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COMBINING ABILITY ANALYSIS AND HETEROSIS ESTIMATES IN HIGH QUALITY PROTEIN MAIZE INBRED LINES*

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ABSTRACT

Combining ability analysis using top cross method was performed in high quality protein maize (QPM) inbred lines for yield and yield contributing characters in order to assess the QPM inbred lines for general combining ability (gca) and to estimate mid parent and standard heterosis. The major interest was to seek out specific set of lines having maximum genetic distance that maximizes expression of heterosis in hybrid combination. The top cross, I_{14} x S superceded the checks in grain yield followed by the other crosses I_6 x S, I_4 x S, I_3 x S, I_{18} x S and I_7 x S. Significant positive gca effects for grain yield were revealed by the inbred I_3, I_4 and I_6. Mid parent heterosis was observed to be 53.08% for grain yield in cross, I_{14} x S. The cross showed highest standard heterosis for grain yield (36.83%). The inbred line I_7, I_{18} and I_{20} revealed negative significant gca effects for days to 50% silking which can be utilized for developing early maturing hybrids.

INTRODUCTION

Maize has worldwide significance as human food, animal feed as grain and fodder and for a large number of many other industrial products like glucose, starch, oil etc. The commercial maize varieties usually contain 9-12% protein which is enough to meet the physiological needs of human body. However, the quality of protein is nutritionally poor due to lower contents of two essential amino acids, lysine and tryptophan and an undesirable ratio of leucine and isoleucine. Lysine is important for general growth in human beings and animals. Its deficiency impedes utilization of other amino acids. The maize carrying opaque-2 gene in homozygous condition is referred to as opaque-2 and the hard modified endosperm opaque-2 maize with vitreous kernels is known as Quality Protein Maize (QPM). Such modified opaque-2 mutants contain lysine and tryptophan twice than the normal maize varieties along with low amount of leucine.

The opaque-2 gene can be incorporated into any maize population, inbred line or other germplasm through backcross breeding method in selected genetic backgrounds.

QPM hybrids are more successful among the farmers as they are always planted with fresh F_1 seed every year and thus remain unaffected from contamination through normal maize cultivars. Since, the seed of open pollinated maize varieties can be saved and used for next 3-4 years it gets contaminated if not grown in isolation. In recent past, two QPM hybrids namely Shaktiman-1 and Shaktiman-2 have been developed at R.A.U., Pusa, Samastipur and released for cultivation in Bihar. Shaktiman-1 was recommended for cultivation in U.P. also in 2001. The present study was undertaken to evaluate the combining ability of QPM inbred lines using top cross method and to examine the magnitude and directions of mid parent and standard heterosis of the top crosses.

MATERIAL AND METHODS

Twenty high quality protein maize inbred lines were top crossed with Shakti-1, a high lysine maize variety released for cultivation in 1997. These inbred lines and their top crosses were evaluated with two standard checks *viz.*, Shakti-1 and a normal maize hybrid, JH 3459 in a randomized complete block design with three replications during *kharif*, 2002 at the Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttaranchal. Each plot consisted two rows each 5 m long and 0.75 m apart i.e., the plot area was 7.5 m^2. Data were recorded on days to 50% tasselling, days to 50% silking, plant height (cm), ear height (cm), ear length (cm), ear diameter (cm), 100-kernel weight (g), grain yield (kg/ha) and quality parameters like protein, lysine and tryptophan contents. Observations for days to 50% tasselling and silking and grain yield were recorded on whole plot basis whereas for remaining characters data were taken on ten randomly selected competitive plants/ears from a plot and average values for each character were used out for statistical analysis.

The analysis for protein was done by AOAC method while lysine and tryptophan were estimated by colorimetric method in the Biochemical Unit of Directorate of Maize Research, IARI Campus, New Delhi.

