Heterosis, Potence Ratio and Genetic Distance for yield and yield contributing traits in single cross maize hybrids

Aditi Ghosh*, Prakash Kanti Das, Amitava Ghosh and Sabyaschi Kundagrami

Department of Genetics and Plant Breeding, Institute of Agricultural Science, University of Calcutta, 51/2 Hazra Road, Kolkata-700019, West Bengal, India

Corresponding author : aditihosh010@yahoo.com *

Abstract

The study is concerned with the development of single cross heterotic hybrids and to understand the underlying genetic principle for heterosis as well as to establish its relation with parental genetic divergence to formulate a breeding strategy for maize improvement. Heterosis was trait dependent exhibiting high level for plant height, cob characters and grain yield/plant. Two hybrids were better than standard checks, but only DMR QPM 103 x CML 539 recorded 26-28% heterosis over both checks and also displayed positive heterosis for cob characters as well for grain weight. Significantly it was almost seven days earlier in flowering which favoured pollination advantage with better flowering synchrony. Cob characters were positively correlated with yield heterosis's cob diameter was positively correlated with all cob characters. Cob diameter heterosis could be effective predictor for grain yield heterosis. Majority of the traits were controlled by over dominance gene effect, where more than 80% of hybrids recorded over dominance gene effect for plant height and cob characters. The breeding strategy has to be adopted to maximize heterosis. In this context it appears that inbred tester would improve the population more than the population tester because in an inbred, alleles are fixed whereas in population they are intermediate in frequency. As many as 34 hybrids recorded mid parent heterosis of 100% or above. Of them 25 (74%) belonged to the medium parental divergence group having parental grain yield of 50 g or above. It was observed that parents with high per se performance and intermediate genetic divergence produced highly heterotic and high yielding hybrids.

KeyWords *Maize hybrids, Heterosis, Parental divergence, Potence ratio*

Introduction

Maize is one of the versatile crops of global importance being widely used as food, feed and raw material for industrial products. In India, maize sector has shown rapid growth over the last few years. In traditional maize growing States of India, it is primarily grown as a subsistence crop to meet food needs while in the non-traditional areas it is grown for commercial purposes i.e., mainly to meet the feed requirements of the thriving poultry sector. Maize in West Bengal covers a little over one hundred thousand hectare (156.000 ha) area but productivity is more than 4 tons/ha which is almost twice that of national average (2.5 tons/ha). Thus, it shows significant growth opportunities for maize cultivation in West Bengal. Much effort is devoted to increase its productivity. Maize breeders are consistently emphasizing the importance of diversity among parental inbreds as a significant factor contributing to high yielding hybrids (Moll et al., 1965; Hallauer, 1972) with greater heterotic expression. As greater emphasis has been laid on single cross hybrids as commercial proposition it becomes obligatory to enhance yield of inbred parents. Hence, several inbred lines collected from different sources need to be assessed for their yield and divergence. Usually genetic diversity becomes prerequisite for any crop improvement programme as it helps in the development of superior recombinants (Naik et al., 2006). In this context breeder should have enough knowledge about the inheritance and nature of gene action of yield and its contributing traits to carry out a successful breeding strategy (Alhadi et al., 2013). The present study is concerned with the following objectives: (1) Performance of Single Cross Maize hybrids and Identification of outstanding single cross hybrid/hybrids through measure of heterosis relative to mid and better parents as well against standard check, (2) Estimation of potence ratio to record gene action of different traits for their heterotic expression and finally, (3) Role of genetic distance of parents involved in heterosis.

Materials and Methods

Materials and Experiment

18 QPM (Quality Protein Maize) and 2 Non QPM inbred lines were crossed randomly to raise 52 F1 hybrids

along with 2 standard checks, 900M Gold & HQPM1 (Table 1). They were grown on last week of November, 2014 at the University Experimental Farm, Baruipur, South 24 Parganas, West Bengal (22.3597° N, 88.4318° E at an elevation of 9 m above sea level) following Randomized Block Design with three replications, maintaining 60 cm row to row distance and 20 cm plant to plant. The prescribed packages of practices were followed. Harvesting was done by 2nd week of April, 2015. The average temperature throughout the experimental period ranged 28-35°C maximum and 11-16°C minimum.

Observations

Data were recorded from five randomly taken healthy disease free plants for Days to 50% tasseling (DT 50%), Days to 50% silking (DS 50%), Plant height (cm) – PH, Cob length (cm) – CL, Cob diameter (cm) - CD, Number of grain rows per cob – GR/C, Number of grains per row - G/R, Number of grains per cob – G/C, 100 grain weight (g) – 100 GW, Grain yield per plant (g) – GY/P.

Statistical analysis

ANOVA for each trait was performed. Estimation of Heterosis, Potence ratio, phenotypic distance were carried out as follows.

Heterosis

Heterosis percentages relative to the mid parents (Average heterosis), better parents (Heterobeltiosis i.e. superiority of the F1 hybrid over its better parent) and the standard checks (Standard heterosis) for different characters were calculated using the procedure illustrated by Mather and Jinks (1971) as follows -

$$\text{Mid-Parent (MP \%)} = \frac{F_1 - MP}{MP} \times 100, \quad \text{Better-Parent (BP \%)} = \frac{F_1 - BP}{BP} \times 100$$

$$\text{Standard Check (SH \%)} = \frac{F_1 - SC}{SC} \times 100$$

Where, **F1** is the mean performance of the cross, **MP** is mean of the two inbred parents, **BP** is the mean value of the highest performing parent and **SC** is mean of the Standard check varieties.

Potence ratio: The potence ratio was calculated according to Mather (1949) and Smith (1952) to determine the degree of dominance as follows –

$$P = \frac{F_1 - MP}{0.5\ (P_2 - P_1)}$$

Where, **P** = relative potence of gene set, **F1** = first generation mean, **P1** = the mean of lower parent, **P2** = the mean of higher parent, **MP** = mid-parents value **(P1 + P2)/2. Complete dominance** was indicated when Potence ratio = +1, **Partial dominance** is indicated when Potence ratio is between −1 and +1, **Overdominance** is indicated when potence ratio exceeds ±1. **Absence of dominance** is indicated when Potence ratio = 0. The positive and negative signs indicate the direction of dominance of either parent.

