Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(2): 784-788
Received: 18-01-2020
Accepted: 21-02-2020

Gammingi Solomon Raj
Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Prayagraj, Uttar Pradesh, India

Shailesh Marker
Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Prayagraj, Uttar Pradesh, India

Silpa Scaria
Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Prayagraj, Uttar Pradesh, India

Saif Mohd Saleh Ansari
Department of Biochemistry, Joseph Institute of Biotechnology and Bioengineering, SHUATS, Prayagraj, Uttar Pradesh, India

Quantitative studies on heterosis and inbreeding depression in quality protein maize for terminal heat tolerance

Gammingi Solomon Raj, Shailesh Marker, Silpa Scaria and Saif Mohd Saleh Ansari

Abstract
The present investigation was carried out for studying heterosis and inbreeding depression of twenty eight hybrids (F_1's) and their F_2's made by crossing of eight Quality Protein Maize inbreds in all possible cross combinations excluding reciprocals. Five cross combinations were found to be heat tolerant as they didn't show any symptoms of leaf firing, tassel blast, root lodging and no severe loss of yield in the present investigation. Variable magnitude of heterosis was observed for different cross combinations for all the traits. Based on higher mean performance for grain yield per plant (30.53 to 40.47 g/plant) and higher heterotic response (0.74% to 18.24%), sixteen crosses were selected. Response of inbreeding depression was significant in positive direction for most of the traits. Among these sixteen crosses, eight crosses were selected having high heterotic value (3.46 to 18.24%) and lower inbreeding depression (< 15%) and may be further utilized for the development of superior hybrids after confirming their consistency in Allahabad agro-climatic conditions.

Keywords: Heterosis, Inbreeding depression, Quality Protein Maize, Tassel blast and Terminal heat tolerance

Introduction
Maize is the third most important food crop of India. It has assumed greater significance due to its demand for food, feed and industrial utilization. Nearly 49% of the maize produced is being utilized as raw material in the poultry feed industry (Rajitha *et al.* 2014) [16]. Terminal heat stress at grain filling stage in spring Quality Protein Maize is the major environmental stress that limits plant growth, metabolism, and productivity in North-West India. Although high temperatures affect plant growth at all developmental stages, later phenological stages, in particular anthesis and grain filling are generally more susceptible. Pollen viability, patterns of assimilate partitioning, and growth and development of seed/grain are adversely affected. Tassel blast and leaf firing is considered as negative traits for selection of tropical maize lines/hybrids under heat stress conditions (Krishnaji *et al.* 2018) [7].
The development of high productive potential QPM hybrids is one of the main objectives of plant breeders; therefore the knowledge on the extent of heterosis for grain yield and its contributing components is the main criteria. Inbreeding depression, however, is conceptually opposite of heterosis and it is the loss of vigour following related mating.
The present investigation has been undertaken to study the heterosis in F_1 over standard check (SC) and inbreeding depression over F_2 segregating generation for yield and its related characters under terminal heat stress conditions in Quality Protein Maize. Since, inbreeding depression and heterosis are completely opposite in terms of their manifested effect, it is essential to generate precise information on heterosis and inbreeding depression with respect to characters, in order to assess the relative potential of experimental hybrids for extraction of inbred.

Materials and methods
The experiment was conducted at the Field Experimentation Centre of Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, U.P. Materials for the present investigation were generated from eight inbred lines of quality protein maize (QPM) *viz.*, (BHU-N1, LM-13, HY10RN-10235-462, BHU-N6, CML-K5/ATM CO571, HKI-34, NBPGR-32809 and CML-40) obtained from different sources. These 8 inbred lines were grown in *Rabi* 2017-18 and a crossing programme was undertaken as per Diallel analysis (Griffing, method II, model I, 1956) to generate28 F_1's. F_2 seeds were generated by selfing the F_1 plants. The 28 F_1's

Gammingi Solomon Raj
Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Prayagraj, Uttar Pradesh, India

together with eight parental lines, 28F_2's and a QPM check HQPM-5 were evaluated in Randomized Block Design (RBD) in three replications. The sowing was done on 20th February, 2019. Recommended package of practices was followed to raise a good crop.

To obtain the estimates of heterosis and inbreeding depression of 28 crosses, eighteen quantitative and heat stress traits were assessed. Observations were recorded on whole plot basis for days to 50% tasseling and days to 50% silking by counting the number of days from sowing to the emergence of tassel and silk in 50% plants. Five randomly selected plants in each replication were used for recording observations on plant height (cm), stem girth (cm), leaf area index (cm^2), cob height (cm), cob length (cm), cob girth (cm), cob weight (g), number of kernel rows per ear, number of kernels per row, 100 seed weight (g) and seed yield per plant (g) for parents, F_1's and F_2's. Observations for leaf firing (score), tassel blast (score), root lodging (score) were recorded based on scoring. Estimation of protein content (%) was done by using Lowry method.