RESULTS AND DISCUSSION

The analysis of variance including all inbred lines, their top crosses and two standard checks revealed that mean squares due to genotypes were highly significant for all the characters except days to 50% tasselling and silking (Table 1). This indicated that sufficient variability was present in the material under study. Combining ability analysis is of special importance in a highly cross fertilized crop like maize as it helps in identifying potential inbred lines which cab be used for developing hybrids and synthetic varieties and thus assists in isolating basic material on which the success of any breeding programme depends. The inbred lines showing high gca effect are good for producing synthetics. The variance of gca depicted the possible types of gene action involved. The variance of gca includes additive genetic portion.

Based on mean performance, none of inbreds was excellent for all the characters suggesting the value of synthetics for substantial yield improvement. However, the cross (I_{14} x S) superceded the checks in grain yield followed by other crosses (I_6 x S), (I_4 x S), (I_3 x S), (I_{18} x S) and (I_7 x S). These top crosses were either *at par* or earlier in days to silking as compared to the best check, Shakti-1. Singh (1984) obtained similar results in his studies, where he found significant differences in top crosses and selected lines on the basis of higher gca values. This result also supports the findings of Joshi *et al.* (1998), Mather *et al.* (1998) and Desai and Singh (2000).

The inbred I_3 showed significant negative gca effect for days to 50% tasselling with significant positive gca effect for 100-kernel weight and grain yield (Table 1). Inbred I_4 showed significant positive gca effect for days to 50% tasselling, days to 50% silking and grain yield. Inbred I_6 revealed positive significant gca effect for plant height and grain yield. Inbred I_{20} showed significant negative gca effect for days to 50% tasselling and silking and thus can be used for developing early maturing maize cultivars. Based on the estimates of gca effects, I_3, I_4 and I_6 were found to be good general combiners for grain yield. The non corresponding pattern between gca effects and *per se* performance may be due to the fact that a particular parent may have better performance for a character but may not be competent with other genotypes in the desirable direction in a series of cross combinations primarily because it may have recessive genes for higher expression of the character which may be dominated by the undesirable dominant genes of the other parents in cross combinations. These findings were similar to those of Kabdal (2000). The point of major interest in the present study as to identify the specific set of lines having maximum genetic distance that maximizes expression of heterosis in hybrid combination. The inbred line I_4 and I_8 showed positive significant gca effects for days to 50% tasselling and silking while inbred line I_7, I_{18} and I_{20}

Table 1. Estimates of general combining ability effects of QPM maize inbreds and mean squares of experimental genotypes for different characters

S.No.	Inbred lines	Days to 50% tasselling	Days to 50% flowering	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	100-kernal weight (g)	Grain yield (kg/ha)
1.	I_1	0.783	1.157	15.67*	-9.37*	0.195	0.165	-0.398	-250.233
2.	I_2	0.116	1.026	20.67**	8.01*	1.279	0.608**	1.808	313.76
3.	I_3	-1.217*	-1.66	4.00	2.33	0.679	0.392	2.625**	539.09*
4.	I_4	1.450*	1.371*	6.00	-2.85	-0.374	-0.024	0.968	688.43**
5.	I_5	0.117	0.500	8.67	3.41	0.039	0.122	1.481	-96.56
6.	I_6	0.783	0.500	14.33*	-7.01	0.979	0.265	0.844	803.09**
7.	I_7	-0.883	-1.278*	-6.67	-2.33	0.013	0.532*	0.605	355.09
8.	I_8	1.450*	1.500*	-15.33*	-8.69*	1.245	0.218	-0.794	23.09
9.	I_9	1.117	1.345*	-13.67*	-6.67	-0.587	0.002	1.228	-699.90**
10.	I_{10}	-1.217*	-0.167	-5.33	3.00	-1.187	-0.634**	-2.67**	-209.90
11.	I_{11}	-0.883	1.50*	-4.67	-1.67	-0.554	0.126	1.161	-725.23
12.	I_{12}	0.450	0.500	-2.67	-1.93	1.212	0.185	-0.54	-158.90
13.	I_{13}	-2.17	0.166	-0.667	0.85	-0.754	0.135	1.99*	-386.56
14.	I_{14}	0.783	0.547	-9.33	4.78	0.774	-0.141	-0.394	135.09
15.	I_{15}	0.488	0.500	7.33	1.22	0.087	0.797**	1.89	278.23
16.	I_{16}	-0.549	-0.833	-25.00**	14.69**	-1.040	-0.904**	-2.24*	226.43
17.	I_{17}	-0.549	-1.166	6.00	2.00	-1.154	0.032	-0.54	-613.90*
18.	I_{18}	0.417	-1.240*	-14.67*	8.21*	-1.354*	-0.250	-0.651	432.76
19.	I_{19}	-0.217	-0.543	-3.33	1.43	1.589*	-0.037	0.161	-418.23
20.	I_{20}	-1.217*	-1.321*	2.67	1.69	0.689	0.002	-1.061	-689.23**
Mean squares		2.824	4.259	465.156**	137.625**	2.308**	0.544**	5.111**	819564.8**
SEd±		1.438	1.333	1.544	1.397	0.506	0.268	0.386	206.207
SEM		0.62	0.61	6.92	3.61	0.691	0.216	0.98	255.224