Phenotypic Distance

It was estimated by Mean Euclidean distance using Hierarchical cluster method (Darwin 6 software). Parents were classified into three categories namely, high, medium and low divergence group. The mean (m) and standard deviation (SD) of the inter cluster distances were calculated. Phenotypic distance between the parents greater than **(m+SD)** value indicated **high divergence group**, **(m-SD)** value represented **lower divergence group** and **medium divergence group** belonged to in between these two values (Datta et al., 2004).

Correlations

Correlations of yield with Potence ratio, phenotypic distance and Heterosis were computed (SPSS version 20 software).

Results and Discussion

Mean Performance

Using twenty inbred lines fifty two hybrids were raised of which nineteen belonged to QPM x Non-QPM cross combination and rest thirty two were obtained from QPM x QPM crosses. For each trait there was high degree of range values indicating presence of great deal of variability which corroborates the reports of Ihasn et al. (2005) and Waqar et al. (2007). Hybrids were significantly different for majority of the traits (Table 1). Yield performance of only three hybrids was either at par with check or better than; for example, two hybrid combinations CML 539xCML 537 (Non QPM x QPM) and DMR QPM 103xCML 509 (QPM x QPM) were as good as standard checks as they recorded grain yield/plant of 169 g and 164 g respectively which were very similar to either of the checks. As compared to checks they produced less number of grains but their grain weight were significantly higher than the checks indicating a compensating mechanism in operation which confirms the earlier observations of Zarei et al. (2012) and Kumar et al. (2017) in maize. The hybrid DMR QPM 103xCML 539 was the best surpassing significantly the two standard checks in yield performance, where it recorded around 210 g grain yield/plant. It had a

Table 1. Means of different traits for different hybrids along with standard checks

CROSSES	DT 50%	DS 50%	PH (cm)	EH (cm)	CL (cm)	CD (cm)	GR/C	G/R	G/C	GW (g)	GY/P (g)
170x103	83.3	87.7	175.9	73.7	12.9	13.6	12.9	27.6	332.7	24.9	87.6
170x539	84.0	90.0	151.3	70.8	12.2	12.8	14.0	25.1	327.9	24.3	81.2
102x170	83.3	88.0	162.2	74.7	14.4	12.0	11.3	28.3	315.3	29.1	92.7
102x03-121	81.7	87.7	153.9	78.6	13.9	12.8	12.2	28.4	344.5	33.5	83.3
102x103	89.7	92.3	185.2	87.9	12.7	12.2	13.5	27.6	304.6	35.2	131.4
03-121x103	85.0	88.0	183.1	93.1	13.2	13.8	17.5	29.4	419.6	29.6	123.6
03-121x509	86.7	91.0	176.7	88.3	13.9	13.4	15.9	24.4	306.1	31.1	95.9
03-121x511	89.3	91.3	173.9	90.9	13.1	13.4	13.7	24.5	338.4	29.7	99.4
03-121x03-104	86.0	88.7	159.6	75.1	13.8	13.7	14.1	29.4	407.7	29.4	118.7
103x03-121	86.7	90.3	179.0	86.5	13.4	13.1	13.3	27.4	372.9	30.9	112.5
103x509	85.0	88.0	207.9	98.7	14.9	14.8	14.0	33.5	453.7	36.1	164.1
167x507	87.7	90.7	214.9	100.7	16.2	13.8	13.4	32.3	429.8	36.5	155.4
167x537	92.0	95.7	210.4	96.7	15.5	15.2	16.0	29.3	466.7	34.5	160.3
102x511	85.0	89.3	191.5	86.9	14.9	13.0	11.8	25.6	312.8	36.2	121.9
167x169	90.7	94.3	208.7	102.0	15.2	14.5	16.1	29.4	472.9	27.6	129.9
511x102	87.3	91.3	204.1	97.2	14.7	14.0	13.2	28.4	379.0	33.7	127.1
511x539	88.3	91.7	207.2	102.1	14.4	15.2	13.8	28.8	399.1	33.9	133.9
509x539	84.3	89.3	208.3	96.5	14.5	14.1	12.7	27.8	350.1	39.2	133.1
509x538	87.0	92.0	212.6	103.6	15.0	14.9	13.1	26.1	341.3	37.4	126.0
509x102	85.7	92.0	214.1	100.7	15.8	14.1	13.2	25.9	340.8	38.2	127.4
509x167	87.7	92.3	216.5	100.7	16.3	14.3	14.3	31.9	461.2	28.2	134.7
539x03-121	84.7	88.0	177.5	87.4	14.5	13.9	13.7	28.9	385.3	31.2	122.3
539x167	90.0	94.3	185.9	86.7	12.9	13.3	13.3	25.1	342.8	28.5	96.5
539x537	88.0	92.0	202.1	88.9	16.9	15.3	13.7	31.3	457.7	37.5	169.1
539x102	90.0	94.0	193.1	88.6	12.4	14.7	13.4	22.6	320.9	34.7	117.0
539x504	88.3	93.7	186.2	79.9	14.5	15.1	13.7	28.2	386.7	33.5	129.0
507x539	84.0	89.3	207.9	87.0	16.2	14.8	12.4	30.3	345.9	41.1	151.6
507x504	86.7	91.7	202.7	88.0	15.5	15.0	13.3	26.5	353.4	37.8	131.5
507x538	92.0	98.3	205.9	92.3	15.6	15.2	13.2	26.6	346.3	38.0	136.4
504x539	87.7	92.7	198.6	92.7	15.5	15.8	13.4	29.7	400.4	38.3	152.4
502x103	94.7	97.3	201.7	89.7	12.5	15.2	14.7	29.0	426.7	29.0	126.1
503x 539	96.7	100.3	188.0	82.7	13.5	14.6	13.8	19.8	318.4	29.0	91.7
510x539	92.3	98.7	185.6	85.3	14.5	14.4	13.6	27.7	379.5	30.3	113.0
169x167	87.7	91.7	209.6	91.7	15.7	15.0	16.9	31.2	517.9	26.5	140.4
538X509	90.0	96.3	201.7	94.6	14.5	15.1	12.8	22.9	297.2	36.2	106.1
538X510	88.0	95.0	196.1	87.9	13.5	14.1	13.7	26.8	369.2	29.2	105.6
161X507	90.7	98.0	213.3	96.9	14.1	14.5	13.6	18.6	269.9	40.6	105.6
163X539	89.0	97.3	205.5	92.8	13.8	13.3	12.4	26.0	326.0	32.6	101.0
193-1X163	93.0	99.7	217.4	104.3	16.3	14.9	14.5	30.2	454.9	32.5	145.8
102X509	94.0	98.0	197.7	87.5	11.7	14.9	13.6	21.7	297.0	28.9	95.6
102X539	87.3	90.0	203.5	107.0	16.1	14.9	13.2	29.4	387.6	31.2	120.0
102X167	85.7	89.3	193.0	83.2	16.5	15.4	14.8	27.5	406.5	33.5	134.9
170X509	90.0	94.3	200.6	97.1	15.1	14.6	13.5	28.3	377.8	30.7	124.0
170X511	85.0	88.3	172.3	77.3	13.5	13.7	13.3	26.7	353.0	32.6	112.2
170X167	88.7	91.0	198.6	82.5	16.3	14.6	13.9	37.2	518.1	30.2	155.0
103X539	86.7	89.3	219.8	98.5	19.3	17.2	15.4	37.7	562.5	39.7	210.3
103X167	95.0	97.0	201.4	96.6	14.4	15.4	18.8	30.4	423.8	29.0	129.9
103X511	83.3	87.0	186.8	85.9	15.3	13.8	14.0	28.0	411.5	31.0	128.7
03-121X167	88.3	92.3	213.9	90.0	16.9	14.8	14.2	33.3	460.7	27.5	129.7
03-121X539	91.7	96.0	213.0	104.5	16.2	15.6	13.1	31.0	408.0	36.8	147.6
511X167	93.3	97.3	212.0	107.1	18.1	13.7	15.1	34.9	508.3	26.1	137.7
509X539	84.0	87.0	209.7	98.1	17.9	13.8	14.1	32.1	451.3	30.6	138.0
SC 1	90.7	95.0	229.5	110.9	16.1	17.1	15.4	33.6	515.9	32.9	167.4
SC 2	89.0	94.3	201.2	107.6	18.0	15.7	14.2	34.4	490.0	33.5	164.0
CD 1%	6.0	7.2	31.4	22.4	3.8	1.6	3.6	9.9	121.3	1.7	44.1
CD 5 %	4.5	5.4	23.6	16.8	2.9	1.2	2.7	7.4	91.2	1.3	33.2

