

Genetic Evaluation of Grain Yield and Kernel Micronutrient Traits in Maize

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Abstract

Forty-one maize inbred lines and 16 experimental hybrids were analyzed in this study for grain yield and related traits, besides kernel micronutrients (iron and zinc). The study revealed considerable genetic variability for the traits under study. Most of the yield components displayed significant positive correlation with yield, except days to fifty percent male flowering and silking, which also displayed negative correlation with kernel Zn concentration. While kernel Fe concentration was negatively correlated to grain yield, kernel zinc concentration did not display any significant correlation, indicating the possibility of developing early maturing maize genotypes with higher kernel Zn density without compromising grain yield. The two kernel micronutrients were not correlated among themselves. Among all the traits, kernel number per ear row was found to have significant direct effect on grain yield in both genotypic and phenotypic path analysis, whereas no significant direct or indirect effects of kernel iron and zinc concentration on grain yield was observed. The study also led to the identification of two promising single cross experimental hybrids (CM139 × BAJIM-06-12 and CM140 × V334) on the basis of grain yield and its components.

Key words: Maize, grain yield, kernel micronutrients, correlations

Introduction

Maize provides a large proportion of the daily intake of energy and other nutrients, including micronutrients for poor populations in many areas of South East Asia and sub-Saharan Africa. However, most of the staple food crops including maize display very low concentration of such micronutrients, especially Fe and Zn. More than half of the world's population, especially women and children from the developing countries, suffer from micronutrient malnutrition or hidden hunger, resulting from the consumption staple foods with very low levels of bioavailable vitamins and mineral (UNSCN, 2004). To combat this problem of 'hidden hunger', plant breeding techniques are now being emphasized to develop genotypes of staple foods whose edible portions are denser in bioavailable minerals and vitamins, a process referred to as 'biofortification' (Lodha et al., 2005).

The maize improvement programmes in many countries, including India, presently focus mainly on developing superior high-yielding single-cross hybrids. Improving the nutritional quality, especially for micronutrients, is now an important breeding goal in maize, particularly for kernel Fe and Zn concentrations and Provitamin A (Pfeiffer and McClafferty, 2007). To breed high yielding crops with improved quality, evaluation of genetic variability for the target traits, besides grain yield and its components, is the first important step. It is also useful to study the interrelationships among various component characters to develop selection criteria for improvement of the target traits. However, the knowledge of correlation alone does not present the complete picture, since the understanding of direct and indirect effects of component traits towards the target trait is necessary for achieving gainful increment in a judicious manner. Therefore, the present study was undertaken to analyze the genetic diversity (using Mahalanobis D² analysis) in inbreds of maize, besides assessing the direct and indirect effects of various characters, including kernel micronutrient concentrations, on grain yield.

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Materials and Methods

The materials consisted of a set of 41 inbred lines, including lines developed under the All India Coordinated Maize Improvement Project (AICMIP) [designated as 'CM' lines], lines from CSKHPKV Regional Research Station, Bajaura [designated as 'BAJIM' lines], inbreds developed at VPKAS, Almora [designated as 'V' lines], nine QPM lines developed at different research institutes [designated as 'DQPM' and 'VQL' lines], and one line from the 'HarvestPlus' program, CIMMYT, Mexico [HP-2]. Sixteen experimental hybrid combinations, derived using 11 contrasting inbred lines (CM128, CM129, CM139, CM140, CM145, CM152, V334, V340, BAJIM-06-02, BAJIM-06-12 and BAJIM-06-19) were also evaluated along with two commercial checks (Parkash and BIO-9681).

The 41 inbred lines and the 16 experimental hybrids along with their inbred parents and the commercial checks were evaluated at IARI Experimental Farm during *khariif*-2008 in two separate trials. The materials were planted in randomized complete block design (RCBD) with two replications per entry and one row per replication and with a plant-to-plant spacing of 20 cm and row-to-row spacing of 75 cm. Standard agronomic practices were followed for raising and maintenance of the plants. Five random plants from each row were selfed and the rest was allowed to open-pollinate. For kernel micronutrient analysis, only the selfed ears were hand-harvested, following the procedure suggested by HarvestPlus (www.harvestplus.org). Except for the traits for which data were recorded on standing crops in plots, data for yield components were recorded on ears from five randomly sampled open-pollinated plants or on five randomly sampled open pollinated ears, as applicable to the case. Data were recorded on 10 different characters [grain yield (kg)/plot, ear length (cm), ear diameter (cm), no. of kernel rows, kernel per ear row, hundred kernel weight (g), plant height (cm), ear height (cm), days to 50% anthesis and silking], besides kernel Fe and Zn concentrations.

