3.077	30.095**	34.718**	7.173	1.280	17.647**	41.902**	1.892*	4.133**
2.	Q1 × Q3	-2.769	-1.501	-0.982	40.157**	40.219**	55.989**	41.447**	12.662**	21.875**	71.429**	-0.638	38.343**
3.	Q1 × Q4	-9.938**	-9.366**	-1.761	39.535**	34.752**	93.750**	42.177**	14.331**	42.574**	132.301**	5.534**	46.920**
4.	Q1 × Q5	-6.211**	-6.306**	-5.675**	96.875**	43.613**	54.617**	26.483**	35.474**	32.941**	107.955**	6.303**	106.299**
5.	Q1 × Q6	-2.194	-2.424	-0.594	86.567**	44.101**	77.143**	30.759**	20.657**	8.995*	70.108**	6.261**	94.510**
6.	Q1 × Q7	-10.476**	-8.359**	-4.762**	78.873**	35.123**	29.383**	38.115**	26.603**	8.179*	37.471**	5.617**	83.691**
7.	Q1 × Q8	-9.375**	-10.303**	-1.195	70.313**	49.254**	41.691**	15.732**	6.785*	-1.596	34.639**	-1.997**	65.657**
8.	Q2 × Q3	-5.590**	-5.740**	-0.392	20.325	38.123**	28.877**	43.274**	30.864**	33.333**	117.237**	0.064	21.116**
9.	Q2 × Q4	-10.345**	-10.030**	-7.422**	61.600**	11.061*	54.455**	69.514**	59.931**	75.373**	194.118**	4.392**	68.559**
10.	Q2 × Q5	-5.956**	-6.344**	-7.812**	96.774**	39.494**	60.406**	38.000**	51.916**	42.951**	121.017**	2.738**	102.995**
11.	Q2 × Q6	-9.494**	-9.756**	-1.581	73.846**	28.368**	37.000**	28.421**	13.490**	28.280**	53.620**	5.370**	83.047**
12.	Q2 × Q7	-5.769**	-5.296**	-2.970**	85.507**	25.910**	24.762**	26.667**	28.070**	23.256**	40.063**	6.257**	91.589**
13.	Q2 × Q8	-7.886**	-7.927**	-4.970**	62.903**	33.886**	30.726**	17.838**	11.606**	20.235**	53.191**	5.317**	71.832**
14.	Q3 × Q4	-6.502**	-6.627**	-1.569	18.033	27.861**	53.846**	78.543**	56.098**	100.866**	102.087**	5.987**	18.979**
15.	Q3 × Q5	-6.502**	-6.587**	-0.392	113.223**	37.838**	48.077**	56.114**	69.610**	61.194**	158.708**	0.935	115.705**
16.	Q3 × Q6	-4.375**	-5.136**	-1.190	76.378**	25.112**	23.697**	18.113**	25.714**	30.065**	82.803**	2.209**	71.995**
17.	Q3 × Q7	-3.797*	-3.703**	0.994	57.037**	23.768**	35.294**	40.357**	25.628**	46.580**	30.136**	1.104	55.650**
18.	Q3 × Q8	-8.411**	-6.344**	-0.599	5.785	39.247**	40.526**	29.042**	27.675**	42.763**	35.288**	-3.476**	0.058**
19.	Q4 × Q5	-10.000**	-8.434**	-6.641**	111.382**	33.480**	82.609**	57.366**	58.317**	73.705**	164.083**	0.723	112.733**
20.	Q4 × Q6	-6.625**	-6.991**	-3.162**	101.550**	27.432**	88.034**	37.520**	29.489**	47.405**	104.703**	0.510	100.934**
21.	Q4 × Q7	-12.460**	-10.559**	-7.327**	21.168*	13.034**	31.536**	7.873	22.167**	44.828**	32.895**	5.353**	26.928**
22.	Q4 × Q8	-12.579**	-13.070**	-6.163**	75.610**	25.768**	92.880**	31.605**	31.408**	40.767**	68.490**	5.346**	78.254**
23.	Q5 × Q6	-8.517**	-9.366**	-7.115**	90.625**	30.490**	55.656**	32.162**	40.199**	30.061**	93.016**	6.891**	103.119**
24.	Q5 × Q7	-6.070**	-5.556**	-2.178*	75.000**	12.826**	24.242**	36.571**	8.940**	13.150**	5.579	-1.657*	72.847**
25.	Q5 × Q8	-6.289**	-5.740**	-1.789	81.967**	37.860**	67.000**	30.556**	50.820**	29.630**	71.075**	3.608**	87.461**
26.	Q6 × Q7	-10.323**	-10.903**	-5.010**	49.296**	21.495**	11.966	7.105	8.146**	12.329**	24.664**	1.487*	50.157**
27.	Q6 × Q8	-7.937**	-7.927**	1.811	89.063**	35.395**	32.020**	12.308**	21.461**	12.707**	47.811**	5.603**	98.261**
28.	Q7 × Q8	-10.611**	-9.034**	-5.645**	35.294**	22.819**	19.249**	16.216**	24.431**	16.253**	7.618	2.036**	37.115**
SEd		0.827	0.712	0.810	0.227	6.694	5.099	0.487	0.334	0.435	1.125	0.571	376.437