List of Parents (Inbred Lines)	
QPM	CML 161, CML 163, CML502, CML504, CML507, CML509, CML510, CML511, CML537, CML167, CML169, CML170, DMR QPM 102, DMR QPM 103, DMR QPM 03-104, DMR QPM 03-121, H.K.I 163, H.K.I 193 - 1
NON QPM	CML 538, CML 539

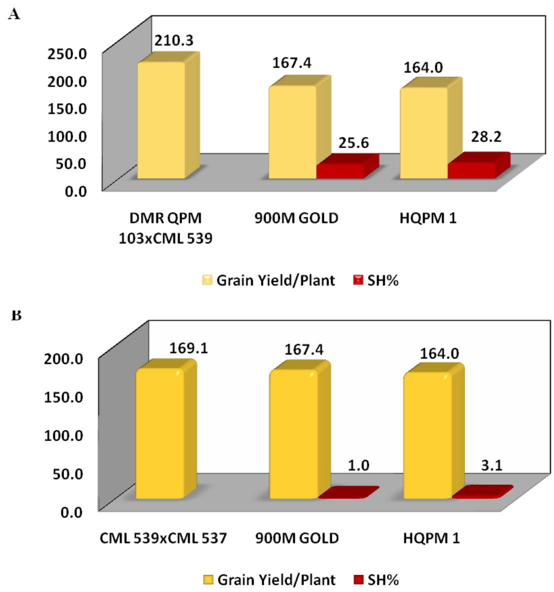
*Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P yield advantage of 25.8 to 28.2% over the checks. For majority of the cob characters including grain weight it displayed significantly higher mean performances than the standard checks. However, it was fairly tall (about 220 cm) also its ear placement was lower than the checks and its anthesis-silking interval period was around two days suggesting its better synchronization in flowering. This particular outstanding hybrid is a cross combination between QPM x Non QPM. Other hybrid combinations though they differed in different traits among themselves they failed to perform better than standard checks.

Heterosis

The level of heterosis differed for different traits. Heterosis over mid parent, better parent and standard checks for different traits appeared in different frequencies. All hybrids displayed heterosis over mid parent for six traits but for better parent it was only four. However, all of them registered heterosis for plant height, number of grains/row, number of grains/cob and grain yield/plant over both mid and better parent. Against standard checks less number of hybrids exhibited heterosis for different traits. Though plant height heterosis was found against standard check 2, mid parent and better parent but 100 grain weight heterosis was unanimously obtained against all these measurements for heterosis. Conspicuously against best standard check (SC 1) heterosis for grain yield/plant was observed in only two hybrids (Table 2A).

It becomes evident from the study that the amount of heterosis in any hybrid was trait dependent as observed by Flint-Garcia et al. (2009) in maize hybrids for seventeen traits. This would indicate that to unravel the mechanism of heterosis the search must be conducted within the biological context of specific traits and to predict better heterotic hybrids with maximum productivity one should look for specific traits of interest. Nevertheless three F1 hybrids were identified which showed heterosis at par with or better than standard checks.

