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MULTI-ENVIRONMENT EVALUATION FOR DETERMINING GRAIN YIELD, COMBINING ABILITY, HETEROSIS AND THEIR INTER-RELATIONSHIPS IN MAIZE

P. KUMAR[1], N. K. SINGH[1*] and S. K. JHA[2]

[1]Department of Genetics and Plant Breeding, G. B. Pant University of Agriculture and Technology, Pantnagar-263145 (Udhamsingh Nagar) Uttarakhand, India
[2]Division of Genetics, ICAR-Indian Agricultural Research Institute, Pusa, New Delhi-110012, India
[*]Corresponding author's email: narendraksingh2@gmail.com
Co-authors' email addresses: vaidya.pankaj4@gmail.com, jhashail78@gmail.com

SUMMARY

Thirty-one maize genotypes were evaluated in 4 environments to estimate combining abilities and heterosis for grain yield. Spearman's rank correlations and linear regressions were determined to identify the most important factor determining grain yield of F1s and heterosis. The inbred line 4 (IL4), IL7 and IL9 had high and significant positive GCA effects. The top three high yielding hybrids also had high mean general combining ability (MGCA) in the same order but did not match with order of specific combining ability (SCA) effects of cross combinations. The SCA, MGCA, low parent heterosis (LPH), mid-parent heterosis (MPH) and high parent heterosis (HPH) exhibited significant positive rank correlations and high coefficients of determination (R^2) with grain yield of F1s (GYF1s). Similar patterns were also noted for SCA with the LPH, MPH and HPH. The MGCA was found to be relatively more important in determination of heterosis and GYF1s. Due to very low coefficient of determination, parental mean (PM) seems to have little value in prediction of performance or selection of lines for hybrid development.

Key words: Combining ability, heterosis, rank correlation, maize, environment

Key findings: The HPH and MGCA were observed as more important whereas PM was emerged as least important parameters than the SCA effects in determination GYF1s. The information generated in the study can be helpful to maize breeder in development of high yielding single cross hybrids in maize.

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INTRODUCTION

Maize improvement program is under technological transition from open pollinated varieties (OPVs) and multi-parent hybrids (MHs) to single cross hybrids especially in those countries where OPVs or MHs were common in maize production system. The single cross hybrids have potential to exploit maximum heterosis and also ease in maintenance as well as in seed production. However, germplasm specific to single cross with high *per se* performance of the parents is essential for its commercial viability. Homozygous lines used as parents are generally extracted from diverse source populations and pools, and their *per se* performance as well as performance in various cross combinations are determined through performance evaluation. Performance of the parents involved in single cross hybrids definitely determines cost effective seed production and ultimately commercial viability of hybrids. Further, the degree of heterosis depends on the relative performance of inbred parents and the corresponding hybrids (Betran *et al*., 2003). However, environment can differentially affect the performance of inbred lines and hybrids and distort the relationship. Hallauer and Miranda (1995) however observed little role of *per se* performance of maize inbred lines in the prediction of performance of hybrid maize. Quantifying relationships of grain yield of hybrids with general and specific combining abilities, heterosis and parental means based on the evaluation of parents and their single crosses in multi-environment field experiments probably may be helpful in determination of heterosis of hybrids and selection of parents for hybrid development ((Balestre *et al*., 2008; Devi and Singh, 2011). In this investigation, we, therefore, evaluated 21 single cross hybrids along with their 10 parental lines of maize in 4 environments and determined relationships among grain yield and heterosis of F1s, combining abilities and parental mean.

MATERIALS AND METHODS

The experimental materials consisted of 10 short duration maize inbred lines. Of these 7 lines namely IL1 (YHP B⊗161), IL2 (Pob445⊗-12), IL3 (YHPA⊗85), IL4 (YHPB⊗45), IL5 (Pob445⊗-54), IL6 (Pob45C8⊗-86) and IL7 (Pob45C8⊗-72) were used as seed parents and crossed with 3 pollen parents namely IL8 (Pop31⊗-18), IL9 (Tarun⊗-61) and IL10 (Pob445C8⊗-101) to develop 21 single cross combinations. The resulting 21 single cross hybrids along with 10 parents were evaluated during rainy season (*kharif)* in randomized complete block design (RCBD) with 2 replications at NE Borlaug Crop Research Centre of G. B. Pant University of Agriculture & Technology, Pantnagar, India. Geographically Pantnagar is situated at 29 ºN latitude, 79.3 ºE longitude and at an altitude of 243.84 m above mean sea level. It is under humid subtropical climate zone and is located at the foothills of the Shivalik range of the Himalayas in a narrow belt called Tarai. Environments used for evaluation include normal nitrogen (NN 120 kg/ha), high nitrogen (HN 160 kg/ha), low nitrogen (LN 80 kg/ha) and excess water (EW). Excess water stress condition was created by applying irrigation water of 5.0 cm continuously for 7 days starting at 35 days after sowing. In case of EW condition, N @ 120 kg/ha was used. All the recommended cultural practices were followed uniformly right from sowing to harvesting in each plot of size 3.0 m^2. Fresh cobs were harvested at physiological maturity and finally grain yield/ha at 15% moisture was calculated using following formula:

