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Mean Performance and Heterosis in Single Crosses of Selected Quality Protein Maize (QPM) Inbred Lines

Gudeta Nepir[1†], Dagne Wegary[2], Wassu Mohamod[1], Habtamu Zeleke[1], and Adefris Teklewold[2]
[1]Hramaya University, PO Box 138, Alemaya, Dire Dawa, Ethiopia
[2]CIMMYT–Ethiopia, ILRI Campus, PO Box 5689, Addis Ababa, Ethiopia
†Corresponding author: E-mail: gudeta2003@yahoo.com; Cell Phone: +251-911798969

Abstract

Knowledge of the extent of heterosis and per se performance of parental lines plays a crucial role for the breeding programs to develop competitive hybrids. Hence, this research was planned to evaluate the performances of QPM inbred lines and their single crosses; and estimate the magnitudes of mid-parent, better parent and standard heterosis for grain yield and its components. Ten inbred lines were crossed following diallel method II to produce 45 single crosses. A total of 57 genotypes (10 inbred lines, 45 single crosses and two standard checks) were evaluated in alpha lattice design at Ambo and Bako in 2014, with two replications. Combined analysis of variance showed highly significant ($P \leq 0.01$) variations among genotypes for grain yield and yield components studied. Interaction effects of all traits with the environments except for ears plant^{-1} were highly significant ($P \leq 0.01$). Five hybrids, viz., P3 x P10, P7 xP10, P4 x P10, P6 x P10 and P9 x P10 were significantly superior to AMH760Q (the best check) with yield advantages ranging of 45.9 to 29.7%. These hybrids also had significantly higher percentage of mid-parent (MPH) and better - parent heterosis (BPH) for grain yield ranging from 292.7 to 163% and 248.4 % to 128.6%, respectively. Indeed these hybrids shared P10 as common male parent which had no pedigree relationship with the parental lines used to form the crosses. The result is, therefore, in line with the established fact of positive association between heterosis and genetic distance of parental lines. P10 is not only a distant relative to these other parents but had also desirable traits for high grain yield, which could be exploited in the breeding program. Moreover, the five highest yielding hybrids identified in this study need to be further evaluated across locations for possible release as single cross hybrids.

Keywords: Diallel cross, grain yield, mid-and better-parent heterosis, yield components

Introduction

Maize has a crucial role to secure food self-sufficiency of the Ethiopian community due to its highest yield potential per unite area (3.68 t ha^{-1}) as compared to other grain crops (CSA, 2017). Despite its productivity, normal maize is deficient in two essential amino acids, lysine and tryptophan (NRC, 1988; Adefris *et al*., 2015) which affects the health, growth and development of maize dependent community. To alleviate these problems, the International Maize and Wheat Improvement Centre (CIMMYT) have developed Quality Protein Maize (QPM) germplasm, which contain twice the levels of lysine and tryptophan than that of the normal maize germplasm. As a result, QPM provides double the amount of biologically usable protein that could be derived from the same quantity of normal maize-based diets (Adefris *et al*., 2015). To utilize the potential nutritional benefits of QPM, research on QPM was started in Ethiopia in 1994 (Adefris *et al*., 2015) with introduction and evaluation of open pollinated varieties (OPVs) and pools introduced from CIMMYT. Through a rigorous selection and evaluation of the introduced QPM germplasm, it had been possible to identify good combining and adapted parental lines crossed to form BHQP542, the 1st QPM hybrid released in the country. Since then the Ethiopian maize improvement programs has released seven other QPM varieties (five hybrids and two OPVs) through introduction and evaluation, and converting elite normal maize genotypes to QPM version.

Based on the landmark established at CIMMYT and motives of national maize breeding efforts, a number of maize inbred lines in CIMMYT-Ethiopia maize breeding programs have been converted to QPM since 2001 to strengthen QPM improvement efforts of the National Research Programs. These QPM version inbred lines were rigorously selected for yield and resistance to gray leaf spot and maize streak viruses (Twumasi-Afriyie *et al*, 2012).

Success of maize yield improvement is mainly due to exploitation of higher heterosis when parents are divergent. Genetic divergence provides superior performance to the hybrids (Acquah, 2007). Thus, success of hybrid breeding programs depends on capacity to detect and maximize genetic diversity of source parental lines in their program to maximize heterozygosity in the newly developing products and develop superior varieties periodically.