Figure 1. *Top two hybrids A. DMR QPM 103xCML 539 and B. CML 539xCML 537 identified based on mean grain yield/plant (g) and standard heterosis (SH %) over two standard checks 900M Gold and HQPM 1*



Their expressed heterosis over standard checks is presented (Table 2B and Figures 1- A, B). Two hybrids namely, CML 539xCML 537 (Non QPM x QPM) and DMR QPM 103xCML 509 (QPM x QPM) which were at par with standard checks recorded negative heterosis for 50% tasseling and silking as well as for ear height, cob diameter, number of grain rows/cob, number of grains/row and number of grains/cob. Significantly they recorded positive heterosis for grain weight. This demonstrates that negative heterotic expression for different cob characters is countered by positive heterosis for grain weight resulting in no depression in ultimate grain yield. Very important plus point for these two hybrids is that they are early in flowering almost by 7 to 10 days as compared to checks (Table 1). The outstanding single cross F1 hybrid i.e. DMR QPM 103 x CML 539 exhibited positive heterosis for all cob

Table 2A. Mean and range values of heterosis (%) over mid parent, better parent and standard checks with frequencies of F1 hybrids for eleven traits (Figures rounded)

TRAITS	MID PARENT HETEROSIS			BETTER PARENT HETEROSIS			STANDARD CHECKS 900 M GOLD (SC1)			STANDARD CHECKS HQPM 1 (SC2)		
	Mean	Range	F1	Mean	Range	F1	Mean	Range	F1	Mean	Range	F1
DT 50%	-5	-11 to 4	46	-2	-9 to 6	38	-3	-10 to 7	10	-1	-8 to 9	18
DS 50%	-4	-10 to 5	47	-1	-10 to 8	32	-3	-8 to 6	13	-2	-8 to 6	14
PH (cm)	35	13 to 79	52	24	3 to 47	52	-15	-4 to -34	0	-3	9 to -25	27
EH(cm)	35	6 to 91	52	20	-9 to 73	47	-18	-3 to -36	3	-15	-.4 to -34	3
CL (cm)	27	-9 to 73	52	19	-9 to70	46	-8	20 to 28	12	-18	7 to -35	2
CD(cm)	18	-1 to 39	51	14	-5 to 34	50	-16	1 to -30	1	-9	10 to -24	2
GR/C	13	-10 to 38	46	5	-21 to 37	33	-10	22 to -30	7	-2	32 to -21	12
G/R	55	18 to 123	52	36	3 to 80	52	-16	12 to -45	3	-18	9 to -48	3
G/C	71	13 to188	52	46	-14 to122	52	-25	9 to -48	3	-21	15 to -45	4
GW(g)	15	-16 to 56	43	2	-35 to 42	30	-1	25 to -26	23	-3	23 to -27	23
GY/P (g)	105	1 to 205	52	79	-3 to 201	52	-25	26 to -52	2	-23	28 to -51	3

Table 2B. Heterosis (%) of selected hybrids against Mid and Better Parent as well Standard checks

TRAITS	MID PARENT HETEROSIS			BETTER PARENT HETEROSIS			STANDARD CHECKS					
							900 M GOLD (SC1)			HQPM 1 (SC2)		
	103x 509	539x 537	103x 539	103x 509	539x 537	103x 539	103x 509	539x 537	103x539	103x 509	539x 537	103x539
DT 50%	-7	-8	-4	-6	-2	-4	-6	-3	-4	-5	-1	-3
DS 50%	-9	-8	-11	-6	-3	-5	-7	-3	-6	-7	-3	-5
PH (cm)	30	46	50	21	40	47	-9	-12	-4	13	11	9
EH(cm)	35	50	63	15	47	62	-11	-20	-11	-8	-17	-9
CL (cm)	25	50	73	17	49	70	-8	5	20	-18	-6	7
CD(cm)	21	29	39	15	29	34	-13	-11	1	-5	-3	10
GR/C	18	22	30	10	18	21	-9	-11	0	-1	-3	9
G/R	83	102	72	30	75	46	0	-7	12	-3	-9	9
G/C	108	144	110	38	122	71	-12	-11	9	-7	-7	15
GW(g)	29	20	35	3	-1	5	10	14	21	8	12	19
GY/P (g)	172	195	205	142	142	201	-2	1	26	0	3	28

* Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P

characters (Length, diameter, number of grain rows and grains) including grain weight known to be important influencing traits for yield. Consequently it recorded as high as 26-28% positive heterosis over both the checks. Similar observations were also recorded in maize by Raghu et al. (2012) and Kumar et al. (2014). In addition it recorded negative heterosis for days to 50% tasseling and silking as well as ear height meaning that this particular hybrid tends to be flowering early with ear placement relatively at short height distance. In fact its plant height was around 220 cm and ear height about 99 cm (Table 1) suggesting silk position almost at half of the height (considered to be ideal) and at the same time it recorded a least difference in days for tasseling and silking. Thus this hybrid combination enjoys favourable pollination advantage which may be the underlying cause for realizing higher yield as suggested by Ca´rcova et al. (2000). Significantly this hybrid is a cross combination between QPM x Non QPM (Table 1) which has brought forward change in plant type with increased height and early flowering where inbred parents were shorter and late in flowering with different pattern of ear positions.

It is further evident that heterosis for cob characters are significantly and positively correlated with the grain yield heterosis (Table 3). This is very welcome situation and is not entirely unexpected. Cob characters are significant yield components in maize (Ghosh et al., 2014; Sadaiah et al., 2013, Shinde et al., 2009; Pradeep Kumar and Satyanarayana, 2001). Interestingly, cob diameter heterosis maintains significantly positive association with heterosis values of different cob characters (Table 3). This would suggest that cob diameter is a unique character whose heterosis would effectively describe grain yield heterosis in maize. Thus, if there is heterosis for cob diameter one would expect to realize grain yield heterosis for maize. In fact the outstanding F1 cross combination (DMR QPM 103xCML 539) continues to maintain high positive heterosis for cob diameter (Table 2B). It is reasonable to suggest that under this kind of situation grain yield heterosis can be predicted early on the basis of fully developed mature cob diameter.