*,** Significant at 5% and 1% probability levels, respectively.

revealed negative significant gca effects for days to 50% silking which can be utilized for developing early maturing hybrids. It may be observed that inbred line I_2 and I_{15} showed positive gca effects for all characters whereas I_5 and I_6 exhibited positive gca effects for most of the characters except grain yield and ear height, respectively. On the other hand, inbred line I_{10} and I_{16} revealed negative gca effects for the most of the characters.

Inbred lines need to be classified into heterotic groups according to their hybrid performance. In the present study, heterosis has been studied with respect to superiority of hybrids over the mid parent and standard check. The mid parent heterosis ranged from -30.93% for ear diameter in cross (I_{16} x S) to 53.08% for grain yield in cross (I_{14} x S). Dehghanpour *et al.* (1996) reported that mid parent heterosis ranged from -6% for silking date to 15.2% for grain yield. The cross (I_3 x S), (I_4 x S) and (I_7 x S) showed significant positive heterosis for most of the characters (Table 2). The cross (I_3 x S) showed significant positive heterosis for plant height (21.54%), ear height (38.40%), ear length (4.13%), ear diameter (5.43%), 100-kernel weight (14.16%) and grain yield (27.57%). The cross (I_4 x S) showed significant positive heterosis for plant height (22.77%), ear height (12.32%), ear diameter (5.40%), 100-kernel weight (6.14%) and grain yield (42.29%) and depicted negative heterosis for ear length (-3.17%). The cross (I_7 x S) attributed significant positive heterosis for plant height (4.56%), ear height (27.09%), ear diameter (10.06%), 100-kernel weight (4.40%) and grain yield (20.40%) while significant negative heterosis for ear length.