$$\text{Grain yield (kg/ha)} = \frac{\text{FCY/plot (kg) x (100-MC) x 10000 (m}^2\text{) x SC}}{\text{85 x Plot area (m}^2\text{)}}$$

Where FCY = fresh cob yield, MC = moisture content (%) in grains at harvest, SC = shelling coefficient.

Data on grain yield over the environments were analyzed for general and specific combining ability. Further, percent heterosis over low parent (LPH%), mid-parent (MPH%) and high parent (HPH%) were estimated to determine the heterosis of each hybrids over the parents. The Spearman's rank correlation coefficients amongst GYF1s, SCA, MGCA, LPH%, HPH%, MPH% and mean of the *per se* performance of the 2 parents of a hybrid (MP) were calculated (Spearman, 1904) and their significances were determined (Kendall, 1962; David *et al*., 1951). The regression analysis along with coefficient of determination (R^2) was also performed (Snedecor and Cochran, 1989). The data were analysed using the INDOSTAT software (IndoStat Inc. Hyderabad, India) to estimate heterosis and combining ability. However, regression analysis and rank correlation was analyzed using Excel program.

RESULTS AND DISCUSSION

The pooled analysis of variance for grain yield data recorded on 21 single cross hybrids and their 10 parental lines over 4 environments revealed significant variance for environments, hybrids and parents (Table 1).

Table 1. Combining ability analysis of variance for grain yield over 4 environments in maize.

Source of variation	Degree of freedom	Mean squares Grain yield
Environment (E)	3	53731469.7**
Treatments (Parents + F1s)	30	15841228.9**
Parents	9	1711089.4**
Crosses	20	4804102.9**
Line x Tester	12	3152017.9**
Treatment x E	90	2013066.8**
Crosses x E	60	2609478.8**
Line X E	18	3185781.6
Tester x E	6	1521662.8
Line x Tester x E	36	2502630.1**
Error	120	295279.0

** Significant at 1% probability level

Differences in environmental index of one experiment to another indicate that environments chosen for experimentation were adequate to quantify the response of genotypes. Further, significant interaction variance of treatment x environment and crosses x environment also support that environmental conditions used for evaluation were adequate to make valid inferences. Treatments including crosses and parents were found to have significant variance for grain yield analyzed either simultaneously or separately. Thus, significant variance for grain yield in crosses and parents indicates that the materials chosen for the study had genetic polymorphism.

The GCA effects of parents for grain yield were varied from -785.4 (IL6) to 851.7 (IL4) in seed parents whereas 3 lines used as pollen parents had GCA values of -110.1 (IL8), 191.2 (IL9) and -81.0 (IL10) (Table 2). The IL4 (851.7) and IL7 (699.0) among the seed parents and IL9 (191.2) among the pollen parents had high and significant positive GCA whereas IL6 (-785.4), IL3 (-603.1) and IL2 (-298.4) had significant negative GCA effects for grain yield. The GCA effects of the 2 parents of a hybrid were averaged to determine the mean GCA (MGCA) effect of the parents. The MGCA was minimum of -447.8 in IL6 x IL8 and maximum of 521.4 in IL4 x IL9 (Table 2). The highly significant positive SCA effects (Table 2) were noted in IL3 x IL8 (1068.5), IL1 x IL10 (745.1), IL7 x IL9 (595.8) and IL4 x IL9 (523.4). The crosses which exhibited significant negative SCA effects were IL1 x IL8 (-850.9), IL3 x IL9 (-665.6) and IL4 x IL8 (-635.2). It is interesting to note that the top 3 high yielding cross combinations namely IL4 x IL9, IL7 x IL9 and IL4 x IL10 had also high MGCA values in the same order. However, SCA value was highest for cross combination IL3 x IL8 followed by IL1 x IL10 and IL7 x IL10 which did not match with top 3 cross combinations in respect to grain yield and MGCA.