Various scholars reported variable ranges of results on manifestation of heterosis in maize with regard to genetic distance of parents. For example heterosis for grain yield was reported to be lower among crosses of genetically similar germplasm and among crosses obtained from genetically broad genetic base germplasm or very distant germplasm as well (Hallauer and Miranda, 1981; Beck *et al*., 1990; Vasal *et al*., 1993a). On the other hand, heterosis increases with an increase in genetic distance among the parents up to a certain optimum level of divergence and decreases thereafter (CIMMYT, 1997). Raposo *et al*. (2004) suggested that the productive potential of the maize hybrid could be a function of both *per se* performance of the parental lines and heterosis among them. Similarly, Wegary *et al*. (2013) indicated that the degree of heterosis depends on the relative performance of inbred parents and the corresponding hybrids. Duvick (1999) also suggested that maize hybrid yield gain is primarily due to improvements in tolerance to biotic and abiotic stresses of parental lines as well as their hybrid progenies.

Furthermore, possibility of predicting hybrid performance on the basis advanced generations of elite inbred parents with proven performances across N-supplies has been suggested (Zaidi *et al.,* 2003). This suggestion may indicate that exploitation of heterosis in hybrid development programs could be complimented through the use of environmentally adaptive and genetically divergent inbred lines with good *per se* performance.

Studies made so far to quantify the extent of heterosis showed variable ranges of MPH and BPH for different traits considered. For example, Wegary *et al*. (2013) found above 100% HPH in about 38% of the crosses and very high BPH for grain yield but negative MPH and BPH for days to anthesis and silking in diallel crosses of tropical mid altitude white grained QPM inbred lines. Whereas a study made on heterosis and combining ability of highland QPM early generation inbred lines using line x tester revealed positive and high MPH and HPH for grain yield, ranging from 81.2 to 315% and 61.0 to 281.8%, respectively (Gudeta *et al*., 2015). The authors also reported standard heterosis for grain yield to range from -0.5 to 97.5% with an average value of 34.9%. A study by Ali *et al*. (2012) on manifestation of heterosis in conventional maize indicated that the extent of heterosis differ substantially depending on the choice of the parents and the traits considered.

In view of the ever changing environment, continuous development of competitive hybrid varieties to exploit potential yield benefits from heterotically responsive parental lines periodically infused into breeding materials requires adequate information on magnitude of heterosis among the newly synthesized inbred lines. Accordingly, this study was conducted to (i) identify superior QPM hybrids and inbred lines which could be used in the breeding programs or for commercial cultivation; and (ii) generate information on the magnitudes and extents of heterosis over mid- and- better parent as well as over the commercial variety in diallel crosses of 10 QPM parental lines.

Materials and Methods

Description of experimental sites

The experiment was conducted at Ambo and Bako Research Centers. Ambo and Bako Research Centers respectively represent moist highland and sub-humid mid-altitude maize growing ecologies of Ethiopia. Ambo lies at 8°57′N; 38°07′E at an altitude of 2,225 masl; and receives an average annual rainfall of 1022 mm with average minimum and maximum temperatures of 9.6 and 26.7°C. Bako, high potential maize growing area in Ethiopia, is situated at 9°12′N; 37°08′E at an altitude of 1600 masl; and receives an average annual rainfall of 1067 mm with average minimum and maximum temperatures of 13.8 and 29.3°C.

Experimental materials

Ten QPM inbred lines (Table 1) and two standard check hybrids AMH760Q and AMH851 (adapted to most high potential maize growing ecologies of Ethiopia and highland environment, respectively) were obtained from EIAR and CIMMYT-Ethiopia joint Highland Maize Breeding Program at Ambo Research Center. The 10 parental lines were selected based on their *per se* performances. The lines were originally generated from Kitale heterotic group [KIT/SNSYN[N3/TUX], and highland adapted pool [POOL9Ac7-SR(BC2)]. POOL9Ac7-SR(BC2) is a Pool 9A version introgresed with CIMMYT's mid-altitude materials, and has good potential for resistance to gray leaf spot (GLS) and maize streak virus (MSV). CML144 and CML176 were used as *Opaque-2*(*o2*) donor parents to convert the conventional inbred lines to QPM versions. The standard check AMH760Q is a three-way QPM hybrid while AMH851 is a three-way non-QPM hybrid, both released for the highland and transitional highland ecologies of Ethiopia. During the main cropping season of 2013, the 10 parental lines including CML144 and CML159were crossed plant to plant in diallel mating design following Griffing's (1956) model-I and method-II and obtained 45 F_1 single crosses.

