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Genetic variability and stability for kernel iron and zinc concentration in maize (*Zea mays* L.) genotypes

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Abstract

Evaluation of kernel iron (Fe) and zinc (Zn) of 67 diverse maize genotypes grown during 2006-08 indicated significant variation for both the micronutrients. Kernel Fe concentration during 2006 varied from 20.38-43.79 mg/kg, whereas the same ranged from 23.23-54.29 mg/kg and 29.22-49.24 mg/kg, during 2007 and 2008, respectively. Kernel Zn varied from 15.06-29.88 mg/kg, 7.01-22.01 mg/kg and 13.64-26.54 mg/kg, during 2006, 2007 and 2008, respectively. No correlation was observed between kernel Fe and Zn concentration in the selected set of maize genotypes. For Fe concentration, CM140 (43.79 mg/kg) was found to be the most promising genotype during 2006, with HP-3 (54.29 mg/kg) during 2007 and CM212 (49.24 mg/kg) during 2008 as the best genotype. In case of kernel Zn, BAJIM-06-6 (29.88 mg/kg), V336 (22.01 mg/kg) and BAJIM-06-10 (26.45 mg/kg) were identified to be the best genotype in 2006, 2007 and 2008, respectively. The study revealed significant genotypes x environment interaction for both kernel Fe and Zn concentration, of which kernel Fe was found to be affected more by the change of environmental conditions, while it was of less extent for kernel Zn. Taking into consideration of stability parameters V336, VQL5, CM139, VQL1, CM129, and V340 were observed to be stable and promising genotypes for kernel Fe concentration, while in case of kernel Zn, V336, BAJIM-06-10, V340, BAJIM-06-7, CM129, and VQL1 were identified as the stable genotypes.

Key words: Maize kernel, iron, zinc, variability, environment, stability

Introduction

Micronutrient malnutrition has emerged as one of the major problems afflicting more than half of the world's population, especially women and preschool children in resource poor countries [1]. Among the various mineral elements, iron (Fe) and zinc (Zn) are the most common micronutrients that have been found deficient predominantly in cereal-based human diet [2, 3]. Fe related deficiencies affect cognitive development, growth, reproductive performance and work productivity, while deficiency in Zn leads to depression and psychosis, impaired growth and development besides affecting immune system [4-6]. Enrichment of micronutrients through breeding approaches holds significant promise to eradicate the problem of micronutrient deficiency due to its cost-effectiveness and sustainability [2, 3, 7, 8]. Biofortified cultivars offer scope for enhanced household income, nutritional security and overall livelihoods [6].

Maize is an important food and feed crop. Together with rice and wheat, maize provides at least 30% of the food calories to more than 4.5 billion people in 94 developing countries [9]. In India, approximately 25% of maize produce is used for human consumption [10]. Studying the genetic variability for kernel Fe and Zn concentration in the available maize germplasm and their potential to be utilized in breeding programmes is thus a priority. Research efforts with respect to understanding the variability of kernel micronutrients especially Fe and Zn in maize have been undertaken so far only in few countries under an International Collaborative Programme (HarvestPlus) for biofortification of selected staple food crops [7, 11-13]. In India as well, very few reports on variability of kernel Fe and Zn in maize are available [14]. The present investigation thus was undertaken to study the genetic

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variability and stability of kernel Fe and Zn concentration among a selected set of Indian as well as HarvestPlus-derived maize inbred lines, and to identify promising genotypes for utilization in the breeding programme with special reference to hilly states of India.

Materials and methods

A set of 67 maize entries, including 20 inbreds developed by the CSK-Himachal Pradesh Krishi Viswavidyalaya (CSK-HPKV, HAREC, Bajaura, India); 12 elite lines developed under the All-India Coordinated Maize Improvement Programme; 11 inbreds from Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS, Almora, India); 10 inbreds from the HarvestPlus Programme (CIMMYT-HarvestPlus, Mexico), 2 inbreds developed by CIMMYT, Mexico, besides 12 selected maize landrace accessions from India (Indian Maize Landraces/Locals; IMLs), were analyzed for kernel Fe and Zn concentration at the Hawalbagh Experimental Farm, VPKAS, Almora during 2006-08 (*kharif* season). Pedigree detail of these genotypes has been presented in Table 1. 40 diverse inbred lines were evaluated during 2006, while 60 and 24 maize genotypes were analyzed during 2007 and 2008, respectively. For maintenance of genotypes in the breeding programme, inbreds were selfed, while landrace accessions were maintained through bulk-sibbing.