Biochemical analysis for kernel Fe and Zn concentrations was carried out on triplicate samples by open air digestion with 9:4 diacid

mixture, followed by atomic absorption spectrometry (AAS) method using ECIL AAS (Perkin Elmer) available at the Grain Quality Laboratory, Division of Genetics, IARI, New Delhi, as per the protocol described by Zarcinas et al. (1987) with some modifications suggested by Singh et al. (2005).

ANOVA was carried out by SAS-6.12. Path analysis was undertaken using the Windostat (Version 8.0, Indostat Services) and Statistical Package for Agricultural Researchers (SPAR1) software. Heterosis was calculated using MS-Excel.

Results

ANOVA revealed significant differences among the genotypes for all the 12 traits under study. The contributions of the component traits towards total divergence of the genotypes were studied. Days to 50% anthesis was found to contribute the maximum (44.27%); other important traits included plant height (19.63%), days to 50% silking (9.15), ear length (6.46%), kernel Fe concentration (5.49%), kernel Zn concentration (4.51%) and grain yield (4.02%).

Genotypic and phenotypic correlations were computed for all the traits under study (Table 1). Almost all the yield related traits under study showed significant positive correlation with grain yield, except for days to 50% anthesis and silking which showed significant negative correlation. No significant correlations were found for kernel Fe and Zn concentrations with most of the yield related traits. However, kernel Fe concentration was found to be negatively correlated with grain yield per plot (at $P = 0.05$), whereas kernel Zn concentration exhibited no significant correlation with grain yield. Kernel Zn concentration was negatively correlated to days to 50% anthesis and silking. No significant correlation was recorded between kernel Fe and Zn concentrations.

Genotypic and phenotypic path coefficient analyses for grain yield per plot was carried out from the same dataset as per method suggested by Wright (1921) and later modified by Dewey and Lu (1959) and presented in Fig. 1. The direct effect of kernel numbers per ear row was the

Table 1. Correlation coefficients among the 12 different traits in the 41 inbred lines

	YLD	EL	ED	KR	KPR	HKW	IRON	ZINC	PH	EH	MF	FF
YLD	-	0.75**	0.74**	0.68**	0.83**	0.51**	-0.25*	0.17	0.67**	0.60**	-0.64**	-0.64**
EL	0.76**	-	0.67**	0.56**	0.84**	0.39**	-0.08	-0.10	0.49**	0.37**	-0.41**	-0.41**
ED	0.79**	0.70**	-	0.85**	0.78**	0.51**	0.03	0.06	0.46**	0.43**	-0.60**	-0.55**
KR	0.72**	0.60**	0.89**	-	0.69**	0.47**	-0.02	0.05	0.25*	0.33**	-0.48**	-0.45**
KPR	0.88**	0.89**	0.85**	0.75**	-	0.39**	-0.01	0.05	0.55**	0.49**	-0.70**	-0.68**
HKW	0.54**	0.39**	0.53**	0.49**	0.41**	-	-0.05	-0.09	0.35**	0.37**	-0.37**	-0.40**
IRON	-0.26*	-0.09	0.05	0.00	-0.02	-0.05	-	-0.05	-0.17	-0.12	0.01	-0.01
ZINC	0.18	-0.10	0.06	0.04	0.05	-0.09	-0.05	-	0.89	0.18	-0.27*	-0.24*
PH	0.68**	0.50**	0.49**	0.25*	0.58**	0.37**	-0.18	0.14	-	0.86**	-0.52**	-0.54**
EH	0.61**	0.39**	0.46**	0.33**	0.52**	0.40**	-0.12	0.19	0.87**	-	-0.48**	-0.52**
MF	-0.65**	-0.42**	-0.65**	0.52**	-0.74**	-0.41**	0.01	-0.27*	-0.52**	-0.49**	-	0.99**
FF	-0.64**	-0.41**	-0.62**	0.48**	-0.73**	-0.43**	-0.01	-0.25*	-0.54**	-0.53**	0.99**	-

Above Diagonal: Phenotypic correlation coefficient; Below Diagonal: Genotypic correlation coefficient;