Table 3. Correlations between heterosis values of better parent and standard check 1 for different traits

	DT 50%	DS 50%	PH (cm)	EH (cm)	CL (cm)	CD (cm)	GR/C	G/R	G/C	GW (g)	GY/P (g)
DT 50%	1.00	0.86**	-0.06	0.11	-0.20	0.11	0.03	-0.08	-0.08	-0.21	-0.17
DS 50%	0.92**	1.00	-0.19	0.00	-0.20	0.00	-0.09	-0.14	-0.14	-0.27	-0.27
PH (cm)	0.37**	0.37**	1.00	0.73**	0.48**	0.45**	0.26	0.19	0.33*	0.25	0.45**
EH (cm)	0.34*	0.30*	0.82**	1.00	0.45**	0.25	0.42**	0.08	0.23	0.04	0.33*
CL (cm)	-0.08	-0.10	0.61**	0.50**	1.00	0.43**	0.19	0.55**	0.42**	0.16	0.61**
CD (cm)	0.39**	0.32*	0.63**	0.42**	0.46**	1.00	0.47**	0.46**	0.64**	0.01	0.63**
GR/C	0.32*	0.14	0.18	0.24	0.13	0.33*	1.00	-0.03	0.50**	0.01	0.43**
G/R	-0.17	-0.31*	0.32*	0.27	0.69**	0.26	0.28*	1.00	0.62**	-0.19	0.46**
G/C	0.08	-0.09	0.43**	0.36*	0.68**	0.45**	0.55**	0.87**	1.00	-0.27	0.51**
GW (g)	-0.13	-0.03	0.40**	0.30*	0.29	0.37**	-0.33*	-0.05	-0.17	1.00	0.32*
GY/P (g)	0.04	-0.08	0.65**	0.49**	0.75**	0.64**	0.28*	0.72**	0.74**	0.48**	1.00

*Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P

Correlation values: Upper Diagonal – Better parent, Lower Diagonal – Standard check 1(SC 1) **. Significant at 0.01 level; *. Significant at 0.05 level

Table 4. Potence ratio of traits for 52 F1 Hybrids

CROSSES	DT 50%	DS 50%	PH (cm)	EH (cm)	CL (cm)	CD (cm)	GR/C	G/R	G/C	GW (g)	GY/P (g)
170x103	0.9	0.6	1.5	1.1	3.1	1.9	-0.4	1.4	0.6	2.6	1.8
170x539	0.8	0.2	0.8	1.0	3.0	4.7	0.4	8.6	1.7	-0.2	1.2
102x170	1.0	0.5	3.4	0.9	1.1	0.4	-0.2	4.5	1.1	0.2	4.0
102x03-121	1.9	0.8	1.0	1.3	1.0	2.3	3.9	16.5	2.1	0.4	1.6
102x103	0.5	1.5	2.7	5.4	0.5	-0.1	0.8	1.7	0.3	0.6	10.5
03-121x103	0.8	0.7	1.1	3.2	6.2	1.6	1.3	2.1	1.5	1.4	2.6
03-121x509	-0.4	0.3	0.6	0.6	1.1	4.7	2.4	2.2	1.0	0.1	4.3
03-121x511	-0.2	0.3	0.7	0.9	5.2	7.1	1.5	4.5	2.7	0.9	3.2
03-121x03-104	-0.6	0.5	1.7	5.5	0.3	2.6	0.2	3.2	7.1	2.7	2.7
103x03-121	-0.4	0.2	1.0	2.6	6.8	1.2	0.2	0.7	2.0	1.7	2.2
103x509	-2.8	1.4	2.1	1.0	1.7	2.2	1.1	1.0	2.1	0.6	6.9
167x507	-3.7	1.6	4.7	1.3	1.2	9.0	-0.1	1.3	0.7	7.8	1.7
167x537	1.4	0.7	1.7	0.8	1.0	1.3	18.6	0.9	0.8	4.9	1.6
102x511	1.2	1.1	2.0	1.1	1.3	1.9	2.4	1.8	6.6	0.9	14.4
167x169	3.5	1.4	6.9	10.1	0.9	2.3	1.9	1.8	1.1	0.8	1.4
511x102	0.9	0.8	2.5	1.8	1.2	3.5	1.7	2.5	9.9	0.4	15.6
511x539	0.8	1.0	4.8	1.7	3.0	9.4	4.1	8.2	11.7	0.1	5.6
509x539	2.8	-1.4	2.9	2.0	1.2	4.3	2.1	5.1	2.5	1.1	18.0
509x538	1.4	2.4	2.7	1.6	2.3	2.1	2.1	2.5	1.5	0.8	9.0
509x102	1.8	0.6	1.6	1.2	0.2	0.4	4.1	2.1	3.3	3.4	8.1
509x167	2.0	2.6	13.4	16.6	7.2	6.4	0.1	2.1	1.4	-0.3	1.2
539x03-121	1.0	0.7	1.1	2.8	5.2	0.6	1.1	6.7	5.6	0.0	2.4
539x167	0.5	0.5	1.3	0.5	1.2	1.9	-0.1	0.6	0.2	-0.3	0.4
539x537	0.7	0.7	4.9	11.7	1.9	0.5	3.3	3.4	7.2	0.5	4.5
539x102	0.5	-0.3	4.6	5.3	1.1	1.5	4.0	1.4	3.6	-0.3	6.2
539x504	1.5	1.2	1.8	0.2	3.2	1.5	7.7	4.2	2.9	0.3	2.6
507x539	2.0	1.0	4.6	2.5	9.0	3.3	3.2	4.8	3.5	0.8	5.2
507x504	2.6	0.9	7.8	0.5	2.9	4.5	3.6	3.8	5.5	1.8	8.0
507x538	0.9	0.3	11.7	40.3	6.3	1.6	4.1	2.1	7.8	52.8	9.7
504x539	1.9	2.2	2.5	0.7	4.3	18.3	6.0	4.8	3.1	0.5	3.5
502x103	-0.1	0.2	10.0	3.8	0.9	9.9	2.0	0.8	1.2	0.6	3.7
503x 539	-0.4	0.4	3.0	0.8	1.2	5.3	0.0	16.2	116.9	0.0	5.0
510x539	-0.1	0.1	2.6	10.6	3.2	2.8	1.2	2.8	5.7	0.1	1.8
169x167	5.8	2.2	7.0	15.0	1.1	3.8	1.6	2.2	1.4	0.4	1.7
538X509	0.9	1.3	2.1	1.0	6.0	6.9	3.5	0.9	1.1	0.7	6.4
538X510	2.9	29.5	2.1	2.9	7.1	9.8	1.5	1.7	3.1	0.6	2.3
161X507	2.5	2.3	2.4	3.0	5.8	4.5	12.4	0.0	0.9	20.0	14.5
163X539	0.6	0.1	1.2	0.6	5.8	1.3	0.6	6.8	5.2	0.1	2.3
193-1X163	0.8	0.6	4.7	1.1	0.7	3.8	0.5	1.2	2.2	2.0	3.0
102X509	-0.9	-0.2	1.2	0.6	-0.1	0.5	9.3	0.6	2.6	-5.1	4.4
102X539	7.6	2.8	5.5	9.8	2.8	1.6	7.4	4.0	5.3	-1.2	6.6
102X167	1.1	1.3	1.2	0.3	7.6	1.4	0.5	1.3	0.5	0.4	1.4
170X509	0.1	0.0	1.1	0.7	1.5	7.8	0.2	2.9	1.3	0.2	27.1
170X511	-0.5	0.5	1.0	0.5	1.2	9.7	1.9	22.4	1.8	0.9	12.7
170X167	-0.2	0.2	1.2	0.4	1.1	1.1	-0.7	2.0	1.4	1.0	1.7
103X539	-10.6	7.1	15.7	22.8	5.9	4.8	1.9	2.0	2.4	0.6	75.2
103X167	0.3	-0.4	2.3	0.9	11.3	2.8	1.1	3.6	0.9	0.9	1.4
103X511	-1.7	1.6	4.7	0.9	8.5	1.9	4.5	0.7	2.2	0.8	6.2
03-121X167	-0.3	0.1	1.1	0.6	1.4	1.2	-2.6	2.3	1.8	1.2	1.0
03-121X539	1.0	-0.8	1.8	4.9	7.1	1.2	4.5	8.1	6.4	0.4	3.3
511X167	-8.6	0.5	4.2	3.8	1.6	2.1	5.6	1.8	1.0	-0.8	1.4
509X539	-2.7	1.9	1.9	1.0	16.3	0.7	0.4	2.5	3.0	-2.2	4.5