The superiority of hybrids was estimated in percent over low parent (LPH%), mid-parent (MPH%) and high parent (HPH%). The cross combination IL4 x IL9 had maximum LPH of 92.6% whereas IL3 x IL10 exhibited minimum LPH of 19.4%. The maximum MPH of 79.9 percent was found in cross combination IL7 x IL9 whereas minimum MPH of 19.0% was associated with cross combination IL3 x IL10. In reference to high parent, the most promising cross combination was IL7 x IL9 with highest HPH of 70.1% whereas minimum HPH of 18.5% was recorded with IL3 x IL10. Considering heterosis, grain yield of hybrids and MGCA together, it was observed that the crosses with high HPH exhibited by and large similar pattern as noted in crosses with high grain yield and high MGCA.

Table 2. General and specific combining ability for grain yield in maize.

Seed parent \ Pollen parent	SCA and MGCA			GCA of Seed parent
	IL8	IL9	IL10	
IL1	-850.9** (5.3)	105.9 (155.9)	745.1** (19.8)	120.7
IL2	343.9 (-204.3)	-305.1 (-53.6)	-38.8 (-189.7)	-298.4**
IL3	1068.5** (-356.6)	-666.6** (-206.0)	-401.9* (-342.1)	-603.1**
IL4	-635.1** (370.8)	523.5** (521.4)	111.6 (385.4)	851.7**
IL5	362.3 (-47.3)	-105.8 (103.3)	-256.5 (-32.8)	15.5
IL6	-7.7 (-447.8)	-147.7 (-297.1)	155.4 (-433.2)	-785.4**
IL7	-280.9 (294.4)	595.8** (445.1)	-315.0 (309.0)	699.0 **
GCA of pollen parent	-110.1	191.1 *	-81.0	

Values in parenthesis are MGCA. *, ** Significant at 5% and 1% probability level

Table 3. Spearman's rank correlation coefficients among different parameters in maize.

	SCA	LPH	MPH	HPH	PM	MGCA
GYF1	0.63**	0.72**	0.84**	0.91**	-0.03	0.75**
SCA		0.51*	0.56**	0.54**	-0.01	0.04
LPH			0.94**	0.74**	-0.62**	0.48*
MPH				0.90**	-0.53**	0.61**
HPH					-0.26	0.76**
PM						0.01

*, ** Significant at 5% and 1% probability level

The Spearman's rank correlation coefficients were computed using data pooled over the environments to analyze relationships among GYF1s, combining abilities, heterosis and parental mean (Table 3). The GYF1s had significant positive correlation with SCA value (0.63), LPH (0.72), MPH (0.84), HPH (0.91) and MGCA (0.75). The linear regression analysis of SCA and MGCA on GYF1s indicated that 39.0% variance in GYF1s was due to SCA effects of crosses whereas MGCA accounted for 61.0% variation in GYF1s (Figure 1). The Spearman's rank correlation analysis also indicated that SCA value had significant positive correlations with LPH (0.51), MPH (0.56) and HPH (0.54). The regression analysis of SCA on LPH, MPH and HPH determined that 24.8%, 28.6% and 25.0% of the variation in LPH, MPH and HPH could be explained by SCA effects, respectively (Figure 2). In the present investigation, SCA appeared as moderate determinants of GYF1s and heterosis. However, SCA values have been reported to be a major determinant of heterosis as well as hybrid performance and in the choice of parents or populations for hybrid development program (Hallauer and Miranda, 1995; Falconer and Mackay, 1996). The SCA and MGCA emerged as independent parameters since they exhibited poor relationship and negligible R^2 value (Table 3 and Figure 3).