Experimental design and field procedures

The 57 genotypes (45 F_1s, two standard checks and 10 parental lines) were organized in alpha-lattice (0, 1) design (Patterson and Williams, 1976) and replicated twice adjacently in two independent trials. Each plot consisted a single row of 5 m long with inter and intra row spacing of 0.75 m and 0.25 m, respectively. Plots were planted with two seeds per hill and later thinned to one plant per hill retaining 53,333 plant stands ha^{-1} at both locations. Nitrogen fertilizer was applied in two splits per the recommendation: half at planting and the rest at 37 days after emergence. The recommended rate of P_2O_5 was applied at planting. All other management practices were performed according to the recommendations for the crop.

Field and laboratory measurements

Field data were recorded for grain yield (kg), moisture content and number of ears $plant^{-1}$ at harvesting. Grain yield was measured from entire ears of each experimental unit, adjusted to 12.5% moisture content and converted to ton ha^{-1}. Five random ears were collected from each experimental unit and data were taken on ear length, ear diameter, rows $cobe^{-1}$ and kernels row^{-1}. For 1000 seed weight, random kernels from the bulk of each experimental unit after shelling taken to the laboratory and counted using a photoelectric seed counter and weighed in grams after the moisture was adjusted to 12.5%.

Table 1. Pedigree of quality protein maize (QPM) inbred lines used for diallel cross in the study

Code	Pedigree
P1	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-2-2-1-#-1-B-2
P2	[KIT/SNSYN[N3/TUX]]c1F1-##(GLS=2.5)-32-1-1-#/CML176BC1F1-12-1-3-4-2-#-2-B-1
P3	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-3-3-4-#-1-B-4
P4	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-3-2-2-#-1-B-1
P5	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-21-1-3-2-2-#-2-B-4
P6	[POOL9Ac7-SR(BC2)]FS67-1-2-3-1-#/CML144(BC2)-10-2-1-1-4-5-#-2-B-2
P7	[POOL9Ac7-SR(BC2)]FS59-2-2-1-1-#/CML144(BC1)F1-3-2-1-2-1-#-1-B-2
P8	[KIT/SNSYN[N3/TUX]]c1F1-##(GLS=2.5)-17-1-1-#/CML144(BC1)F1-5-1-2-1-1-#-2-B-1
P9	CML144
P10	CML159

Statistical analysis

Analysis of variance was done for individual environments using the PROC MIXED procedure of SAS (SAS, 2003) for the 57 genotypes, as well as for parental lines and the F1 single hybrid plus standard checks separately. Later combined analysis of variance was performed for grain yield, number of ears plant^{-1}, ear length, ear diameter, rows ear^{-1} and number of kernels row^{-1} that showed significant variation among the genotype at both environments and showed homogeneity of error variances through Bartlett's test. . In the analysis, the genotypes were considered as fixed effects and replications and incomplete blocks within replications as random effects. Mean sum squares due to genotypes were tested against genotype interaction with the environments. Mid-parent heterosis (MPH), better-parent heterosis (BPH) and standard heterosis (SH) were computed as follows:

- MPH= [(F1-MPV)/MPV] x 100, where, F_1 is the mean performance of the cross and MPV is mean value of the two inbred parents over locations.
- BPH= [(F1-BPV)/BPV] x 100, where, BPV is the mean value of the high performing parent involved in producing the hybrid.
- SH= [(F1-CHV)/CHV] x 100, where. SH is standard heterosis and CHV is the mean value of the best check hybrid variety.

Significance of the heterosis effects was determined by the t-test, using standard errors of the respective heterosis. For computation of standard error of MPH and BPH, check varieties were excluded from computation of mean square of error whereas parental lines were excluded from computation of mean square of error which is used to compute standard error of standard heterosis.

Results

Analysis of variance

Analysis of variance for individual environment (data not shown) and combined over environments revealed highly significant variations among quality protein maize genotypes for grain yield, number of ears plant^{-1}, ear length, ear diameter, number of rows cob^{-1} and number of kernels row^{-1} (Table 2). Similarly, separate analysis variance for hybrids and parental lines showed significant variations (data not shown) for the traits considered. Site effect was also significant for the studied traits except for number of rows ear^{-1}, and site x entry interaction was also significant most traits except for number of ears plant^{-1}.