*Days to 50 % tasseling = DT 50%, Days to 50% silking = DS 50%, Plant height = PH, Ear height = EH, Cob length = CL, Cob diameter = CD, Number of grain rows/cob = GR/C, Number of grains/row = G/R, Number of grains/cob = G/C, 100 Grain weight = GW and Grain yield/plant = GY/P

Potence Ratio

The potence ratios for different traits of F1 hybrids indicated the presence of various degrees of dominance effects. Majority of the traits however controlled by overdominance gene effects followed by partial dominance and complete dominance for gene action was infrequent (Table 4). Significantly grain yield/plant for all fifty two hybrids exhibited dominance gene effects as potence ratio estimates were positive and more than one meaning that inheritance of grain yield was exclusively due to overdominance. This corroborates the earlier observations of Alhadi et al. (2013) and Srdić et al. (2008) in maize. Similarly forty six hybrids displayed the role of overdominance for plant height where potence ratio was more than one and positive which would emphasize the major role of overdominance for the inheritance of this trait. The same trend in gene action was observed for cob length, cob diameter, number of grains/row and number of grains/cob where forty two to forty five of F1 hybrids exhibited a positive potence ratio of more than one. Similar observations were also reported by El-Badawy (2012) in maize where he observed the overdominance for inheritance of all these traits. On the other hand days to 50% tasseling and silking, ear height and 100 grain weight appeared to be controlled by both partial and overdominance gene effects. Other than cob diameter, number of grain rows/cob and grain yield/plant for all other traits the complete dominance in gene action was rarely observed where only one to four hybrids recorded a potence ratio equal to one (Table 4). For some crosses namely, CML 539 x DMR QPM 03-121, CML 503 x CML 539, CML 161 x CML 507 and CML 170 x CML 509 absence of dominance effect was also observed in the inheritance of traits 100 grain weight, number of grain rows/cob, number of grains/row and days to 50% silking respectively.

From the above discussion a few important trends in inheritance pattern for different traits emerge. All hybrids for grain yield/plant recorded overdominance while five traits plant height, cob length, cob diameter, number of grains/row, number of grains/cob exhibited overdominance in more than 80% of hybrids. On the other hand partial dominance and overdominance are in operation in different frequencies in hybrids for traits like 100 grain weight, grain rows/cob, ear height, days to 50% tasseling and silking. Overdominance is an intra-allelic interaction in which presence of multiple alleles lead to greater performance than homozygosity for either allelic state. When the predominance of overdominance appears to be in operation for the heterosis of grain yield/plant, number of grains/cob, number of grains/row, cob diameter, cob length and plant height observed in the study the breeding strategy has to be adopted to maximize heterozygosity to realize the best performance

Table 5. Mid parent heterosis for Grain yield/plant, Per se performance of parents and genetic distance between inbred parents