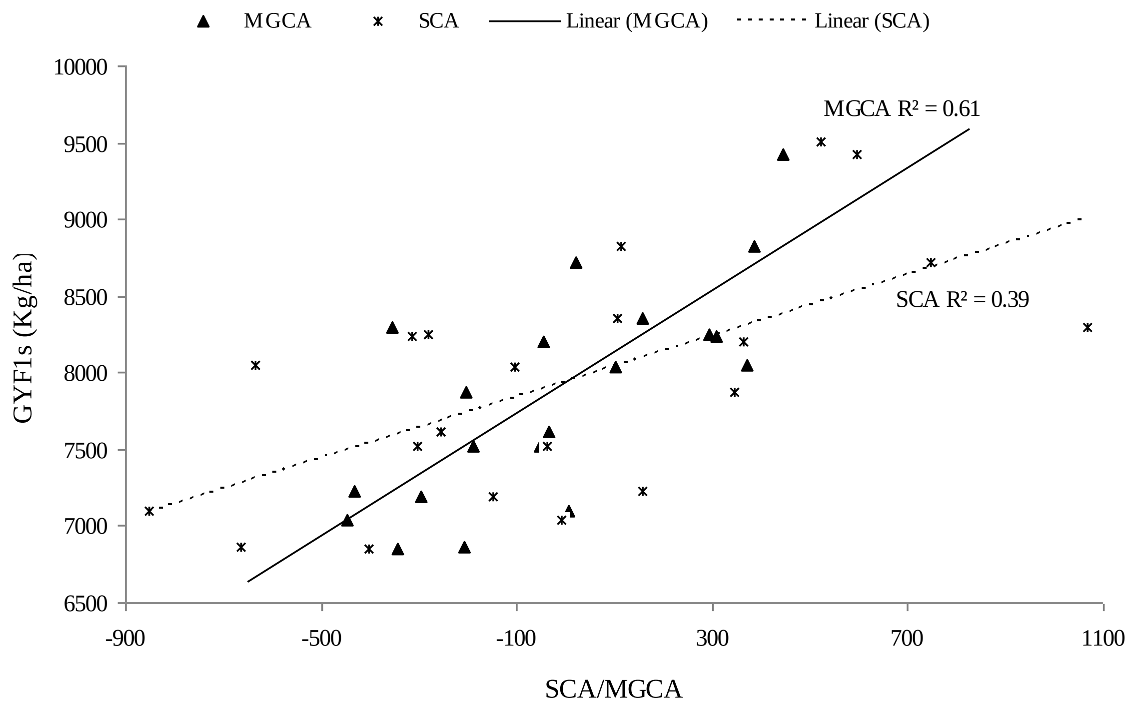

Figure 1. Regression of SCA and MGCA on grain yield of F1s in maize.

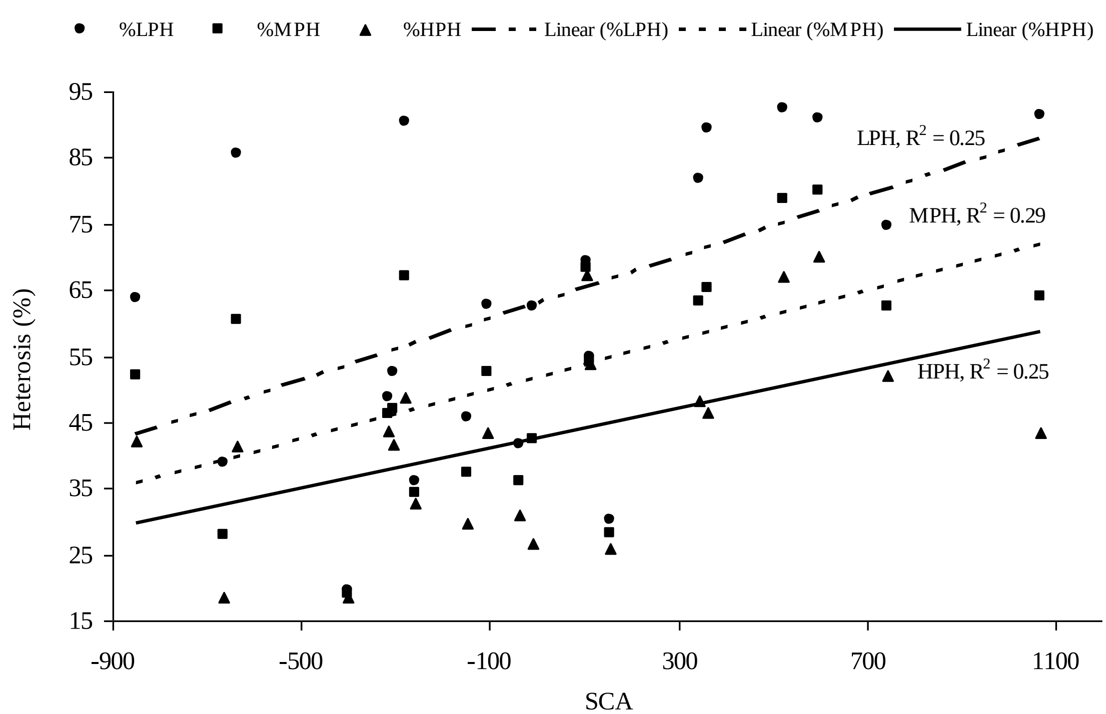

Figure 2. Regression of SCA on heterosis percent of F1s in maize.