*Significant at P = 0.05; **Significant at P = 0.01; YLD: Yield (kg) per plot; EL: Ear length; ED: Ear diameter; KR: No. of kernel rows per ear; KPR: Kernels per ear row; HKW: Hundred kernel weight; IRON: Kernel iron concentration (mg/kg); ZINC: Kernel zinc concentration (mg/kg);

PH: Plant height; EH: Ear height; MF: Days to 50% anthesis; FF: Days to 50% silking

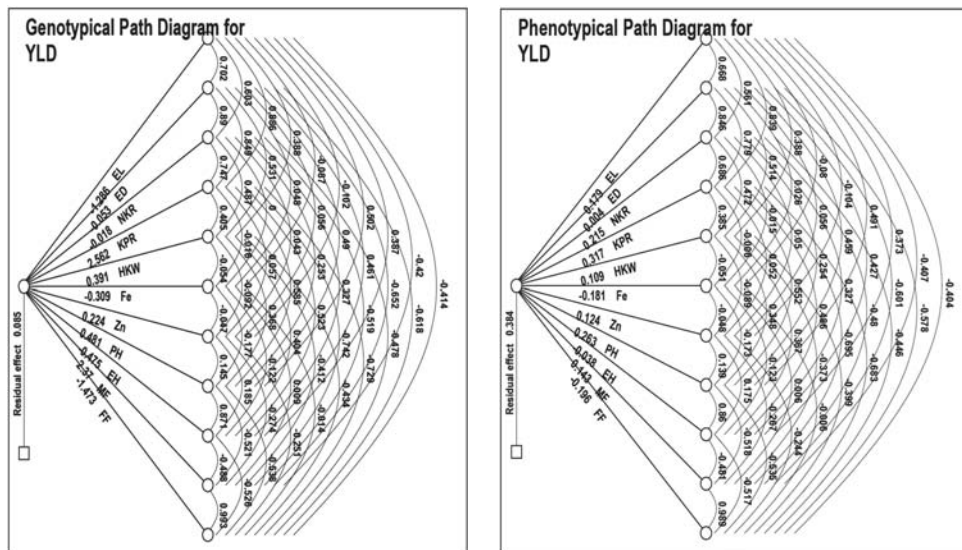


Figure 1. Genotypic and phenotypic path diagrams for grain yield among 41 maize lines

highest followed by plant height in case of phenotypic path. For genotypic path, direct effect was the highest for days to 50% anthesis followed by kernels per ear row. Residual effects were 0.09 and 0.38, respectively, for genotypic and phenotypic path. Kernel Fe and Zn concentrations did not show any significant direct or indirect effects on grain yield.

Significant differences for grain yield and kernel Fe and Zn concentrations were observed among the genotypes. The range for grain yield were found to be 0.91-2.07 kg/plot (mean = 1.36 kg/plot), while the kernel Fe and Zn concentrations varied from 10.11-26.66 mg/kg (mean = 20.46 mg/kg) and 21.27-34.74 mg/kg (mean = 26.59 mg/kg), respectively, among the

hybrid combinations. Among the parental lines, the grain yield ranged from 0.26-0.95 kg/plot (mean = 0.52 kg/plot), while the ranges for kernel Fe and Zn were found to be 12.78-33.52 mg/kg (mean = 25.54 mg/kg) and 24.34-49.67 mg/kg (mean = 26.59 mg/kg), respectively.

Although significant mid-parent heterosis and heterobeltiosis values were obtained for all the experimental hybrids for grain yield, only one hybrid combination (CM139 × BAJIM-06-12) displayed significant positive standard heterosis over both the checks (Tables 2 and 3). CM140 × V334 was found to be at par with BIO-9681 and Parkash, in terms of yield potential. However, both these hybrid combinations showed significant negative mid-parent heterosis and heterobeltiosis for kernel Fe and Zn concentrations. Most of the hybrids displayed negative mid-parent heterosis and heterobeltiosis for kernel Fe concentration, and not even a single hybrid recorded significant positive mid-parent

heterosis and heterobeltiosis for kernel Fe concentration. Similarly, all the hybrid combinations displayed negative mid-parent heterosis and heterobeltiosis for kernel Zn concentration. CM129 × BAJIM-06-02 displayed higher kernel Zn concentration (34.74 mg/kg) but was found to be low yielding (1.16 kg/plot). For kernel Fe concentration, no superior hybrid combination could be identified. Micronutrient concentrations of the commercial checks were also found to be quite low.