The data collected were subjected to Analysis of Variance as suggested by Panse and Sukhatme (1967) [14]. The heterosis was estimated in terms of three parameters, i.e. mid-parent heterosis, heterobeltiosis and standard heterosis. Heterosis analysis was done according to (Turner, 1953) [21]. Inbreeding depression analysis was done according to Miller and Marani, (1963) [13].

Results and discussion

Analysis of Variance revealed highly significant differences among the treatment for most of the traits. Highly significant variance for parents vs F_1's were observed for all the characters except for Anthesis Silking Interval indicating superior performance of hybrids over parents. The mean sum of squares due to F_1's vs F_2's was found to be significant for all the characters indicating the occurrence of inbreeding depression in the expression of all characters.

The cross BHU-N1 x LM-13 (-18.62%) displayed the most negative significant heterosis for plant height. Hence, can be used to produce short stature hybrids which are useful where lodging is a problem. Kulharia and Sharma (2006) [8] earlier reported significant heterosis for dwarfness. The cross BHU-N1 x LM-13 exhibited maximum negative significant standard heterosis for earliness in respect of days to 50% tassel emergence and days to 50% silk emergence. Similar findings were also reported in maize by Kumar *et al.* (2008) [9].

Twenty three crosses exhibited positive significant standard heterosis ranged from 1.62% to 19.12% for number of kernel rows per cob revealed increased number of grain rows in a cob. Out of twenty three crosses, BHU-N1 x NBPGR-32809 (19.12%) exhibited maximum positive standard heterosis. Similar results were reported earlier by Kumar *et al.* (2008) [9], Dubey *et al.* (2009) [5], Singh *et al.* (2010) [20], Kumar *et al.* (2016) [10] and Darshan and Marker (2019) [4] in maize crop. Out of twenty eight cross combinations, seven crosses recorded positive significant heterosis for number of kernels per row, cross LM-13 x CML-K5/ATM CO571 showed maximum (8.20%) standard heterosis.

Sixteen crosses exhibited positive significant standard heterosis for 100 kernel weight. Sixteen crosses registered significant positive standard heterosis for seed yield per plant, BHU-N1 x CML-K5/ATM CO571 recorded highest (18.24%) value for seed yield per plant Similar results were reported earlier by Kumar *et al.* (2008) [9], Dubey *et al.* (2009) [5], Singh *et al.* (2010) [20], Kumar *et al.* (2016) [10] and Darshan and Marker (2019) [4].

Twenty two crosses exhibited positive significant economic heterosis for protein content. LM-13 x BHU-N6 (10.61%) shown highest positive significant economic heterosis Lahane *et al.* (2014) [11], Aminu *et al.* (2017) [1] and Darshan and Marker (2019) [4] were reported the similar results for this trait.

In the present study, for commercial exploitation of heterosis twenty seven crosses were identified as the best cross combination based on their *per se* performance and the magnitude of heterosis in trait(s) of economic importance. Sixteen cross combinations recorded significantly higher mean performance and positive significant standard heterosis for yield (Table I). The result, therefore, revealed that *per se* performance for yield of hybrids reflected the degree of heterosis manifestation in the hybrids. This is in agreement with the earlier reports made by Singh *et al.* (2010) [20] in case of maize crop.

Among different characters studied, the extent of positive heterosis for yield and associated traits of selected crosses are presented in Table II. Heterosis for yield is being manifested as the cumulative effect of heterosis of component traits. In the present investigation, the study of selected crosses on their *per se* revealed that the most of crosses that showed positive and significant heterosis for yield also showed heterosis for ear length, ear girth, kernels row per ear, kernels per row and 100-kernel weight. Similar findings have been reported for these characters in maize crop earlier by Kumar *et al.* (2008) [9] and Singh *et al.* (2010) [20].

Table I: Best crosses selected on the basis of *per se* performance and heterosis (%) for yield.