The MGCA exhibited significant positive rank association with GYF1 (0.75), LPH (0.48), MPH (0.61) and HPH (0.76). Further, regression analysis of MGCA on LPH, MPH and HPH indicated that 24.3% variation in LPH, 43.6% in MPH and 57.2% variation in HPH is due to MGCA. The observations therefore indicate that MGCA of 2 parents of an F1 have relatively more value in choice of parents for hybrid development (Table 3 and Figure 4).

In addition to highly significant rank correlation with GYF1s, LPH, MPH and HPH also exhibited high coefficient of determination of 0.48, 0.72 and 0.82 on GYF1s, respectively (Figure 5). The observations thus indicated that 48.0, 72.0 and 82.0 percent variation in GYF1s could be explained by LPH, MPH and HPH, respectively. The HPH followed by MPH and LPH were therefore identified to be key determinants of *per se* performance of the hybrids (Balestre *et al*., 2008; Devi and Singh, 2011). The SCA, which was affected by parental inbred performance, had better predictive value for F1s grain yield than heterosis as reported earlier by Betran *et al*., (2003) and Devi and Singh (2011). However, in the present investigation heterosis and more specifically HPH exhibited better predictive value for GYF1s than the SCA or MGCA.

The degree of heterosis depends on the relative performance of inbred parents and the corresponding hybrid (Betran *et al*., 2003). The mean yield of the parents (PM) were therefore taken as one factor and its rank correlations along with linear regression coefficient was analyzed with the GYF1s, SCA, MGCA, LPH, MPH and HPH. The PM exhibited significant negative association with LPH (-0.62) and MPH (-0.53), non-significant negative correlation with GYF1s (-0.03), SCA (-0.01) and HPH (-0.26) and non-significant positive association with MGCA (0.01) (Table 3). Thus, negative or negligible association of PM noted in the study with GYF1s, combining abilities and heterosis along with very low coefficient of determination on GYF1s, SCA, MGCA, LPH, MPH and HPH (Figures 6-8) revealed that PM had little value in determination of either GYF1s or combining abilities or heterosis of the hybrids and therefore cannot be used for prediction of hybrid performance as well as selection of parents (Smith, 1986; Hallauer, 1990, Devi and Singh, 2011). The different levels of dominance in the hybrids and the complementary allelic frequencies between the parents used in the crosses could be responsible for low or no correlations of PM with GYF1s, heterosis and combining ability (Bernardo, 1992).

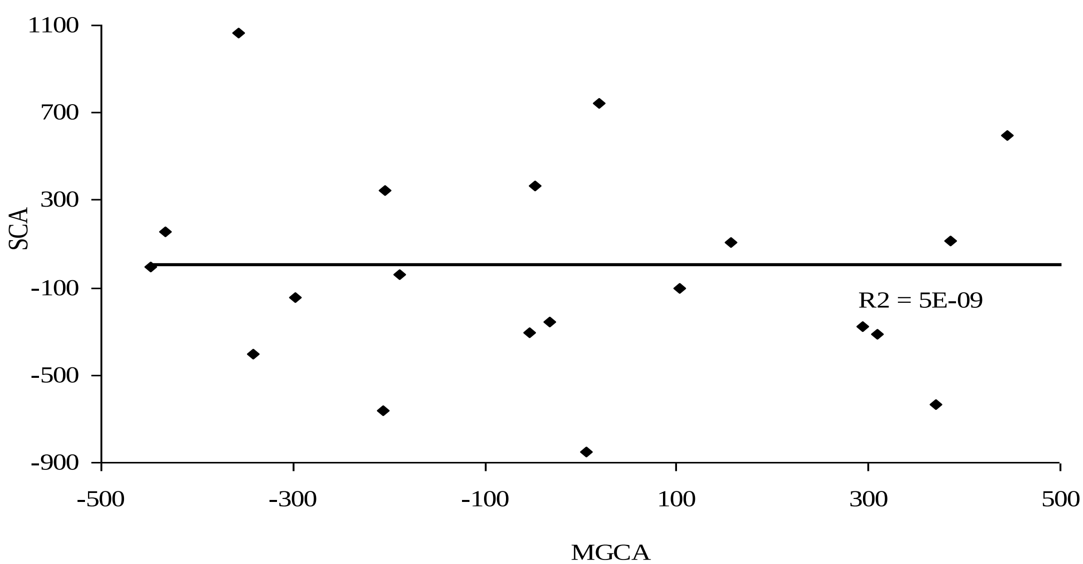

Figure 3. Regression of MGCA on SCA effects of crosses in maize.