* Significant at 5% level of probability ** Significant at 1% level of probability

The crosses Q4 × Q7, Q2 × Q4, and Q4 × Q8 exhibited early maturity characteristics. Significant HB ranged from 11.312 to 56.468% for plant height and 4.098 to 73.292% for ear height, respectively. For yield and component characters, significant positive HB were observed in 27, 22, 20, 21, 22, 17, and 23 crosses with an overall range of 4.918 to 111.475; -10.556 to 71.595%; -7.843 to 67.206%; -5.612 to 87.097%; -20.452 to 128.690%; -3.558 to 6.891% and -0.380 to 115.705% for cob weight, cob length, cob diameter, number of kernel rows per cob, number of grains per row, shelling percentage, and grain yield/ha respectively. The highest significant positive HB for grain yield was recorded by the cross Q3 × Q5, followed by Q4 × Q5, Q2 × Q5, Q1 × Q5 and Q1 × Q6. The crosses Q2 × Q4, Q2 × Q5, Q3 × Q4, Q3 × Q5 and Q4 × Q5 were among the best-performing crosses for yield component characters. These observed results are in harmony with earlier reports by Reddy *et al*., (2015), Bisen *et al*., (2017), Patil *et al*., (2017), and Tafa *et al*., (2020).

D. Standard Heterosis (SH)

The estimates of standard heterosis (SH) for grain yield and component characters over the best check HQPM-7 are presented in Table 4. The SH for days to 50% pollen shedding, days to 50% silking, and days to 75% dry husk over the best check HQPM-7 ranged from -3.521 to 14.085%; -2.055 to 13.699%; and 0.427 to 8.547% respectively. None of the crosses showed significant negative SH over the best check. The SH for plant height ranged from -11.986 to 13.417% with 7 out of 28 crosses being significant, while the SH for ear height ranged from -14.340 to 29.811% with 8 out of 28 crosses being significant. The SH for yield and component characters varied from -42.857 to 16.071%; -25.977 to 16.322%; -20.146 to 12.621%; -18.142 to 3.982%; -32.987 to 26.874%; -6.064 to 3.672%; and -47.310 to 14.518% with 4, 8, 5, 0, 2, 12, and 4 crosses out of total 28 crosses showed significant positive SH for cob weight, cob length, cob diameter, number of rows per cob, number of grains per row, shelling percentage, and grain yield/ha respectively. For grain yield, the cross Q1 × Q5 exhibited the highest significant positive SH of 14.518% followed by Q2 × Q7, Q1 × Q6, Q1 ×Q7 and Q3 × Q5. The crosses, Q1 × Q5, Q1 × Q6, Q1 × Q7, Q3 × Q5 and Q2 × Q4 were among the best performing crosses for yield component characters. Our results in relation to performance of crosses for standard heterosis supports the findings of Amiruzzaman *et al*., (2013), Reddy *et al*., (2015), Bisen *et al*., (2017), Patil *et al*., (2017), Reddy *et al*., (2018) and Tafa *et al*., (2020).

Identification of promising experimental hybrids based on heterosis is the stepping stone for commercial hybrid development. In this context, five best performing crosses with respect to heterosis for twelve characters have been sorted out in Table 5. It is interesting to note that crosses e.g., Q3 × Q5, Q4 × Q5, Q1 × Q5 and Q2 × Q5 were among the five top performing crosses for grain yield as per estimates of average heterosis and heterobeltiosis.

Table 3: Heterobeltiosis estimates of 28 crosses for twelve characters in an 8 × 8 half-diallel mating design in QPM.