Table 2. Combined analysis of variance for grain yield and yield components evaluated of 57 QPM genotypes grown at Ambo and Bako during in 2014

Traits	Sites (df=1)	Rep (Site) df=2	Genotypes (df=56)	G x S (df=56)	Error (df=104)
Grain yield (t ha^{-1})	12.99**	3.25	23.84**	1.98**	1.14
Number of ears plant $^{-1}$	1.25**	0.09	0.37**	0.07	0.05
Ear length (cm)	589.45**	6.79	15.91**	1.91*	1.13
Ear diameter (cm)	5.10**	0.04	0.63**	0.07**	0.04
Rows ear^{-1}	0.81	0.05	6.21**	0.96**	0.40
Number of kernel row^{-1}	1532.97**	29.71	85.96**	15.32**	5.27

Single cross hybrid mean performance

The mean grain yield performances of 45 F_1 hybrids showed that more than 37% and 51% of the hybrids were superior to the best check (AMH760Q) and the combined trials mean, respectively. For ears plant^{-1}, ear length and ear diameter, more than 55%, 37% and 42% of the hybrids performed better than AMH760Q; whereas more than 33%, 55% and 48%, of the hybrids were superior to the combined trial means for the same traits. For rows ear^{-1} and kernels row^{-1} more than 75% and 71% and 51% and 73% of the crosses were superior to AMH760Q and the combined trail means, respectively.

Mean grain yield performances of F_1 hybrids ranged from 1.0 to 10.8 t ha^{-1} with an average of 6.8 t ha^{-1}. For ears plant^{-1}, mean performance was 1.2 with a range of 0.6 to 1.9. Ear length ranged from 12.1 to 17.7 cm with a mean of 16.2 cm whereas and ear diameter ranged from 3.4 to 5.2 cm with a mean value of 4.4 cm. The F1 mean performances for rows ear^{-1} and kernel row^{-1} was 13.2 and 36.7, and ranged from 11.2 to 15.5, and 26.1 to 39.6, respectively (Table 3).

Table 3. Performances of the top yielding 10 QPM single crosses and standard checks evaluated for grain yield and yield components at Ambo and Bako in 2014

Crosses	GY	EPP	EL	ED	RPE	KPR	Crosses	GY	EPP	EL	ED	RPE	KPR
P3 x P10	10.8	1.5	16.9	5.0	14.8	39.6	P6 x P9	8.6	1.4	16.5	4.4	12.9	36.7
P7 x P10	10.7	1.6	16.5	4.9	15.4	36.7	P3 x P8	8.5	1.2	18.9	4.7	12.6	42.6
P4 x P10	10.4	1.8	17.7	4.8	14.5	38.7	P3 x P9	8.3	1.0	19.2	4.3	14.0	40.5
P6 x P10	10.4	1.9	15.6	4.3	13.4	36.9	P2 x P10	8.2	1.3	16.6	4.8	15.0	39.1
P9 x P10	9.6	1.3	16.8	5.2	15.5	36.9	P3 x P6	7.9	1.2	16.7	4.4	11.8	37.0
P4 x P7	9.5	1.5	17.3	4.7	15.0	40.7	P4 x P8	7.9	1.4	17.8	4.3	12.5	39.4
P4 x P6	9.3	1.8	16.5	4.4	12.3	37.0	P1 x P6	7.6	1.5	16.1	4.0	11.9	36.7
P7 x P9	9.2	1.0	18.7	5.2	16.1	36.9	P1 x P8	7.3	0.9	17.8	4.5	12.6	38.6
P4 x P9	8.9	1.2	18.2	4.7	13.8	38.9	P3 x P7	7.2	1.0	16.7	4.8	14.1	37.7
P5 x P10	8.6	1.4	14.9	4.9	14.4	36.6	P8 x P10	7.2	1.5	15.5	4.4	13.8	34.9
Check1	7.4	1.0	16.7	4.5	12.3	36.4	Check1	7.4	1.0	16.7	4.5	12.3	36.4
Check2	6.3	1.2	16.5	4.6	12.4	35.9	Check2	6.3	1.2	16.5	4.6	12.4	35.9
Mean	6.8	1.2	16.2	4.4	13.2	36.7		6.8	1.2	16.2	4.4	13.2	36.7
Min	1.0	0.6	12.1	3.4	11.2	26.1		1.0	0.6	12.1	3.4	11.2	26.1
Max	10.8	1.9	17.7	5.2	15.5	39.6		10.8	1.9	17.7	5.2	15.5	39.6
LSD	1.6	0.3	1.5	0.3	0.9	3.2		1.6	0.3	1.5	0.3	0.9	3.2
F-test	**	**	**	**	**	**		**	**	**	**	**	**
CV (%)	17.0	19.1	6.4	4.4	4.6	6.2		17.0	19.1	6.4	4.4	4.6	6.2