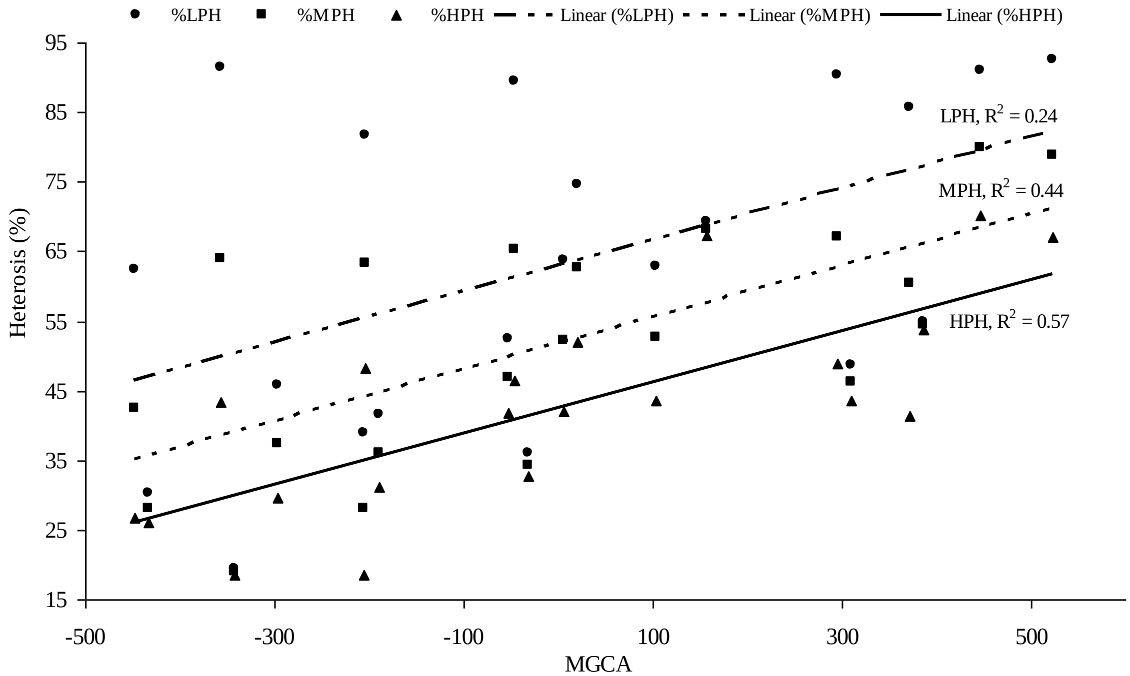

Figure 4. Regression of MGCA on heterosis percent of F1s in maize.

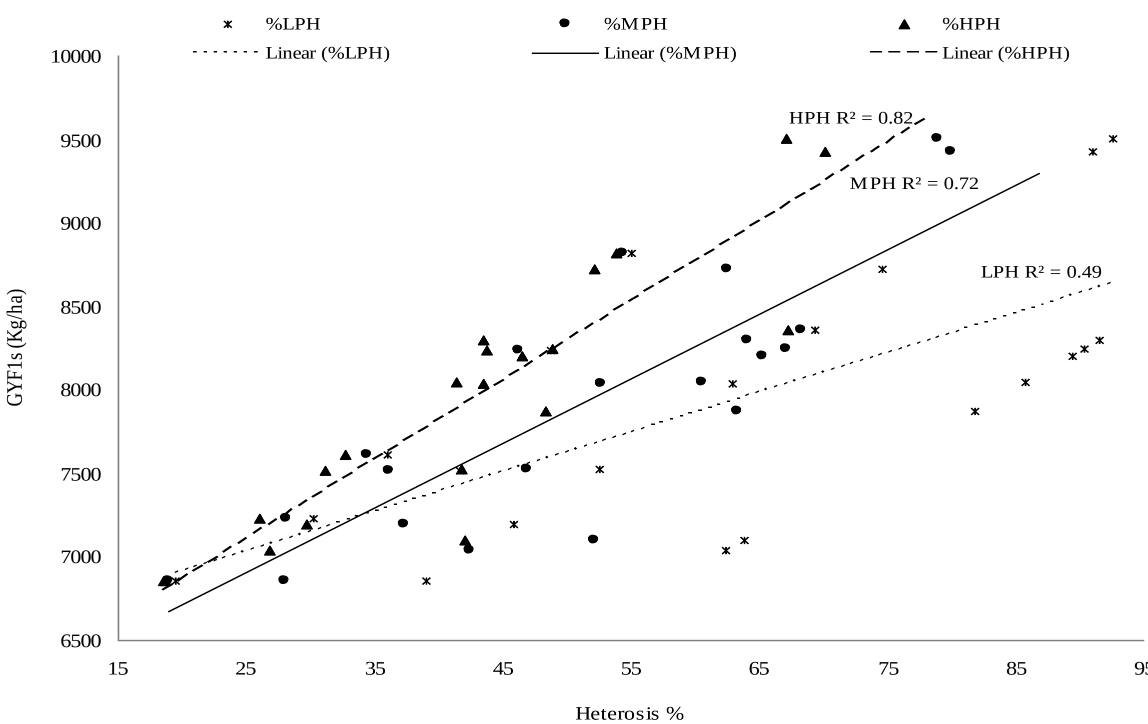

Figure 5. Regression heterosis percent on GYF1s in maize.