Sr. No.	Crosses	Days to 50% pollen shedding	Days to 50% silking	Days to 75% dry husk	Cob weight (kg)	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	No. of kernel rows per cob	No. of grains per row	Shelling percentage (%)	Grain yield (kg/ ha)
1.	Q1 × Q2	1.887	1.220	-0.392	0.000	36.567**	28.977**	5.833	-5.319	7.143	41.164**	1.568	0.583
2.	Q1 × Q3	-2.469	-1.205	-0.787	32.836**	43.532**	41.414**	22.507**	-7.713*	-0.510	41.176**	-0.891	31.157*
3.	Q1 x Q4	-9.375**	-9.091**	-1.569	34.328**	41.791**	73.292**	19.088**	-4.521	10.204**	81.303**	5.355**	41.017**
4.	Q1 × Q5	-5.625**	-6.024**	-5.490**	88.060**	55.224**	34.404**	24.501**	12.234**	15.306**	92.227**	6.168**	95.741**
5.	Q1 × Q6	-0.637	-1.829	0.400	86.567**	56.468**	52.232**	22.750**	17.287**	5.102	59.889**	6.125**	94.187**
6.	Q1 × Q7	-7.843**	-5.732**	-3.614**	69.333**	50.249**	7.377	36.389**	23.404**	4.592	9.787*	5.393**	74.742**
7.	Q1 × Q8	-8.228**	-9.756**	0.405	62.687**	49.254**	33.516**	11.316*	-3.723	-5.612	16.847**	-2.330	57.710**
8.	Q2 × Q3	-4.403*	-4.878**	0.000	17.460	41.568**	21.717**	22.778**	13.456**	5.556	78.170**	0.000	18.797
9.	Q2 × Q4	-10.063**	-9.756**	-7.422**	60.317**	11.312*	32.955**	40.556**	41.590**	30.556**	128.690**	4.237**	67.459**
10.	Q2 × Q5	-5.660**	-5.488**	-7.812**	93.651**	43.439**	44.954**	34.167**	33.333**	21.111**	103.326**	2.542**	99.274**
11.	Q2 × Q6	-8.917**	-9.756**	-0.400	68.657**	32.579**	22.321**	22.000**	9.014**	20.879**	45.102**	5.169**	76.523**
12.	Q2 × Q7	-3.922*	-3.185*	-1.606	70.667**	33.032**	7.377	26.667**	22.689**	15.847**	12.296*	6.144**	76.359**
13.	Q2 ×Q8	-7.595**	-7.927**	-3.239**	60.317**	40.547**	28.571**	14.737**	7.339*	13.889**	33.539**	5.294**	69.274**
14.	Q3 × Q4	-5.625**	-6.061**	-1.181	16.129	31.354**	26.263**	71.595**	52.381**	87.097**	88.636**	5.897**	17.458
15.	Q3 × Q5	-5.625**	-6.587**	0.000	111.475**	45.368**	41.284**	37.059**	67.206**	50.000**	127.970**	0.806	115.523**
16.	Q3 × Q6	-2.548	-4.268**	-0.400	67.164**	32.542**	16.518*	-3.000	5.352	9.341*	43.438**	2.079*	62.806**
17.	Q3 × Q7	-0.654	-0.637	2.008	41.333**	34.204**	22.541**	20.278**	5.042	22.951**	-9.787*	1.061	40.771**
18.	Q3 × Q8	-6.962**	-5.488**	0.810	4.918	42.537**	46.703**	8.158	14.570**	20.556**	-0.155	-3.558	-0.380
19.	Q4 × Q5	-10.000**	-7.879**	-6.641**	109.677**	36.937**	44.495**	33.529**	56.746**	51.389**	119.307**	0.680	110.188**
20.	Q4 × Q6	-5.732**	-6.707**	-2.000	94.030**	31.306**	47.321**	9.500*	10.704**	17.033**	52.865**	0.467	92.554**
21.	Q4 × Q7	-10.458**	-8.280**	-6.024**	10.667	19.144**	0.000	-10.556*	4.202	14.754**	-11.292*	5.308**	16.142
22.	Q4 × Q8	-12.025**	-12.805**	-4.453**	74.194**	32.338**	63.736**	6.842	20.530**	12.222**	19.011**	5.167**	76.743**
23.	Q5 × Q6	-7.643**	-8.537**	-6.000**	82.090**	31.049**	53.571**	22.250**	18.873**	16.484**	68.577**	6.891**	92.421**
24.	Q5 × Q7	-3.922*	-2.548	-0.803	58.667**	15.846**	17.623*	32.778**	-7.843*	1.093	-20.452**	-1.741	56.442**
25.	Q5 × Q8	-5.696**	-4.878**	0.000	81.967**	49.005**	53.211**	23.684**	37.086**	16.667**	38.949**	3.388**	86.796**
26.	Q6 × Q7	-9.150**	-8.917**	-4.819**	41.333**	24.204**	7.377	1.750	7.843*	12.022**	4.642	1.401	43.067**
27.	Q6 × Q8	-7.643**	-7.927**	2.429*	80.597**	47.015**	19.643*	9.500*	12.394**	12.088**	35.703**	5.379**	88.453**
28.	Q7 × Q8	-9.150**	-7.006**	-5.263**	22.667*	36.567**	4.098	13.158**	14.846**	15.301**	-2.509	1.906*	24.499*
	SEd	0.955	0.822	0.935	0.262	7.730	5.888	0.562	0.386	0.503	1.299	0.659	434.673