Cross combinations	GY/P of crosses (g)	Parental Per se yield (g)	MPH %	GD	PDC	Cross combinations	GY/P of crosses (g)	Parental Per se yield (g)	MPH %	GD	PDC
170x103	87.60	52.7,67.9	1.07	3.92	M	**507x539**	151.61	52.4,69.8	148.17	3.39	M
170x539	81.17	52.7,89.8	32.5	5.11	M	**507x504**	131.47	52.4,41.8	179.13	3.28	M
102x170	92.74	61.6,52.7	62.32	5.08	M	**507x538**	136.42	52.4,60.6	141.47	2.98	L
102x03-121	83.33	61.6,41.6	61.55	3.91	M	**504x539**	152.37	41.8,69.8	172.97	4.84	M
102x103	131.38	61.6,67.9	102.92	4.50	M	**502x103**	126.06	49.6,67.9	114.59	4.96	M
03-121x103	123.58	41.6,67.9	125.66	4.24	M	**503x 539**	91.68	49.6,57.2	71.7	2.31	L
03-121x509	95.86	41.6,52.9	102.88	6.29	H	**510x539**	113.01	35.3,69.8	115.09	5.39	M
03-121x511	99.41	41.6,57.2	101.17	4.86	M	**169x167**	140.37	66.6,99.8	68.64	3.78	M
03-121x03-104	118.69	41.6,66.0	120.55	3.24	M	**538X509**	106.08	60.6,52.9	86.89	4.07	M
103x03-121	112.5	67.9,41.6	105.42	4.24	M	**538X510**	105.62	60.6,35.3	120.29	4.29	M
103x509	164.07	67.9,52.9	171.57	6.44	H	**161X507**	105.60	48.6,52.4	109.21	2.20	L
167x507	155.43	99.8,52.4	104.23	6.88	H	**163X539**	100.97	52.3,69.8	65.44	5.01	M
167x537	160.28	99.8,44.9	121.53	7.56	H	**193-1X163**	145.84	82.9,57.7	107.45	3.98	M
102x511	121.86	61.6,57.2	105.17	3.33	M	**102X509**	95.61	61.6,52.9	67.06	3.69	M
167x169	129.92	99.8,66.6	56.09	3.78	M	**102X539**	120.04	61.6,69.8	82.75	1.72	L
511x102	127.08	57.2,61.6	113.96	3.33	M	**102X167**	134.94	61.6,99.8	67.21	6.99	H
511x539	133.89	57.2,69.8	110.78	3.09	M	**170X509**	124.02	52.7,52.9	134.86	6.69	H
509x539	133.07	52.9,57.2	141.66	3.01	L	**170X511**	112.24	52.7,57.2	104.18	5.15	M
509x538	125.98	52.9,60.6	121.95	4.07	M	**170X167**	155.04	52.7,99.8	103.26	7.19	H
509x102	127.44	52.9,61.6	122.68	3.69	M	**103X539**	210.32	67.9,69.8	205.39	4.55	M
509x167	134.71	52.9,99.8	76.39	7.68	H	**103X167**	129.85	67.9,99.8	54.8	4.65	M
539x03-121	122.29	69.8,41.6	119.53	4.36	M	**103X511**	128.72	67.9,57.2	105.69	4.18	M
539x167	96.51	69.8,99.8	13.78	6.60	H	**03-121X167**	129.66	41.6,99.8	83.34	7.74	H
539x537	169.12	69.8,44.9	194.97	4.48	M	**03-121X539**	147.61	41.6,69.8	164.99	4.36	M
539x102	117.03	69.8,61.6	78.17	1.72	L	**511X167**	137.72	57.2,99.8	75.36	6.21	H
539x504	128.95	69.8,41.8	131.01	4.84	M	**509X539**	137.99	52.9,69.8	124.9	3.58	M

***GY/P = Grain yield/plant, MPH % = Mid parent heterosis, GD = Genetic distance, PDC = Parental divergence class**

***Genetic divergence: >6.07 = High (H), Between 3.07 – 6.07 = Medium (M), <3.07 = Low (L)**

in relation to these traits. According to Russell et al. (1978) under the overdominance scenario on performance of the population cross the populations would diverge due to selection and there would be increased homozygosity of alternative alleles within the population to maximize heterozygosity and performance of the population cross. As opposite to this with the partial dominance the average degree of dominance would decrease and most loci contributing to heterosis would likely to be coupled with repulsion phase linkage. This may be the case with traits like 100 grain weight, number of grain rows/cob, and days to 50% tasseling and silking which recorded partial dominance in large number of hybrids. However against the backdrop of observations recorded where importance of overdominance for the expression of heterosis in majority of hybrids for maximum traits becomes apparent it would be reasonable to suggest that the inbred tester would improve the population more than the population tester because in an inbred, alleles are fixed whereas in population they are intermediate in frequency.

Genetic Distance

Quantitative genetic theory suggests a linear relationship between heterosis of a hybrid and the genetic distance between its parents considering all loci underlying the quantitative trait of interest (Falconer and Mackay, 1996). Consequently, predicting hybrid performance based on mid-parent performance and genetic distances was suggested (Melchinger, 1999). The observations are presented in Table 5 showing fifty two cross combinations with their mean grain yield, inbred parental per se yield, mid parent heterosis and genetic divergence between respective parents. A perusal of the table brings forth relationship of heterosis with genetic divergence group. Genetic distance of inbred parents ranged from 1.72 to 7.74 and their average grain yield/plant ranged from 35.3 to 99.8 g. Inbred CML 167 gave as high as 99.8 g grain yield/plant followed by H.K.I 193-1 with 82.9 g. Minimum grain yield of 35.3 g was exhibited by CML 510. Heterosis for grain yield/plant over mid-parents ranged from 13.8 to 205.4% where thirty four hybrids displayed high level of heterosis ranging from 100 to 200%. This would suggest around 65% cross combinations exhibited very high mid parental heterosis. Significantly twenty five out of these thirty four belonged to medium parental divergence group meaning that as high as 74% of high heterotic hybrids were from medium parental divergence (between 3.07 to 6.07). Interestingly inbreds with high per se yield performance of 50 g or above were always involved in these high heterotic cross combinations with medium parental divergence. In fact the identified outstanding hybrid cross i.e. DMR QPM 103 X CML 539 belonged to the medium parental divergence group with inbred parents having around 68 to 70 g grain yield/plant. Thus a general trend is observed where medium parental divergence with high yield tends to produce high heterosis. Arunachalam and Bandhopadhyay (1984) observed that the frequency of heterotic crosses and magnitude of heterosis for yield was high in crosses with intermediate parental diversity. Based on the present observation it can be suggested that for the selection of parents it is better to avoid parental combinations with low and extremely high genetic divergence for the extraction of superior hybrids. It further follows that medium parental divergence coupled with high per se performance of inbreds is more important than merely high genetic diversity which finds support from the observations of Dutta et al. (2004) in maize.