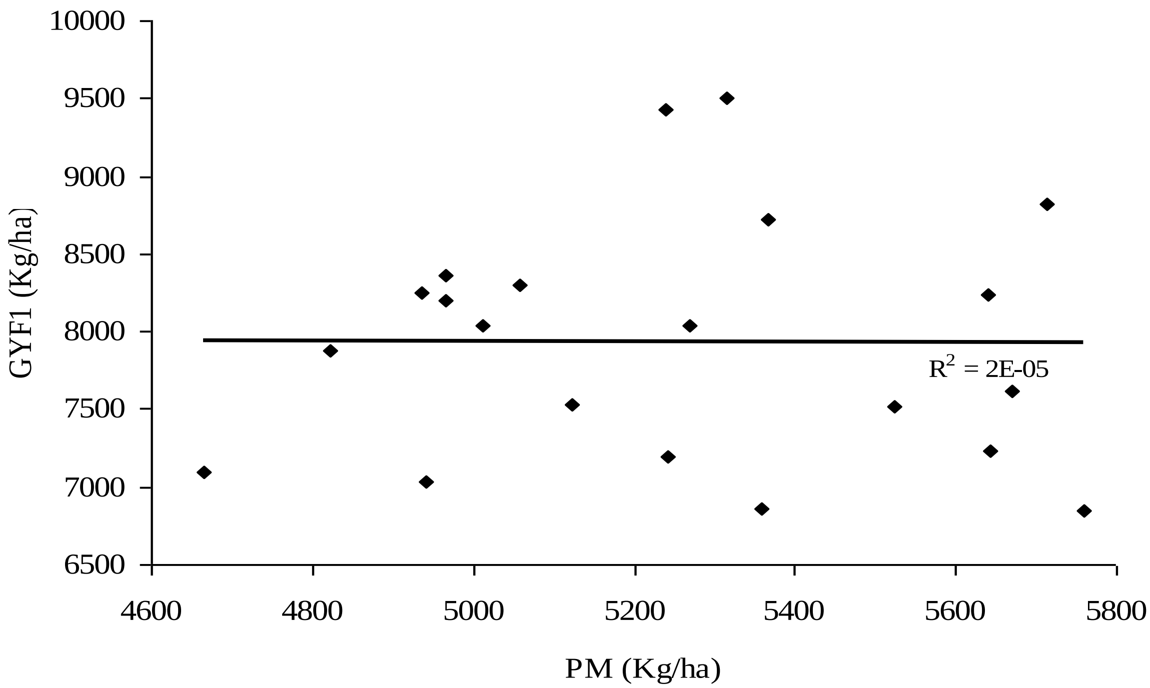

Figure 6. Regression of mean of parents (PM) on GYF1s in maize.