S. No.	Hybrid combinations	*Per se* performance of yield (g)	Standard heterosis (%)
1	BHU-N1 x CML-K5/ATM CO571	37.99	18.24**
2	HY10RN-10235-462 x CML-K5/ATM CO571	37.96	10.91**
3	HY10RN-10235-462 x NBPGR-32809	37.93	10.82**
4	BHU-N1 x HY10RN-10235-462	37.65	10.00**
5	BHU-N1 x BHU-N6	37.45	9.42**
6	HY10RN-10235-462 x BHU-N6	37.14	8.51**
7	HY10RN-10235-462 x HKI-34	37.11	8.43**
8	BHU-N6 x HKI-34	37.05	8.25**
9	LM-13 x HY10RN-10235-462	36.81	7.55**
10	NBPGR-32809 x CML-40	36.61	6.96**
11	BHU-N1 x HKI-34	36.04	5.30**
12	LM-13 x BHU-N6	35.94	5.01**
13	CML-K5/ATM CO571 x CML-40	35.57	3.93**
14	BHU-N1 x NBPGR-32809	35.41	3.46**
15	LM-13 x HKI-34	35.14	2.67**
16	BHU-N1 x LM-13	34.48	0.74**

**Significant at 1% level

It may be seen from the present study that hybrid combinations that showed higher estimates of heterosis in general found to show substantial inbreeding depression (Table III). In maize, inbreeding is accompanied by a reduction in the mean phenotypic value of most of the traits of economic importance simply because of reduction in fitness.

Value of positive significant inbreeding depression for plant height varied between 1.67 % to 16.47 %. Low inbreeding depression for plant height in positive direction was also reported earlier in maize by Maldonado and Miranda-Filho (2002) [12] and Kulharia and Sharma (2006) [8]. The F_2 population derived from these crosses recorded positive estimate of inbreeding depression for plant height hence helpful in screening of transgressive segregants from F_2 population having reduced plant height. The F_2 population derived from the cross LM-13 x CML-K5/ATM CO571 recorded positive and useful estimate of inbreeding depression for days to 50% tasseling and days to 50% silking indicating earliness. The results, therefore, suggested that formation of new gene combination as a result of segregation and recombination may lead to increase in the degree of expression of a trait in the F_2 population. The statistically significant values of inbreeding depression for stem girth, leaf area index, cob height, cob length, cob girth, cob weight, number of kernels per cob, number of kernels per row, 100 seed weight, grain yield per plant and protein content ranged between -34.61% to 42.51%, 1.96% to 12.6%, -9.02% to 19.40%, 0.22% to 10.32%, 13.21% to 23.67%, 3.27% to 23.89%, 9.76% to 30.41%, -30.21% to 29.65%, 2.74% to 20.68%, 1.63% to 23.63% and -28.65% to 24.08% respectively. Less inbreeding depression for yield attributing traits *viz.*, ear diameter, number of rows per ear and number of kernels per row was reported earlier by San-Vicente and Hallauer (1993) [17]. High inbreeding depression for yield in maize was reported by many workers (Singh and Khalidi, 2001; Aramendiz *et al*. 2006; Simon *et al.* 2004 and Andreoli *et al.* 2006) [19, 3, 18, 2].

In the present study, eight crosses, having higher heterosis, inbreeding depression less than 15% and high mean performance in F_2 generation were identified for their further utilization in recombination breeding programmes (Table II). A perusal of mean value of yield and yield contributing characters along with heat stress traits revealed that hybrids BHU-N1 x CMLK5/ATM CO571, HY10RN-10235-462 x CML-K5/ATM CO571, HY10RN-10235-462 x NBPGR-32809, BHU-N1 x HY10RN-10235-462 and BHU-N1 x BHU-N6 were the best five high yielding QPM hybrids tolerant to terminal heat stress as they didn't show any symptoms of leaf firing, tassel blast, root lodging and no severe loss of yield in the present investigation (Table IV).

It was concluded that cross BHU-N1 x CML-K5/ATM CO571 recorded maximum significant positive standard heterosis for grain yield per plant. Cross CML-K5/ATM CO571 x HKI-34 (H2) was found to be heat tolerant genotype as it didn't show any symptoms of leaf firing, tassel blast, root lodging and no severe loss of yield. Keeping greater magnitude of heterosis, higher mean performance and lesser inbreeding depression (<15%) into consideration, eight crosses were identified which can be further utilized for the development of superior hybrids after confirming their consistency in Allahabad agro-climatic conditions.

Table 2a: Heterotic effect and estimates of inbreeding depression of eleven crosses for yield and other component characters.