The genotypes were planted in a randomized complete block design (RCBD) with two replications per entry and one row (3 m length) per replication in each of the three experiments spanning 2006-08. The plant-to-plant spacing of 20 cm and row-to-row spacing of 60 cm were maintained. Standard agronomic practices were followed for raising and maintenance of the plants. The soil status of the experimental block and the major meteorological parameters recorded during the experimental seasons (2006-2008) are presented in Table 2. Ears with the husk were hand harvested and dried under the clean shade to lower post harvest grain moisture concentration to 14%. Representative grain samples were drawn in triplicate by quartering method and the individual samples were ground into fine powder using iron free Cyclotech Sample Mill. Biochemical analysis for kernel Fe and Zn concentration was carried out by digestion with 9:4 diacid mixture (HNO_3: $HClO_4$) followed by observation by the atomic absorption spectrometry (AAS) method, using protocol as described by Zarcinas *et al.* [15] with some modifications suggested by Singh *et al.* [16]. The individual datasets were analyzed for analysis of variance (ANOVA) and comparison of means using PROC GLM of SAS Version 9.1 (SAS Institute, 2005). The data set of common 17 genotypes evaluated during 2006-08, was analyzed for stability analysis using Windostat Version 8.0.

Results and discussion

Analysis of variance indicated significant variation for both kernel Fe and Zn concentration in all the three years (table not presented), suggesting the availability of wider genetic variation. Presence of similar variation have been reported in earlier studies [7, 11-14, 17], indicating that the genetic behavior of the genes influencing the micronutrient concentration gives enough opportunity for the micronutrient enhancement in maize by following conventional plant breeding methods. The presence of genetic variation for kernel Fe and Zn concentration in other major cereals have also been reported earlier [18].

The kernel Fe concentration during 2006 varied from 20.38-43.79 mg/kg, while it ranged from 23.23-54.29 mg/kg and 29.22-49.24 mg/kg, during 2007 and 2008, respectively. In case of kernel Zn, all the three years experienced much lower value varying from 15.06 - 29.88 mg/kg, 7.01-22.01 mg/kg and 13.64-26.54 mg/kg, during 2006, 2007 and 2008, respectively. On the other hand, Banziger and Long [7] reported 9.6-63.2 mg/kg kernel Fe, whereas Zn ranged from 12.9-57.6 mg/kg, among large set of maize genotypes grown in different places of Mexico and Zimbabwe. Prasanna *et al.* [14] reported that kernel Fe varied from 11.28-60.11 mg/kg, while kernel Zn ranged from 15.14-52.95 mg/kg, in a set of maize genotypes across three years. On the contrary, much narrower range (16.8-24.4 mg/kg for Fe and 16.5-24.6 mg/kg for Zn) was reported by Oikeh *et al*. [11]. Chen *et al.* [19] reported kernel Fe concentration as high as 68.1 mg/kg among the inbred lines of maize.

The mean for kernel Fe across all genotypes was 31.27 mg/kg during 2006, while the same was 33.51 mg/kg and 36.63 mg/kg during 2007 and 2008, respectively. On the other hand, 2006 recorded 21.72 mg/kg of Zn in the kernel, while the same was 17.19 mg/kg and 20.15 mg/kg in 2007 and 2008, respectively. Among the 40 genotypes grown during 2006, CM140 was found to be most promising genotype with 43.79 mg/kg of kernel Fe concentration (Table 3). Other promising genotypes with $\geq$ 40 mg/kg, include CM145 (42.38 mg/kg), HP-4 (41.82 mg/kg), HP-6 (39.34 mg/kg) and V336 (39.17 mg/kg). During 2007, seven genotypes were identified as the promising genotypes with HP-3 (54.29 mg/kg), HP-4 (53.45 mg/kg) and