* Significant at 5% level of probability   ** Significant at 1% level of probability

Table 4: Standard heterosis estimates of 28 crosses for twelve characters in an 8 × 8 half-diallel mating design in QPM.

Sl. No.	Crosses	Days to 50% pollen shedding	Days to 50% silking	Days to 75% dry husk	Cob weight (kg)	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	No. of kernel rows per cob	No. of grains per row	Shelling percentage (%)	Grain yield (kg/ ha)
1.	Q1 × Q2	14.085**	13.699**	8.547**	-40.179**	-1.789	-14.340*	-12.414**	-13.592**	-7.080*	-21.684**	-1.114	-41.154**
2.	Q1 × Q3	11.268**	12.329**	7.692**	-20.536**	3.220	5.660	-1.149	-15.777**	-13.717**	-22.491**	-3.630**	-23.267**
3.	Q1 × Q4	2.113	2.740	7.265**	-19.643**	1.968	5.283	-3.908	-12.864**	-4.425	-0.461	2.269**	-17.498
4.	Q1 × Q5	6.338**	6.849**	2.991*	12.500	11.628**	10.566	0.460	2.427	0.000	5.536	2.970**	14.518*
5.	Q1 × Q6	9.859**	10.274**	7.265**	11.607	12.522**	28.679**	12.874**	7.039*	-8.850**	-0.231	2.929**	13.987*
6.	Q1 × Q7	-0.704	1.370	2.564*	13.393	8.050	-1.132	12.874**	12.621**	-9.292**	0.923	2.393**	13.269
7.	Q1 × Q8	2.113	1.370	5.983**	-2.679	7.335	-8.302	-2.759	-12.136**	-18.142**	-12.803**	-4.868**	-7.732
8.	Q2 × Q3	7.042**	6.849**	8.547**	-33.929**	6.619	-9.057	1.609	-9.951**	-15.929**	-1.153	-2.640**	-35.238**
9.	Q2 × Q4	0.704	1.370	1.282	-9.821	-11.986*	-11.698	16.322**	12.379**	3.982	26.874**	1.485	-8.710
10.	Q2 × Q5	5.634**	6.164**	0.855	8.929	13.417**	19.245**	11.034**	5.825*	-3.540	12.803**	-0.165	8.634
11.	Q2 × Q6	0.704	1.370	6.410**	0.893	4.830	3.396	12.184**	-6.068*	-2.655	-9.458*	2.393**	3.618
12.	Q2 × Q7	3.521	4.110*	4.701**	14.286*	5.188	-1.132	4.828	6.311*	-6.195	3.230	3.342**	14.317*
13.	Q2 × Q8	2.817	3.425*	2.137	-9.821	1.073	-11.698	0.230	-14.806**	-9.292**	-0.346	2.558**	-7.720
14.	Q3 × Q4	6.338**	6.164**	7.265**	-35.714**	-1.073	-5.660	1.379	-6.796*	2.655	-32.987**	2.970**	-36.803**
15.	Q3 × Q5	6.338**	6.849**	8.547**	15.179*	9.481*	16.226*	7.126	0.243	-4.425	6.228	-1.980*	13.185
16.	Q3 × Q6	7.746**	7.534**	6.410**	0.000	-0.179	-1.509	-10.805**	-9.223**	-11.947**	-10.496*	-0.743	-4.434
17.	Q3 × Q7	7.042**	6.849**	8.547**	-5.357	1.073	12.830	-0.460	-8.981**	-0.442	-17.070**	-1.733*	-8.751
18.	Q3 × Q8	3.521	6.164**	6.410**	-42.857**	2.504	0.755	-5.517	-16.019**	-3.982	-25.490**	-6.064**	-47.310**
19.	Q4 × Q5	1.408	4.110*	2.137	16.071*	8.766*	18.868**	4.368	-4.126	-3.540	2.191	-2.269**	13.089
20.	Q4 × Q6	4.225*	4.795**	4.701**	16.071*	4.293	24.528**	0.690	-4.612	-5.752	-4.614	-2.475**	13.029
21.	Q4 × Q7	-3.521	-1.370	0.000	-25.893**	-5.367	-7.925	-25.977**	-9.709**	-7.080*	-18.454**	2.310**	-24.716**
22.	Q4 × Q8	-2.113	-2.055	0.855	-3.571	-4.830	12.453	-6.667	-11.650**	-10.619**	-11.188*	2.434**	-4.906
23.	Q5 × Q6	2.113	2.740	0.427	8.929	9.481*	29.811**	12.414**	2.427	-6.195	5.190	3.672**	12.950
24.	Q5 × Q7	3.521	4.795**	5.556**	6.250	-3.220	8.302	9.885*	-20.146**	-18.142**	-26.874**	-4.538**	1.407
25.	Q5 × Q8	4.930*	6.849**	5.556**	-0.893	7.156	26.038**	8.046**	0.485	-7.080*	3.691	0.701	-1.201
26.	Q6 × Q7	-2.113	-2.055	1.282	-5.357	4.651	-1.132	-6.437	-6.553*	-9.292**	-3.806	-1.485	-7.263
27.	Q6 × Q8	2.113	3.425*	8.120**	8.036	5.725	1.132	0.690	-3.155	-9.735**	1.269	2.640**	10.621
28.	Q7 × Q8	-2.113	0.000	0.000	-17.857	-1.789	-4.151	-1.149	-0.485	-6.637	-10.381*	-0.743	-19.299**
	SEd	0.955	0.822	0.935	0.262	7.730	5.888	0.562	0.386	0.503	1.299	0.659	434.673