S. No.	Hybrid combinations		Days to 50% tasseling	Days to 50% silking	ASI	Plant height	Stem girth	Leaf area index	Cob height	Cob length	Cob girth	Number of kernel rows per cob	Number of kernels per cob	Cob weight	100 seed weight	Grain yield per plant	Protein content
1	BHU-N1 x CML-K5/ATM CO571	H	-15.96**	-15.70**	-10.00	-1.94	-0.64	53.38**	-6.23	-8.42	-6.58	18.04**	-6.70**	12.31**	24.15**	18.24**	4.88**
		ID	-6.79	1.06*	-11.11	3.70	-5.88*	7.39	3.22**	0.14	14.13	18.79	29.23**	5.06*	20.68**	4.15**	10.32**
2	HY10RN-10235-462 x CML-K5/ATM CO571	H	-9.39**	-9.42**	-10.00	-3.48	12.86**	-5.06**	-15.39	-5.89	3.73	10.37**	-4.82**	7.21**	15.89**	10.91**	9.06**
		ID	1.11	-2.97	-22.22	-1.36	23.47*	10.12*	5.95**	9.79	21.98**	9.21	-2.03**	22.62**	8.91***	17.07	-4.87**
3	HY10RN-10235-462 x NBPGR-32809	H	-14.08**	-14.80**	-30.00*	-3.25	22.51**	29.61**	0.76	-2.83	-1.81	13.08**	3.03**	7.30**	15.52**	10.82**	3.04**
		ID	-4.69	-1.58	-14.29	0.07	15.35**	3.41	2.65**	9.66**	20.20	21.62	-2.22**	13.50**	14.71*	17.01**	-12.04**
4	BHU-N1 x HY10RN-10235-462	H	-11.27**	-12.11**	-30.00*	-1.23	1.13	37.40**	-9.02	0.63	6.69	9.47**	-1.75**	6.53**	14.72**	10.00**	10.03**
		ID	-1.43	-2.04	-28.57	5.96	14.15*	11.53	2.30**	0.75**	22.04**	23.86	15.41*	4.11**	16.42	9.86**	24.08**
5	BHU-N1 x BHU-N6	H	-2.35	-4.04	-40.00**	10.79	-23.04**	25.71**	-4.13	-7.06	2.06	-5.86**	-7.17**	6.14**	12.68**	9.42**	5.47**
		ID	7.82	-0.93	-66.67	15.44**	-34.61**	1.96**	5.34*	10.32**	21.66**	30.41*	29.65**	5.01**	20.68**	9.93	10.32**
6	HY10RN-10235-462 x BHU-N6	H	-10.80**	-11.66**	-30.00*	13.49	9.00	11.69*	11.16	-8.99	-7.20	0.00	5.80**	2.95**	12.25**	8.51**	2.94**
		ID	-0.56	-3.05	-28.57	14.46	-7.43**	7.91	11.80	3.43**	16.79**	34.76	-7.59**	8.66	12.59	9.58**	-2.30*
7	HY10RN-10235-462 x HKI-34	H	-17.37**	-17.94**	-30.00*	0.39	7.23	26.10**	22.36	-3.31	-3.98	8.84**	0.09	4.52**	12.06**	8.43**	7.60**
		ID	-8.17	-0.55	-14.29	2.93*	19.08**	3.09	17.83*	8.41	19.58**	6.59	14.41	3.27**	9.97**	4.62**	-4.40**
8	BHU-N6 x HKI-34	H	-13.62**	-13.90**	-20.00	10.50	1.77	-5.45**	7.59	-2.46	-1.37	12.63**	-8.11**	4.52**	11.41**	8.25**	2.94**
		ID	-4.11	-2.60	-12.50	9.64	22.12	5.50	4.22**	9.49	23.78	11.46	6.50**	16.91**	11.03**	17.42**	-4.79**

**Significant at 1% and *Significant at 5% level, H - Heterotic effect, ID - Inbreeding depression

Table 2b: Heterotic effect and estimates of inbreeding depression of eleven crosses for yield and other component characters.