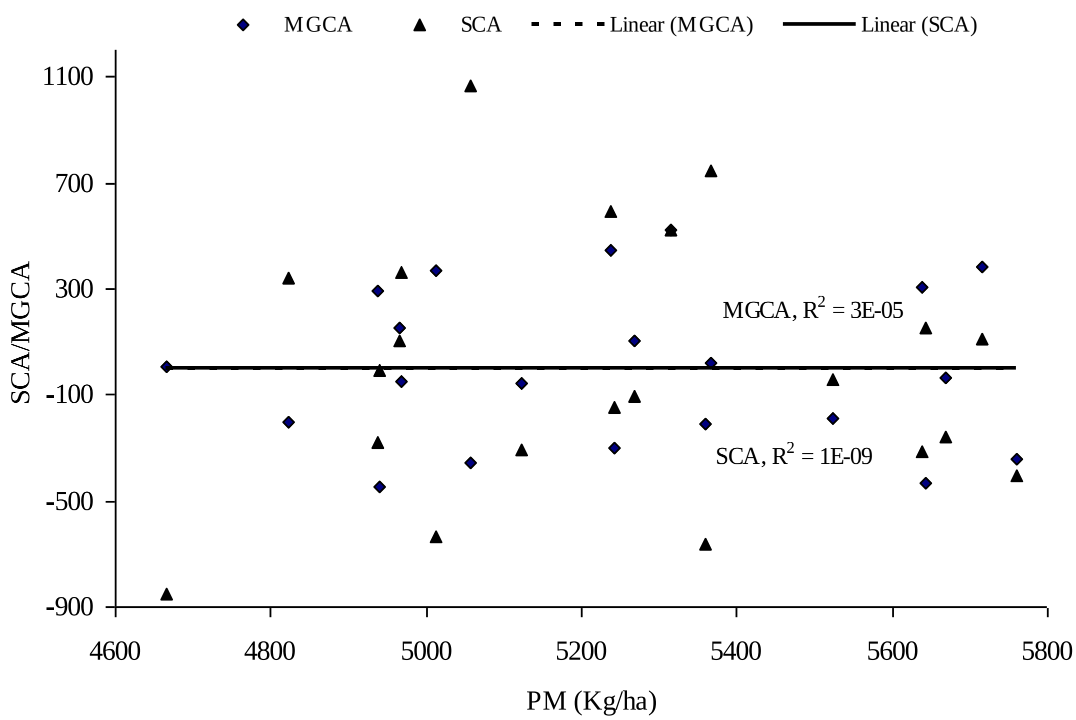

Figure 7. Regression of PM on SCA effects and MGCA in maize.

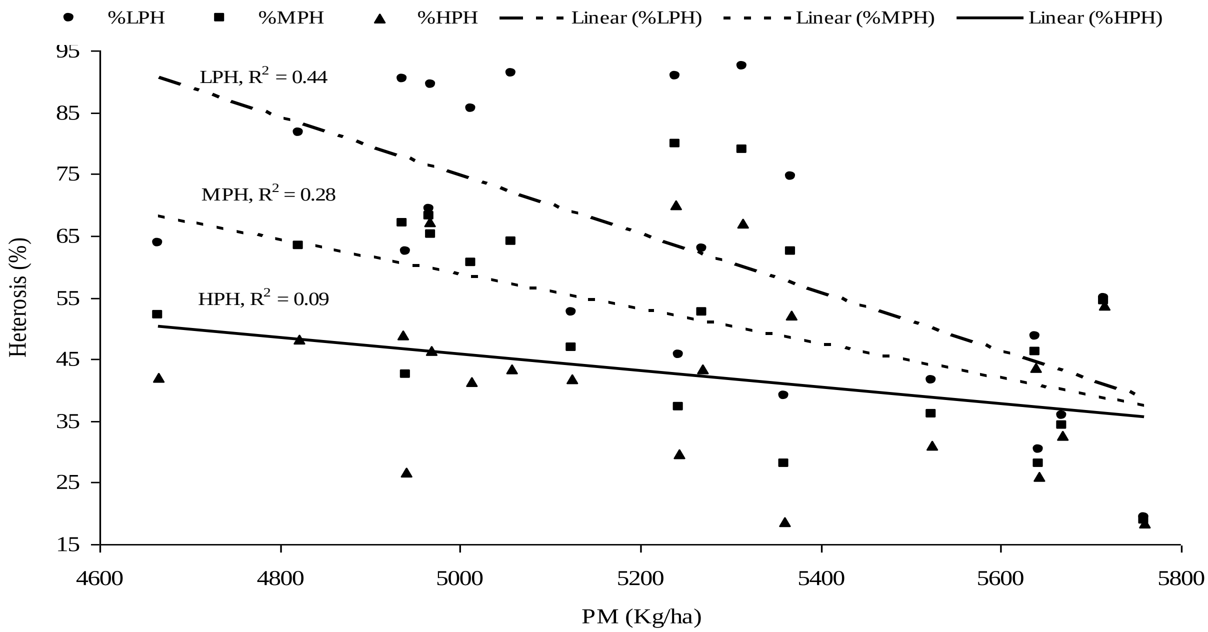

Figure 8. Regression of PM on heterosis percent in maize.

In this investigation, 21 hybrids and 10 parents of short duration maize were evaluated for grain yield in 4 environments and GCA, MGCA, SCA, heterosis and PM were determined. Rank correlation followed by regression analysis was used to determine the significance of each parameter in prediction of *per se* performance of F1. The PM did not exhibit any promising relationships with GYF1s, combining abilities or heterosis and therefore its predictive value is limited. Of the combining abilities, MGCA emerged with more predictive value than the SCA in determination of heterosis or GYF1s. Heterosis and more specifically HPH appeared to be more closely associated with GYF1s.

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