* Significant at 5% level of probability   ** Significant at 1% level of probability

Table 5: Five best performing crosses with respect to heterosis for twelve morpho-agronomic traits in an 8 × 8 half-diallel mating design in QPM.

Sr. No.	Particulars	Days to 50% pollen shedding	Days to 50% silking	Days to 75% dry husk	Cob weight (kg)	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	No. of kernel rows per cob	No. of grains per row	Shelling percentage (%)	Grain yield (kg/ ha)
2.	Average Heterosis	Q4 × Q8	Q4 × Q8	Q2 × Q5	Q3 x Q5	Q2 × Q4	Q6 × Q7	Q3 × Q4	Q3 × Q5	Q3 × Q4	Q2 × Q4	Q5 ×Q6	Q3 × Q5
		Q4 × Q7	Q6 × Q7	Q2 × Q4	Q4 × Q5	Q5 × Q7	Q7 × Q8	Q2 × Q4	Q2 × Q4	Q2 × Q4	Q4 × Q5	Q1 × Q5	Q4 × Q5
		Q7 × Q8	Q4 × Q7	Q4 × Q7	Q4 × Q6	Q4 × Q7	Q3 × Q6	Q4 × Q5	Q4 × Q5	Q4 × Q5	Q3 × Q5	Q1 × Q6	Q1 × Q5
		Q1 × Q7	Q1 × Q8	Q5 × Q6	Q1 × Q5	Q6 × Q7	Q5 × Q7	Q3 × Q5	Q3 × Q4	Q3 × Q5	Q1 × Q4	Q2 × Q7	Q5 × Q6
		Q2 × Q4	Q2 × Q4	Q4 × Q5	Q2 × Q5	Q7 × Q8	Q2 × Q7	Q2 × Q3	Q2 × Q5	Q4 × Q6	Q2 × Q5	Q3 × Q4	Q2 × Q5
3.	Heterobeltiosis	Q4 × Q8	Q4 × Q8	Q2 × Q5	Q3 × Q5	Q2 × Q4	Q3 × Q6	Q3 × Q4	Q3 × Q5	Q3 × Q4	Q2 × Q4	Q5 × Q6	Q3 × Q5
		Q4 ×Q7	Q1 × Q8	Q2 × Q4	Q4 × Q5	Q5 × Q7	Q5 × Q7	Q2 × Q4	Q4 × Q5	Q4 × Q5	Q3 × Q5	Q1 × Q5	Q4 × Q5
		Q2 ×Q4	Q2 × Q4	Q4 × Q5	Q4 × Q6	Q4 ×Q7	Q6 × Q8	Q3 × Q5	Q3 × Q4	Q3 × Q5	Q4 × Q5	Q2 × Q7	Q2 × Q5
		Q4 × Q5	Q2 × Q6	Q4 × Q7	Q2 × Q5	Q6 × Q7	Q2 × Q6	Q1 × Q7	Q2 × Q4	Q2 × Q4	Q2 × Q5	Q1 × Q6	Q1 × Q5
		Q1 × Q4	Q1 × Q4	Q5 × Q6	Q1 × Q5	Q5 × Q6	Q3 × Q7	Q2 × Q5	Q5 × Q8	Q3 × Q7	Q1 × Q5	Q3 × Q4	Q1 × Q6
4.	Standard Heterosis	Q4 × Q7	Q4 ×Q8	Q4 × Q7	Q4 × Q5	Q2 ×Q4	Q1 × Q2	Q2 × Q4	Q1 × Q7	Q2 × Q4	Q2 × Q4	Q5 × Q6	Q1 × Q5
		Q4 × Q8	Q6 × Q7	Q7 × Q8	Q4 × Q6	Q4 × Q7	Q2 × Q4	Q1 × Q6	Q2 × Q4	Q3 × Q4	Q2 × Q5	Q2 × Q7	Q2 × Q7
		Q6 × Q7	Q4 × Q7	Q5 × Q6	Q3 × Q5	Q4 × Q8	Q2 × Q8	Q1 × Q7	Q1 × Q6	Q1 × Q5	Q3 × Q5	Q1 × Q5	Q1 × Q6
		Q7 × Q8	Q7 × Q8	Q2 × Q5	Q2 × Q7	Q5 × Q7	Q2 × Q3	Q5 × Q6	Q2 × Q7	Q3 × Q7	Q1 × Q5	Q3 × Q4	Q1 × Q7
		Q1 × Q7	Q1 × Q7	Q4 × Q8	Q1 × Q7	Q1 × Q2	Q1 × Q8	Q2 ×Q6	Q2 × Q5	Q2 × Q6	Q5 × Q6	Q1 × Q6	Q3 × Q5