Table 1. Pedigree details of 67 maize genotypes used in the present study

S.No.	Genotypes	Pedigree/ Source
HAREC, Bajaura Centre, CSK-HPKV		
1	BAJIM-06-1	Comp.EC-155 -196
2	BAJIM-06-2	Comp.EC-96-62
3	BAJIM-06-3	Comp.EC-220
4	BAJIM-06-4	EC-HS260-137
5	BAJIM-06-5	HEYPool-260-137
6	BAJIM-06-6	HEYPool-204
7	BAJIM-06-7	HAREC 95 Pool-98
8	BAJIM-06-8	HAREC 95 Pool-39
9	BAJIM-06-9	HEY Pool 95-054
10	BAJIM-06-10	HAREC 95 Pool-99
11	BAJIM-06-11	HAREC 95
12	BAJIM-06-12	Pool 98-(6618)
13	BAJIM-06-13	Pool 98-(6615)
14	BAJIM-06-14	HAREC K Pool-703
15	BAJIM-06-15	HAREC K Pool-719
16	BAJIM-06-16	BAJ Pool-95-056
17	BAJIM-06-17	HAREC 95 Pool-98-4
18	BAJIM-06-18	EC-HS-95-97
19	BAJIM-06-19	HAREC K Pool-729
20	BAJIM-06-20	HAREC 95 Pool-22-3
AICMIP		
21	CM127	GCL 32 x Almora local
22	CM128	Anantnag local x WF9 x M14
23	CM129	US 23 x KT 41
24	CM138	IPA 21-10-f-#-f-15
25	CM139	(Tarun x MS 1)-Y63
26	CM140	J 617-61
27	CM141	Pop 62
28	CM145	Pop 31 C4 HS bulk (Alm.)-70
29	CM152	Pop 31 C4 HS bulk (Alm.)
30	CM153	Intercrosses inbreds from Pop 31 C4 HS bulk (V198, V270 and V273)
31	CM212	USA/Acc No. 2132 (Alm.)
32	CM213	IPA 34-62-f-1-1-1-1
CIMMYT, Mexico		
33	CML352	BPVCBA90185-1-1-3-2TL-1-B-##
34	CML356	P800C5F37-1-2TL-1HT-1-10TL-B-#-3
HarvestPlus-CIMMYT		
35	HP-1	B.I.Z.T.V.C. 1-3-1-1-1-1-B-B-B-B
36	HP-2	B.I.Z.T.V.C. 4-2-1-3-1-2-B-B-B-B
37	HP-3	(G9A C6 H 3-1-3-1-1-2P-3P-1P-2-1x G9A C6 H3-1-3-1-1-2P-3P-3P-2-1) 37-1-1-3-1-1-B-B-B
38	HP-4	(G9AC6 H3-1-3-1-6-1P-1-1-1P-1xG9AC 6R.L. 6-1P-1P-1P-2P-2P)65-2-2-1-2-1-B-B-B
39	HP-6	(CML-239 x GWIC) -1-7TL-1-1-1
40	HP-10	[(CML241-BBB x G16 C19 C1)xG16 C19 C1-1-3-1-BBB-49]-4-3-2-3-2-B-B-B-B
41	HP-11	P903 C0 H364-1-8TL-3-2-1-1-B-B-B-B-B-B-B
42	HP-12	P87 C5 F95-24-1-1-2-1-B-B-B-B-B-1-B-B-B-B
43	HP-13	HarvestPlus germplasm
44	HP-35-8	Florida A plus Syn-FS6-1-B
Indian maize land race collections		
45	IML119	Collection from Haryana
46	IML185	Collection from Himachal Pradesh
47	IML205	Collection from Nagaland
48	IML273	Collection from Sikkim
49	IML288	Collection from Bihar
50	IML289	Collection from Bihar
51	IML312	Collection from Sikkim
52	IML331	Collection from Bihar
53	IML390	Collection from Sikkim
54	IML403	Collection from Orissa
55	IML434	Collection from Gujarat
56	IML467	Collection from Tamil Nadu
VPKAS, Almora		
57	V25	Riveirao Preto 8233 (Alm)
58	V334	TZI-9
59.	V336	CML145, P63.COH-C-181 (CIMMYT)
60.	V340	CM128 x CM129
61.	V341	Mexico Acc. No. 3136
62.	V348	Pop 31
63.	V351	Shakti (So) HE 25
64.	V356	SSF53281⊗-2-14-1-3-4- #-#-B-#-#-B
65.	VQL1	QPM version of CM212 (CML180 as donor)
66.	VQL2	QPM version of CM145 (CML170 as donor)
67.	VQL5	QPM version of CM145 (CML170 as donor)

BAJIM: Bajaura Inbred Maize; CM: Coordinated Maize [from All-India Coordinated Maize Improvement Project AICMIP)]; CML: CIMMYT Maize Line; HP: HarvetPlus-CIMMYT inbred; IML: Indian Maize Landrace/Local;
V: Vivek Inbred; VQL: Vivek QPM Line; CSK-HPKV: Chaudhary Sravan Kumar Himachal Pradesh Krishi Viswavidyalay; VPKAS; Vivekananda Parvatiya Krishi Anusandhan Sansthan

Table 2. Soil profile and meteorological parameters during the experimental period