Table 2. Mid parent heterosis for different characters in top crosses of maize

S.No.	Crosses	Days to 50% tasselling	Days to 50% flowering	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	100-kernal weight (g)	Grain yield (kg/ha)
1.	$I_1 \times S$	0.611	0.286	20.139**	24.671**	3.545**	-6.378**	-0.484	-9.467
2.	$I_2 \times S$	0.318	1.704	26.761**	46.106**	10.556**	3.145	10.203**	15.490*
3.	$I_3 \times S$	-1.571	-1.723	21.584**	38.405**	4.133**	5.435**	14.168**	27.572**
4.	$I_4 \times S$	0.613	0.565	22.771**	12.326**	-3.176**	5.471*	6.141**	42.290**
5.	$I_5 \times S$	1.561	1.140	23.226**	34.745**	-1.633	-2.957	8.656**	4.897
6.	$I_6 \times S$	0.611	0.00	24.050**	30.466**	4.054**	-1.053	-2.611**	17.205**
7.	$I_7 \times S$	-2.164	-3.110	4.568**	27.095**	-2.357**	10.068**	4.400**	20.402**
8.	$I_8 \times S$	2.488	1.121	28.751**	40.440**	9.121**	2.204	-2.369**	19.822**
9.	$I_9 \times S$	2.503	2.267	5.302**	0.971	-3.441**	-3.857	6.963**	-29.746**
10.	$I_{10} \times S$	-2.488	-1.136	15.789**	-2.945	-6.424**	-11.318**	-11.460**	0.145
11.	$I_{11} \times S$	-3.358	-5.00*	8.923**	-4.027	-7.548**	5.539*	7.108	-11.742
12.	$I_{12} \times S$	2.205	1.140	12.985**	-3.232	2.575**	-7.188**	-1.112	2.762
13.	$I_{13} \times S$	-0.938	-1.694	14.978**	25.00**	-5.267**	-0.548	11.122**	-21.227**
14.	$I_{14} \times S$	0.919	0.565	4.895**	19.053**	-10.247**	-6.983**	-0.435	53.081**
15.	$I_{15} \times S$	1.239	0.00	15.978**	15.701**	0.761 ns	-3.412	-7.737**	5.353
16.	$I_{16} \times S$	-2.151	-2.806	0.246	-4.196	-7.483**	-30.933**	-9.381**	20.684**
17.	$I_{17} \times S$	0.312	1.444	20.384**	25.163**	-11.027**	-4.736*	-1.161	-8.176
18.	$I_{18} \times S$	0.306	-1.444	7.693**	22.408**	-9.677**	-17.766**	-1.692**	21.350**
19.	$I_{19} \times S$	-1.571	-1.142	15.556**	20.283**	11.294**	3.916	2.273**	-6.074
20.	$I_{20} \times S$	-3.388	-2.000	14.894**	12.371**	3.964**	-2.786	-3.675**	-20.841**

*,** Significant at 5% and 1% probability levels, respectively.

Table 3. Standard heterosis for different characters in top crosses of maize

S.No.	Crosses	Days to 50% tasselling	Days to 50% flowering	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	100-kernal weight (g)	Grain yield (kg/ha)
1.	$I_1 \times S$	0.611	0.00	34.615**	57.364**	0.735	-4.922*	-0.484	-10.662
2.	$I_2 \times S$	-0.611	0.00	38.462**	68.847**	8.024**	6.218**	10.203**	8.673
3.	$I_3 \times S$	-3.193	-3.922	25.638**	49.176**	4.119**	0.518	14.168**	16.398*
4.	$I_4 \times S$	1.852	0.00	27.177**	27.047**	-2.779**	-10.104*	6.141**	21.518**
5.	$I_5 \times S$	-0.630	-1.123	29.231**	55.717**	-0.046	-6.477	8.656**	-5.394
6.	$I_6 \times S$	0.611	-1.123	33.592**	61.470**	6.071**	-2.591	-2.611**	25.448**
7.	$I_7 \times S$	-2.463	-3.922	17.438**	61.470**	-0.241	4.223	4.400**	10.090
8.	$I_8 \times S$	1.854	0.558	34.362**	50.799**	7.828**	-3.886	-2.369**	-1.291
9.	$I_9 \times S$	1.241	0.553	12.054**	27.858**	-4.145**	-9.585**	6.963**	-26.077**
10.	$I_{10} \times S$	-3.093	-2.246	18.462**	8.188**	-8.050**	-25.907**	-11.460**	-9.279
11.	$I_{11} \times S$	-2.463	-4.475*	18.977**	17.212**	-3.950**	-6.218**	7.108**	-26.945**
12.	$I_{12} \times S$	0.00	-1.123	20.515**	22.941**	7.568**	-4.663*	-1.112	-7.531
13.	$I_{13} \times S$	-1.241	-2.246	22.054**	47.529**	-5.186**	-5.186**	-5.959**	11.122**
14.	$I_{14} \times S$	0.611	-1.123	15.385**	45.881**	-5.382**	-13.212**	-0.435	36.830**
15.	$I_{15} \times S$	0.611	-1.123	15.385**	23.752**	-0.892	-30.311**	-7.737**	-11.622
16.	$I_{16} \times S$	-1.852	-3.352	3.331**	12.294**	-7.074**	-32.902**	-9.381**	5.679
17.	$I_{17} \times S$	-1.852	-3.922	27.177**	50.799**	-7.854**	-8.808**	-1.161	-23.129**
18.	$I_{18} \times S$	-0.611	-3.922	11.282**	40.964**	-9.091**	-16.062**	-1.692**	12.753
19.	$I_{19} \times S$	-3.093	-2.799	20.000**	36.046**	9.976**	-10.622**	2.273**	-16.421*
20.	$I_{20} \times S$	-3.093	-3.922	24.615**	37.694**	4.119**	-9.585*	-3.675**	-25.369**