GY= grain yield (t ha^{-1}); EPP= number of ears $plant^{-1}$; EL= ear length (cm); ED= ear diameter (cm); RPE= Number of kernel rows ear^{-1}; KPR= Number of kernels row^{-1}

Single cross hybrids such as P3 x P10, P7 x P10, P4 x P10, P6 x P10 and P9 x P10 showed higher grain yields which ranged from 9.6 to 10.8 t ha^{-1} (Table 3). It is interesting to note that all these hybrids contain P10 as one of their parents. As indicated in Table 1, this parent doesn't have any pedigree relationship with all other parental lines involved in the formation of diallel crosses studied the current diallel cross formation. Furthermore, these hybrids were found to have acceptable level of kernel modification, moderate reaction to gray leaf spot, common rust and Turcicum leaf blight (data not shown).

Parental line performance

Mean performance of the parental lines ranged from 1.2 to 4.2 t ha^{-1} for grain yield; 0.7 to 1.7 for ears $plant^{-1}$; and 10.1 to 14.3 for ear length with corresponding means of 2.8 t ha^{-1}, 1.1 and 12.1. Mean performances of the inbred lines ranged from 3.3 to 4.1 cm for ear diameter, 10.9 to 15.3 for number of kernel rows ear^{-1} and 18.5 to 30.6 for number of kernels row^{-1} with means of 3.7 cm, 12.6 and 24.6 respectively (Table 4). In ascending order of their importance, P9 (with 4.2 t ha^{-1})), P7 (with 3.9 t ha^{-1})) and P6 (with 3.6 t ha^{-1})) were the best three high yielding parental lines.

Table 4. Mean performances of 10 QPM parental inbred lines for grain yield and yield components evaluated at Ambo and Bako in 2014

Trait	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Mean	Min	Max
GY	2.0	1.2	2.4	3.6	1.8	3.6	3.9	2.5	4.2	3.1	2.8	1.2	4.2
EPP	0.8	0.8	1.0	1.6	0.7	1.7	1.1	0.9	1.7	0.9	1.1	0.7	1.7
EL	11.7	10.1	14.3	12.3	10.1	11.3	13.2	13.4	11.7	13.3	12.1	10.1	14.3
ED	3.5	3.5	3.6	3.8	3.8	3.3	4.0	3.7	3.9	4.1	3.7	3.3	4.1
RPE	11.8	12.0	11.5	12.3	12.3	11.9	15.3	10.9	14.4	13.3	12.6	10.9	15.3
KPR	24.3	18.5	26.7	24.8	23.0	23.6	30.6	25.8	26.0	22.8	24.6	18.5	30.6

GY=grain yield (ha^{-1}); ED= ear diameter (cm); Ear length (cm); EPP= number of ears $plant^{-1}$; EL=ear length (cm); KPR= kernels row^{-1}; RPE = rows ear^{-1}

Heterosis

Percent MPH and BPH ranged from -37.5 to 292.7 and -50 to 248.4, respectively (Table 5) for grain yield. As is shown in Table 6, more than 80% of the single cross hybrids manifested significant (P≤0.01) positive MPH and BPH for grain yield (Table 6). High yielding single crosses such as P3 x P10, P7 x 10, P4 x P10, P6 x 10 and P9 x 10 showed 292.7%, 205.7%, 210.4% and 163% MPH and 248.4%, 177.4%, 188.9%, 188.9% and 128.6% BPH , respectively.

Upper limit of percent MPH was highest for grain yield but lowest for rows ear^{-1} whereas lower limit of percent MPH was lowest for grain yield but highest for kernels row^{-1} (Table 5).