While Q1 × Q5, Q2 × Q7 and Q1 × Q6 were the top three heterotic crosses over the best standard check HQPM 7 for grain yield. The crosses Q5 × Q6, Q1 × Q5 and Q2 × Q7 were among the best five for shelling percentage in terms of average heterosis, better parent heterosis (heterobeltiosis) and even standard heterosis over the best standard check HQPM 7.

Besides, the cross Q3 × Q5 topped among the five best crosses in terms of average heterosis and heterobeltiosis; and also ranked among the best five crosses in terms of standard heterosis also for cob weight and seed yield. However, a cross combination Q4 × Q5 recorded the highest estimates of standard heterosis for cob weight and also found to be one of the five best crosses in terms of average heterosis and heterobeltiosis for seed yield but could not rank for standard heterosis in grain yield. The cross Q2 × Q4 was found to be most common cross among top five crosses for yield attributing traits *viz*., cob length, cob diameter, number of kernel rows per cob, number of grains per row. Hence, the above crosses seem to have merit for cultivation owing to their heterotic performance.

CONCLUSION

Now-a-days, cultivation of hybrids is gaining futuristic importance. Therefore, exploring a truly heterotic hybrid in a mating design is an important part of hybrid development. The present investigation revealed majority of the crosses with positive significant average heterosis, heterobeltiosis, and standard heterosis for yield and important yield attributing traits, suggesting dominance nature of genes with positive effect. Besides, a number of crosses showed favourable heterotic behaviour with negative heterosis for maturity-related characteristics indicating that the genes with negative effects were dominant for these traits. A few superior F_1 hybrids were sorted out with higher degrees of heterosis for a number of important yield contributing traits. The top three selected crosses based on standard heterosis included Q1 × Q5, Q2 × Q7 and Q1 × Q6 for grain yield. These crosses may be considered as heterotic QPM hybrids for commercial cultivation.