Discussion

Kernel Fe and Zn concentrations made significant contribution towards the genetic divergence of the lines, indicating the presence of considerable variability for these traits in the inbred lines. Presence of such genetic variation for the micronutrient traits, coupled with grain yield and its attributes, is highly encouraging as this provides a possibility to breed high yielding

Table 2. Evaluation of mid-parent heterosis and heterobeltiosis for yield, kernel iron and zinc concentrations in experimental hybrids

Experimental hybrids	Mid-parent Heterosis			Heterobeltiosis		
	YLD	Fe	Zn	YLD	Fe	Zn
BAJIM-06-19 × V334	387.88**	-20.85*	-34.15**	302.50**	-29.58**	-38.04**
CM128 × BAJIM-06-02	113.04**	5.00	-29.10**	34.25**	3.35	-42.65**
CM128 × CM145	194.12**	33.20*	-4.51	171.74**	6.78	-15.34*
CM129 × BAJIM-06-02	69.34**	11.49	-7.35	58.90**	-17.09	-11.85*
CM129 × CM128	70.91**	-63.53**	-17.66**	46.88**	-67.04**	-30.66**
CM139 × BAJIM-06-12	345.16**	-38.86**	-20.30**	250.85**	-51.03**	-30.30**
CM139 × V334	372.97**	-11.64	-6.62	337.50**	-13.87	-15.59*
CM140 × V334	313.36**	-37.28**	-14.97*	291.11**	-38.88**	-15.78*
CM145 × BAJIM-06-02	103.57**	5.37	-21.03**	56.16**	-14.50	-29.69**
CM145 × V334	201.27**	-17.35	-8.47	197.50**	-37.09**	-10.23
CM145 × V340	216.28**	11.50	-28.45**	189.36**	3.41	-41.55**
CM152 × V334	105.93**	-34.84**	-22.41**	46.32**	-39.59**	-28.79**
V334 × CM128	204.65**	-18.40	-6.65	184.78**	-23.89*	-15.79*
V334 × CM129	155.77**	-10.08	-16.48**	107.81**	-13.07	-22.71**
V340 × CM128	123.26**	1.65	-19.15**	104.26**	-22.96	-39.76**
V340 × CM129	63.96**	-8.26	-39.57**	42.19**	-35.02**	-48.14**

*Significant at P = 0.05; ** Significant at P = 0.01;

YLD: Grain yield (kg) per plot; Fe: Kernel iron content (mg/kg); Zn: Kernel zinc content (mg/kg)

Table 3. Evaluation of standard heterosis for grain yield, kernel iron and zinc concentrations in experimental hybrids

Experimental hybrids	Standard Heterosis (BIO 9681)			Standard Heterosis (Prakash)		
	YLD	Fe	Zn	YLD	Fe	Zn
BAJIM-06-19 × V334	-8.52	-22.07	-27.68**	-4.17	41.87*	-15.60
CM128 × BAJIM-06-02	-44.32**	-1.01	-23.16**	-41.67**	80.23**	-10.32
CM128 × CM145	-28.98**	2.28	-9.38	-25.60**	86.21**	5.75
CM129 × BAJIM-06-02	-34.09**	-1.70	18.12*	-30.95**	78.96**	37.86**
CM129 × CM128	-46.59**	-60.92**	-16.12*	-44.05**	-28.85	-2.10
CM139 × BAJIM-06-12	17.61**	-39.51**	-22.65**	23.21**	10.13	-9.72
CM139 × V334	-0.57	-4.68	-13.12	4.17	73.54**	1.39
CM140 × V334	0.00	-28.72*	-11.63	4.76	29.77	3.13
CM145 × BAJIM-06-02	-35.23**	-20.68	-4.83	-32.14**	44.41*	11.07
CM145 × V334	-32.39**	-30.38*	-3.91	-29.17**	26.74	12.14
CM145 × V340	-22.73**	-40.24**	-1.29	-19.05**	8.80	15.20
CM152 × V334	-21.02**	-21.72	-12.27	-17.26**	42.51*	2.38
V334 × CM128	-25.57**	-15.77	-13.33	-22.02**	53.34**	1.15
V334 × CM129	-24.43**	3.05	-6.49	-20.83**	87.61**	9.13
V340 × CM128	-45.45**	-26.21*	1.73	-42.86**	34.34	18.73
V340 × CM129	-48.30**	-22.96*	-12.41	-45.83**	40.25	2.22

*Significant at P = 0.05; ** Significant at P = 0.01;

YLD: Grain yield (kg) per plot; Fe: Kernel iron content (mg/kg); Zn: Kernel zinc content (mg/kg)

maize genotypes enriched with kernel micronutrients.