Mid-parent heterosis varied from -37.5 to 292.7%, -31.9 to 78.1% and -6.4 to 66.1% for grain yield, ears plant^{-1} and ear length, respectively whereas respective percent BPH of these traits ranged -50.0 to 248.4, -44.6 to 68.9 and -12.9 to 54.9%. For ear diameter, rows ear^{-1} and number of kernel row^{-1}, MPH was in the range of -2.1 to 30.4%, -5.7 to 19.5% and 8.7 to 89.3% with respective range of BPH of -2.6 to 28.8%, -11.4 to 12.8% and 4.9 to 71.5% (Table 5).

Standard heterosis (SH) for grain yield ranged from -86.2 to 45.3 and -83.7 to 71.1% over AMH760Q (the QPM) and AMH851 (CM checks), respectively (Table 5). About 80% of the crosses showed positive and significant higher standard heterosis over both AMH760Q and AMH851 (data not shown). . For ears plant^{-1}, ear length, ear diameter, rows ear^{-1} and kernel row^{-1}, SH over AMH760Q varied from -41 to 83.6, -27.8 to 16.0, -23.9 to 14.4, -8.4 to 31.6 and -28.2 to 17.1, respectively. Generally, SH over the normal check (AMH851) was relatively higher than that of AMH760Q due to lower performance of the CM hybrid check (Table 5).

Table 5. Ranges of % MPH, % BPH and %SH in diallel crosses of 10 QPM parental lines for yield and its components evaluated across Ambo and Bako in 2014

	------%MPH---------			-----%BPH-----------			%SH over AMH760Q			%SH over AMH851		
Trait	Min	Max	SE (±)	Min	Max	SE (±)	Min	Max	SE (±)	Min	Max	SE (±)
GY	-37.5	292.7	0.7	-50.0	248.4	0.8	-86.2	45.3	0.8	-83.7	71.1	0.8
EPP	-31.9	78.1	0.1	-44.6	68.9	0.2	-41.0	83.6	0.2	-50.4	54.3	0.2
EL	-6.4	66.1	0.7	-12.9	54.9	0.8	-27.8	16.0	0.8	-26.9	17.4	0.8
ED	-2.1	30.4	0.1	-2.6	28.8	0.1	-23.9	14.4	0.1	-25.5	12.0	0.1
RPE	-5.7	19.5	0.4	-11.4	12.8	0.4	-8.4	31.6	0.4	-9.3	30.3	0.4
KPR	8.7	89.3	1.4	4.9	71.5	1.6	-28.2	17.1	1.6	-27.3	18.7	1.6

GY=grain yield (t ha^{-1}); ED=ear diameter (cm); EPP=ears plant-1; BPH=better parent heterosis; MPH=mid parent heterosis; EL=ear length;; KPR= kernels row^{-1}; RPE=rows ear^{-1}; Min=minimum, Max= maximum

Table 6. Percent BPH (above diagonal) and MPH (below diagonal) for grain yield of diallel crosses of 10 QPM parental lines (P) evaluated at Ambo and Bako in 2014

Parent	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1		-50.0	0.0	-5.6	130.0**	111.1**	71.8**	192.0**	47.6**	103.2**
P2	-37.5		62.5	-27.8	138.9**	91.7**	71.8**	172.0**	50.0**	164.5**
P3	9.1	116.7**		-33.3	120.8**	119.4**	84.6**	240.0**	97.6**	248.4**
P4	21.4	8.3	-20.0		55.6**	158.3**	143.6**	119.4**	111.9**	188.9**
P5	142.1**	186.7**	152.4**	107.4**		33.3	56.4**	144.0**	59.5**	177.4**
P6	171.4**	187.5**	163.3**	158.3**	77.8**		38.5	91.7**	104.8**	188.9**
P7	127.1**	162.7**	128.6**	153.3**	114.0**	44.0*		76.9**	119.0**	174.4**
P8	224.4**	267.6**	246.9**	159.0**	183.7**	126.2**	115.6**		61.9**	132.3**
P9	100.0**	133.3**	151.5**	128.2**	123.3**	120.5**	127.2**	103.0**		128.6**
P10	147.1**	281.4**	292.7**	210.4**	251.0**	210.4**	205.7**	157.1**	163.9**	