Acknowledgements

International maize and wheat improvement centre (CIMMYT), Hyderabad and Directorate of Maize research (DMR), New Delhi are duly acknowledged for providing the seed material of inbred lines. Thanks to the Department of science and technology, Government of India, for providing Inspire Fellowship to the first author.

References

Alhadi RAA, Hadid ML, AL Ahmad SA, 2013. Potence Ratio and Path Analysis for Yield and Quality Traits in Single Crosses of Maize *(Zea mays L.)* Produced in Syria. Jordan J. Agri. Sci. 9(2): 153-161.

Arunachalam V and Bandyopadhyay A, 1984. Limits to genetic divergence for occurrence of heterosis-Experimental evidence from crop plants. Indian J. Genet. 44(3): 548-554.

Ca´rcova J, Uribelarrea M, Borra´s L, Otegui ME, Ca´tedra de, 2000. Synchronous Pollination within and between ears improves kernel set in Maize. Crop Sci. 40:1056–1061.

Hallauer AR, 1972. Third phase in the yield evaluation of synthetic varieties of maize. Crop Sci. 12: 16-18.

Datta D, Mukheijee BK, Das SP and Barua NS, 2004. Studies on heterosis and its relation to genetic divergence in maize (*Zea mays L.*) inbred lines. Cereal Res. Commun. 32(4): 443-450.

El-Badawy MEIM, 2012. Estimation of genetic parameters in three maize crosses for yield and its attributes. Asian Journal of Crop Sci. 4(4): 127-138.

Flint-Garcia SA, Buckler ES, Tiffin P, Ersoz E, Springer NM, 2009. Heterosis is prevalent for multiple traits in diverse maize germplasm. PLoS ONE 4(10): e7433.

Ghosh A, Subba V, Roy A, Ghosh A and Kundagrami S, 2014. Genetic variability and character association of grain yield components in some inbred lines of maize (*Zea mays L*.). JANRM 1(2): 34-39.

Ihsan H, Khalil IH, Rehman H and Iqbal M, 2005. Genotypic Variability for morphological traits among exotic maize hybrids. Sarhad J. Agric. 21(4): 599-602.

Kumar GP, Prashanth Y, Reddy VN, Kumar SS and Rao PV, 2014. Heterosis for grain yield and its component traits in maize (*Zea mays L*.). Int. J. Pure App. Biosci. 2(1):106-111

Kumar A, Vyas RP, Tomat A and Singh M, 2017. Selection of best germplasm on the basis of selection parameters (Heritability, genetic advance & correlation) in maize (*Zea Mays L*.). J. Pharmacogn. Phytochem. 6(1): 479-481.

Mather K, 1949. Biometrical Genetics. Dover Press, New York

Mather K, Jinks JL, 1971. Biometrical Genetics, Chapman and Hall Ltd. (2nd ed.), London

Melchinger AE, 1999. Genetic diversity and heterosis, "The Genetics and Exploitation of Heterosis in Crops", pp. 99-118. Coors JG, Pandey S eds. Crop Science Society of America, Madison.

Moll RH, Longquist JH, Fortuna JV, and Johnson EC, 1965. The relation of heterosis and genetic divergence in maize. Genetics 52: 139-144.

Naik D, Sao A, Sarawagi SK, Singh P, 2006. Genetic divergence studies in some indigenous scented rice (*Oryza sativa L*.). Accessions of Central India. Asian J. Plant Sci. 5:197-200.

Pradeep Kumar P and Satyanaryana E, 2001. Variability and correlation studies of fall season inbred lines of maize. J. Res. ANGRAU 29:71-75.

Raghu B, Suresh J, Geetha P, Saidaiah, P and Kumar SS, 2012. Heterosis for grain yield and its component traits in maize (*Zea mays L*.). J. Res. ANGRAU 40 (1): 83-90.

Russell WA, Eberhart SA, and Vega UA, 1978. Recurrent selection for specific combining ability for yield in two maize populations. Crop Sci. 13: 257–261.

Sadaiah K, Narsimha Reddy V, and Sudheer Kumar S, 2013. Correlation studies for yield and yield contributing characters in Sweetcorn (*Zea mays L.* saccharata). IJAIR 2(2): 145-148.

Shinde SA, Shelki DK and Sawargaonkar GL, 2009. Intercharacter associations and path analysis of yield components in rabi maize. Int. J. Plant Sci. 4: 49-51.

Smith HH, 1952. Fixing Transgressive Vigour in Nicotiana Rustica, "Heterosis". Iowa State College Press, Ames

Srdić J, Nikolić A and Pajić Z, 2008. SSR markers in characterization of sweet corn inbred line. Genetika 40 (2):169–177.

Waqar A, Rehman Hu, Ahmad K, Munir I and Khan A, 2007. Genetic variability among maize hybrids for yield and yield components. Sarhad J. Agric. 23(1): 75-80.

Zarei B, Kahrizi D, Aboughadareh AP and Sadeghi F, 2012. Correlation and path coefficient analysis for determining interrelationships among grain yield and related characters in corn hybrids (*Zea mays L*.). Int. J. Agric. Crop Sci. 4 (20): 1519-1522.