FUTURE SCOPE

The present findings based on heterotic performance of experimental hybrids will pave the way for production of commercial hybrids for wide scale multi-location testing and follow-up cultivation in the targeted ecosystem.

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Conflict of Interest. The authors declare that there is no conflict of interests.

REFERENCES

Amanullah, S. J., Mansoor, M. & Khan, M. A. (2011). Heterosis studies in diallel crosses of maize. *Sarhad Journal of Agriculture, 27*(2): 207-211.

Amiruzzaman, M., Islam, M.A., Hasan, L., Kadir, M. & Rohman, M. M. (2013). Heterosis and combining ability in a diallel among elite inbred lines of maize (*Zea mays* L.). *Emirates Journal of Food Agriculture, 25*(2): 132-137. doi: 10.9755/ejfa.v25i2.6084

Aziz, M., Patra, P. S., Saha R. S. & Ahmed A. S. (2021). Productivity and Use efficiencies of maize (*Zea mays* L.) in Response to Split Application of Nitrogen. *Biological Forum – An International Journal, 13*(1): 429-434.

Bisen, P., Dadheech, A., Nagar, O., & Meena, R. K. (2017). Exploitation of heterosis in single cross hybrids of quality protein maize (*Zea maize* L.) for yield and quality traits. *International Journal of Bio-Resource & Stress Management*, *8*(1): 12-19.

Dass, S., Kumar, A., Jat, S. L., Parihar, C. M., Singh, A. K., Karjagi, C. G. & Jat M. I. (2012). Maize holds potential for diversification and livelihood security. *Indian Journal of Agronomy, 57*(3rd IAC Special Issue), pp.86-91.

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

Naveena, K., Singh, V. & Tiwari, D. (2021). Evaluation of growth, yield and economics of maize (*Zea mays* L.) Hybrids under Agro Climatic Conditions of Prayagraj (U.P.). *Biological Forum – An International Journal, 13*(1): 633-637.

Panse, V.G & Sukhatme, P.V. 1985. Statistical methods for agricultural workers, *Indian Council of Agricultural Research*, New Delhi.

Patil, A. E., Charjan, S. U., Patil, S. R., Udasi, R. N., Puttawar, M. R., & Palkar, A. B. (2012). Studies on heterosis and combining ability analysis in maize (*Zea mays* L.). *Journal of Soils and Crops*, *22*(1): 129-138.

Patil, B. S., Ahamed, M. L., & Babu, D. R. (2017). Heterosis studies for yield and yield component characters in maize (*Zea mays* L.). *International Journal of Agriculture, Environment and Biotechnology*, *10*(4): 449-455.

Prasanna, B. M., Vasal, S. K., Kassahun, B. & Singh, N. N. (2001). Quality protein maize. *Current Science*, 10: 1308-1319.

Reddy, V. R., 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 and Biotechnology*, *8*(2): 271-283.

Reddy, Y. S., Krishnan, V., Vengadessan, V., Paramasivam, K., & Narayanan, A. L. (2018). Heterosis analysis for grain yield traits in Maize (*Zea mays* L.). *Electronic Journal of Plant Breeding*, *9*(2): 518-527.

Shafiq, S., Adeel, M., Raza, H. Iqbal, R., Ahmad, Z., Naeem, M., Sheraz, M., Ahmed, U. & Azmi, U.R. (2019). Effects of Foliar Application of Selenium in Maize (Zea Mays L.) under cadmium toxicity. *Biological Forum -An International Journal*, *11*(2): 61-71.

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.

Tafa, Z., Nepir, G., & Azmach, G. (2020). Estimation of magnitudes of heterosis for grain yield and yield contributing traits of conventional maize (*Zea mays* L.) single cross hybrids. *African Journal of Agricultural Research*, *16*(12): 1640-1651.

Virmani, S., Aquino, R. C., & Khush, G. S. (1982). Heterosis breeding in rice (*Oryza sativa* L.). *Theoretical and Applied Genetics*, *63*(4): 373-380.

Yadav, M. R., Kumar, R., & Ram, H. (2016). Using Quality Protein Maize as an elite feed and fodder for livestock. *Indian Dairyman*, *68*(10): 88-91.

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