SE(BPH) = ± 0.8; SE(MPH) = ± 0.7; P=parental lines; *,** significant at P≤0.05 and P≤0.01, respectively

Discussions

The hybrids and parental lines exhibited significant variations for grain yield and yield components. This suggests the presence of wide range of differences among hybrids and parental lines for grain yield and its components traits considered in the study. Hence this study suggested further evaluation of some top yielder hybrids for commercial release while the parental lines could be used in QPM breeding programs. In agreement with the current finding, many authors reported the presence of significant differences among QPM hybrids for grain yield and yield components (Pixley and Bjarnason, 1993; Hadji, 2004; Xingming *et al*., 2004; Amiruzzaman *et al*., 2011; Dagne *et al*., 2011; Dagne *et al*., 2014; Gudeta *et al*., 2015; Tulu *et al*., 2016).

In this study, the parental lines P6, P7, P9 and P10 had higher yield and acceptable *per se* performances for most of the yield components studied. About 37% and 51% of the hybrids were significantly superior to the best check (AMH760Q) and combined mean grain yield, respectively out of which P3 x P10, P7 x P10, P4 x P10, P6 x P10 and P9 x P10 were high yielding hybrids with grain yields advantages of 49.5%, 44.6%, 40.5% and 29.7%, respectively. Interestingly, these high yielding hybrids shared P10 as a common male parent which was related in pedigree record to neither of the parental lines by descent. In agreement with the current result, Scott *et al*. (2004) reported the combinations among QPM inbred lines with no common close-by-ancestor as donor parent gave better yielding varieties.

For most of the F_1 crosses MPH and BPH were highly significant for all the traits considered indicating the possibility of developing and selecting QPM hybrids with improved grain yield and agronomic traits. For QPM hybrids to be adopted a consistent genetic gain has to be granted so that farmers can prefer QPM not only by its nutritional advantage but also for its agronomic benefit.

Hallauer and Miranda (1988) interpreted heterotic response as a function of non-additive gene action and degree of genetic distance. Thus, presence of significant higher percent MPH in several crosses indicated presence of adequate genetic distance among some of the lines to use them in contrasting heterotic group to develop superior hybrids. Furthermore it also indicated important roles of non-additive gene actions.

The current set of materials manifested both negative and positive MPH and BPH for grain yield which varied from -37.5 to 292.7% and -50.0 to 248.4%, respectively. Presence of negative heterosis implies that their respective parents resemble same heterotic group or parents are genetically less distant whereas significantly positive heterosis in most crosses reveal that their parents are divergent and could be used to develop heterotically responsive hybrids. On the other hand presence of highly elevated MPH and BPH in the current finding as compared to previous findings of Vasal *et al.* (1992) on CIMMYT's Subtropical and Temperate Early-Maturity Maize Germplasm may also imply that respective parents used in the current study are not as such productive and may suggest the need for *per se* performance improvement of parental lines to make the single cross seed production successful. In agreement with the present finding, Wegary *et al*. (2013) also reported similar finding for grain yield and earsplant^{-1} from the study made on diallel cross of quality protein maize inbred lines across mid-altitudes of Bako and Zimbabwe.The present finding revealed presence of positive and significantly higher SH over a standard quality protein maize hybrid and normal maize hybrid for all traits indicated possibility of using this set of germplasm for QPM improvement and identifying for commercial cultivation. Previously Gudeta *et al*. (2015) reported SH of grain yield in the ranges of -0.5 to 97.5% for test crosses of early generation highland QPM inbred lines which is relatively higher than what is reported here (ranged from -0.86.2 to 45.3%). The deviation in SH of the current hybrids as compared to Gudeta *et al*. (2015) may partly be attributed to the use of recently released high yielding standard check AMH760Q after the testing of the former materials in 2006 and partly due to close relatedness of some parental lines used in this study.

Conclusions

This study indicated higher chance of producing superior QPM hybrids from the present set of parental lines. This research also revealed significant MPH and BPH in several crosses. Thus it implied that there was adequate genetic distance among some parental lines and important role of non-additive gene action to exploit heterosis for QPM hybrid development. This study suggested infusing P6, P7, P9 and P10 to QPM germplasm development. Moreover, hybrids such as P3 x P10, P7 x P10, P4 x P10, P6 x P10 and P9 x P10 with superior yield performance and significant SH can be advanced for further multi-location evaluation to make final recommendation for cultivation.

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