*,** Significant at 5% and 1% probability levels, respectively.

The mid parent heterosis was mostly in negative direction for days to 50% tasselling and silking indicating earliness in maturity. The maximum negative heterosis for days to 50% tasselling and silking was recorded for cross (I_{11} x S) followed by cross (I_{20} x S), (I_7 x S) and (I_6 x S). This indicates that inbred lines involved in these crosses may be used for producing early maturing QPM hybrids.

Estimates of standard heterosis for all characters are presented in Table 3. The cross (I_3 x S), (I_4 x S), (I_6 x S) and (I_{14} x S) showed significant positive standard heterosis for grain yield. Cross (I_3 x S) showed significant positive standard heterosis for plant height (25.63%), ear height (49.17%), ear length (4.11%), 100-kernel weight (14.16%), grain yield (16.39%) and negative heterosis for days to 50% tasselling (-3.19%) and days to 50% silking (-3.92%) depicting its importance in developing early maturing cultivars. The cross (I_4 x S) showed significant positive standard heterosis for plant height (27.17%), ear height (27.04%), 100-kernel weight (6.14%) and grain yield (21.51%). The cross (I_6 x S) revealed significant positive standard heterosis for plant height (33.59%), ear height (61.47%), ear length (6.07%) and grain yield (25.44%). The cross (I_{14} x S) depicted significant positive standard heterosis for plant height (15.38%), ear height (45.88%) and grain yield (36.83%). All the twenty top crosses showed significant positive standard heterosis for plant height and ear height. None of the crosses showed significant heterosis for days to 50% tasselling and days to 50% silking except the cross (I_{11} x S) for days to 50% silking (-4.47%). The cross (I_{11} x S) showed highest negative heterosis for days to 50% tasselling and silking over standard checks followed by the crosses (I_3 x S), (I_{20} x S) and (I_7 x S). Similar findings were reported by Gupta *et al.* (1994).

In case of plant height, all the crosses showed mid parent heterosis and standard heterosis in positive direction. Ganguli *et al.* (1989) and Kabdal (2000) also reported the similar results. For ear height, most of the crosses exhibited positive heterosis over mid parent and standard check. The cross (I_2 x S) showed the highest positive heterosis over mid parent and standard check. For plant height (26.76% and 38.46%) and ear height (46.16% and 68.84%), respectively. The cross (I_{19} x S) showed the highest positive heterosis over mid parent (11.29%) and over standard check (9.97%) for ear length. The cross (I_7 x S) had the maximum amount of positive mid parent heterosis for ear diameter and the cross (I_2 x S) had minimum heterosis over standard check for the same. Similar results were obtained in the studies of Genova (1984), Ganguli *et al.* (1989) and Kabdal (2000). Based on the estimates of gca effects, inbreds I_3, I_4, I_6 and I_{14} were found to be the best combiners for most of the characters including grain yield. The inbred I_4 and I_5 and their top crosses may be further used for developing high quality protein maize hybrids.

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