S. No.	Hybrid combinations		Days to 50% tasseling	Days to 50% silking	ASI	Plant height	Stem girth	Leaf area index	Cob height	Cob length	Cob girth	Number of kernel rows per cob	Number of kernels per cob	Cob weight	100 seed weight	Grain yield per plant	Protein content
9	LM-13 x HY10RN-10235-462	H	-14.08**	-14.80**	-30.00*	5.86	-9.65*	22.21**	14.89	4.72	-6.29	4.06**	-1.49*	4.09**	11.41**	7.55**	2.85**
		ID	-5.02**	-8.42*	-28.57	9.35*	-0.06	6.17	16.39**	4.76**	14.80**	33.70	1.97**	19.57**	10.24*	10.08**	0.59**
10	NBPGR-32809 x CML-40	H	-13.62**	-14.35**	-30.00*	-9.10	3.54	16.36**	8.52	2.01	-10.42	13.35**	-0.85	5.09**	12.03**	6.96**	10.22**
		ID	-5.43	-6.81	-42.86	-16.39	5.12**	6.82	14.91**	9.22	10.82	18.26	25.29**	13.12	7.65**	12.01**	-25.36*
11	BHU-N1 x HKI-34	H	-12.68**	-13.45**	-30.00*	5.97	24.12**	49.87**	-6.84	-4.57	-7.78	13.17**	-1.20*	2.31**	8.68**	5.30**	3.62**
		ID	-3.11	-6.22	-42.86	10.47	42.51**	6.85	6.08**	2.17**	13.21**	20.11	10.65**	11.93**	10.23	10.32	-3.91**
12	LM-13 x BHU-N6	H	-12.68**	-13.00**	-20.00	9.38	7.23	10.91**	4.48	-2.31	-1.56	10.10**	-0.04	3.79**	8.53**	5.01**	10.61**
		ID	-3.20	-4.12*	-37.50	12.03**	28.34**	13.33	-9.02**	5.00	20.16	26.76	19.77**	4.91**	5.63**	10.26*	9.84**
13	CML-K5/ATM CO571 x CML-40	H	-11.74**	-12.11**	-20.00	-3.84	4.98	21.04	0.92	-1.68	-3.62	5.41**	-0.90	2.20**	7.58**	3.93**	1.00
		ID	-2.79	-4.08	-25.00	-2.12	-13.43**	3.85	18.84**	9.35**	17.79**	26.15	-18.49**	15.78	9.33**	7.99	-29.72

14	BHU-N1 x NBPGR-32809	H	-14.55**	-15.25**	-30.00*	-8.78	20.58**	39.74**	20.48	1.77	0.07	19.12**	-3.59**	1.54*	5.36**	3.46**	3.62**
		ID	-5.33*	-1.59*	-42.86	-4.03	7.96	3.90*	1.48	6.13	18.32**	19.17*	4.47**	15.22	6.71**	10.51**	7.32**
15	LM-13 x HKI-34	H	-13.15**	-13.00**	-10.00	11.38	-5.47	22.99**	27.62	-2.49	-8.82	5.41**	3.50**	1.24	5.00**	2.67**	7.12**
		ID	-3.24	-5.67	0.00	12.26	48.21	8.73*	19.40**	1.02*	13.73**	5.28**	20.84**	9.21	15.94**	18.34	16.22**
16	BHU-N1 x LM-13	H	-17.84**	-17.94**	-20.00	-18.62*	-19.61**	61.56**	4.64	5.44	5.82	7.94**	-12.21**	-0.54	2.05**	0.74**	1.10
		ID	-9.41	-6.56	-12.50	-12.37**	9.81	10.46	13.89**	8.59**	23.67**	10.25*	8.90**	22.48	7.74**	9.95	7.25**

**Significant at 1% and *Significant at 5% level, H - Heterotic effect, ID - Inbreeding depression

Table 3: Hybrid combinations showing higher mean value and lesser inbreeding depression in F_2 generation.

S. No.	Hybrid combinations	Mean performance of grain yield per plant in F_2 generation	Inbreeding depression
1	BHU-N1 x CML-K5/ATM CO571	36.41	4.15**
2	BHU-N1 x HY10RN-10235-462	33.74	9.86**
3	HY10RN-10235-462 x BHU-N6	33.48	9.58**
4	HY10RN-10235-462 x HKI-34	32.93	4.62**
5	LM-13 x HY10RN-10235-462	32.29	10.08**
6	NBPGR-32809 x CML-40	32.25	12.01**
7	LM-13 x BHU-N6	32.29	10.26*
8	BHU-N1 x NBPGR-32809	31.41	10.51**

**Significant at 1% and *Significant at 5% level of significanc

Table 4: Best five QPM hybrids identified on the basis of *per se* performance of grain yield per plant and heat stress characters

S. No.	Crosses	Grain yield (g)	100 seed weight (g)	Leaf firing	Tassel blast	Root lodging
1	BHU-N1 x CML-K5/ATM CO571	37.99	34.10	1.00	0.50	0.50
2	HY10RN-10235-462 x CML-K5/ATM CO571	37.96	31.83	0.50	1.00	0.50
3	HY10RN-10235-462 x NBPGR-32809	37.93	31.73	1.00	1.00	0.50
4	BHU-N1 x HY10RN-10235-462	37.65	31.51	0.50	0.50	0.50
5	BHU-N1 x BHU-N6	37.45	30.95	1.00	0.50	2.00

Acknowledgements
Present investigation was done as a part of M.Sc. thesis. The authors are thankful to the Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India, Department of Agriculture, Agriculture Education and Research, Govt. of Uttar Pradesh for providing financial assistance to this project.

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