The study of correlations among grain yield and its component traits, besides kernel micronutrient traits, shall be useful to develop selection criteria to breed high yielding maize genotypes enriched with kernel micronutrient. The present study revealed significant negative correlation between kernel Fe concentration and grain yield; however, no significant correlation of kernel Zn concentration with grain yield was observed. Long et al. (2004) also reported significant negative correlation of grain yield with kernel Fe concentration and no interrelation with kernel Zn concentration, but in a diallel hybrid population. Significant negative correlation of kernel Zn concentration with days to 50% anthesis and silking was recorded. Interestingly, these two traits also displayed negative correlations with grain yield, indicating the possibility of developing high yielding early maturing genotypes with high kernel Zn density. No significant

correlation between Kernel Fe and Zn concentrations was observed.

Genotypic and phenotypic path analysis for grain yield per plot indicated major direct effect of kernels per ear row on grain yield. However, kernel Fe and Zn concentrations did not show any significant direct or indirect effect on grain yield, indicating that kernel Fe and Zn contents were not contributing towards total grain yield. This is also not unexpected as the micronutrients contributes very minor fraction of the grains and deposited at the final stage of plant development (Pfeiffer and McClafferty, 2007). However, this does not undermine the role of micronutrients in plant biology, as they play a major role throughout the life cycle and physiology of crop plants and contribute greatly for their survival and fitness, and ultimately per se performance.

In the study of experimental hybrids, no significant positive heterobeltiosis or mid-parent heterosis was observed in case of both kernel Fe

and Zn concentrations; in fact, most of the experimental hybrids displayed negative heterosis for these traits. The two highest yielding experimental hybrids displayed significant negative mid-parent heterosis and heterobeltiosis for kernel Fe and Zn concentrations. This could be attributed to the 'dilution effect' of seed size and aleurone: endosperm: embryo ratio on the micronutrients in the kernels, particularly manifested in the hybrids as compared to inbreds (Pfeiffer and McClafferty, 2007). The only experimental hybrid (CM129 × BAJIM-06-02) which displayed higher kernel Zn concentration (34.74 mg/kg) was found to be low-yielding and displayed significantly lower 100-kernel weight (20.40g) as compared to the means of all the hybrids studied. Dilution effects of grain yield on kernel Fe concentration in maize hybrids was earlier reported by Chen et al. (2007) and Long et al. (2004). This may prove to be an important constraint in breeding high yielding maize hybrids enriched for kernel Fe and Zn. However, no significant negative correlation was observed between kernel micronutrient concentrations and grain yield in the present study as well as other earlier studies, indicating that the constraint imposed by the 'dilution effect' can be overcome in many of the maize hybrids.

The study led to the identification of one promising hybrid CM139 × BAJIM-06-12 which displayed significantly higher economic/standard heterosis (17.61% over BIO-9681; 23.21% over Parkash) for grain yield. Another potential hybrid identified was CM140 × V334, the yield of which was at par with the commercial checks. This hybrid also showed prolificacy similar to the hybrid 'Parkash' (two ears per plant on an average), indicating its potential to be used as baby corn hybrid. Interestingly, both these experimental hybrids were having one of the parents of Parkash (CM139 and CM140). This indicates the high GCA of these two inbreds along with the high SCA already displayed through the commercial hybrid developed from them. The high genetic and molecular diversity of the parental lines of 'Parkash' (CM139 and CM140) has been reported by several workers (Pushpavalli et al., 2002; Mohammadi et al., 2008).

Overall, the present study revealed high genetic variability among the inbred lines for all the traits studied. Analysis of interrelations among various traits indicated the possibility to develop early maturing high yielding genotypes with enriched kernel Zn concentration. The study also led to the identification of two promising experimental hybrids for grain yield and related traits, although heterosis for the kernel micronutrient traits was not that encouraging in this set of germplasm.

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