Experiment	pH*	Zn* (mg/kg)	Fe* (mg/kg)	Temperature (°C) Avg. Max.	Avg. Min.	Mean	Rainfall (mm)	RH (%)	SH (h)	AWS (Km/h)
Kharif-2006	6.45 (6.65)	8.367 (7.762)	55.963 (33.353)	29.2	17.8	23.5	548.5	76.8	6.18	2.5
Kharif-2007	6.30 (6.50)	8.190 (7.897)	56.756 (33.044)	29.0	18.0	23.5	613.5	78.2	5.93	2.5
Kharif-2008	6.40 (6.65)	8.050 (7.753)	56.437 (32.682)	28.1	17.5	22.8	748.5	79.5	5.05	2.1

*Data without parenthesis from 0-15cm soil depth; data in parenthesis from 15-30cm depth; RH: Relative humidity; EVP: Evaporation; SH: Sunshine hour, AWS: Average wind speed

BAJIM-06-1 (50.03 mg/kg) having ≥ 50 mg/kg of Fe (Table 3). Besides, CM128 (42.01 mg/kg), CM141 (41.95 mg/kg), BAJIM-06-11 (40.03 mg/kg) and IML185 (39.34 mg/kg) were also found to be promising with nearly 40 mg/kg of Fe. In case of 2008, CM212 (49.24 mg/kg), BAJIM-06-3 (46.24 mg/kg), BAJIM-06-1 (45.50 mg/kg), V334 (44.45 mg/kg) and HP-2 (41.53 mg/kg) were observed to be the most promising genotypes for kernel Fe concentration (Table 3).

In case of kernel Zn concentration during 2006, only eight genotypes could be identified with ≥ 25 mg/kg, with BAJIM-06-6 (29.88 mg/kg) being the best genotype (Table 3). Other promising genotype includes V336 (28.40 mg/kg), V351 (27.17 mg/kg), BAJIM-06-7 (26.13 mg/kg), CM140 (25.87 mg/kg), BAJIM-06-20 (25.78 mg/kg), V25 (25.59 mg/kg) and V340 (25.35 mg/kg). In the year 2007, none of the genotypes having ≥ 25 mg/kg could be observed. However, V336 with 22.01mg/kg was found to be the best genotype during 2007. In case of 2008, BAJIM-06-10 (26.45 mg/kg) was found to be only genotype crossing a level of ≥ 25 mg/kg concentration (Table 3).

Taking into account both the kernel Fe and Zn concentration, CM140 (Fe: 43.79 mg/kg, Zn: 25.87 mg/kg), HP-2 (Fe: 41.82 mg/kg, Zn: 23.24 mg/kg) and V336 (Fe: 39.17 mg/kg, Zn: 28.40 mg/kg) were the most promising genotypes during 2006. In case of 2007, V356 (Fe: 38.01 mg/kg, Zn: 21.99 mg/kg), IML434 (Fe: 36.10 mg/kg, Zn: 21.30 mg/kg) and IML288 (Fe: 35.46 mg/kg, Zn: 20.57 mg/kg) were the best genotypes with moderate level of both Fe and Zn concentration. During 2008, although few genotypes showed high kernel Fe concentration, the level of Zn concentration was moderate to low. Considering, both the traits, CM212 (Fe: 49.24 mg/kg, Zn: 20.76 mg/kg), BAJIM-06-3 (Fe: 46.24 mg/kg, Zn: 21.29 mg/kg) and BAJIM-06-1 (Fe:

Table 3. Top five performing genotypes for kernel Fe and Zn concentration during 2006-08

Trait	S. No.	*Kharif*-2006 Genotype	(mg/kg)	*Kharif*-2007 Genotype	(mg/kg)	*Kharif*-2008 Genotype	(mg/kg)
Fe	1	CM140	43.79	HP-3	54.29	CM 212	49.24
	2	CM145	42.38	HP-4	53.45	BAJIM-06-3	46.24
	3	HP-4	41.82	BAJIM-06-1	50.03	BAJIM-06-1	45.50
	4	HP-6	39.34	CM128	42.01	V334	44.45
	5	V336	39.17	CM141	41.95	HP-2	41.53
Zn	1	BAJIM-06-6	29.88	V336	22.01	BAJIM-06-10	26.45
	2	V336	28.40	V356	21.99	V348	23.89
	3	V351	27.17	V340	21.62	V336	23.88
	4	BAJIM-06-7	26.13	IML403	21.50	CM129	23.69
	5	CM140	25.87	CML352	21.47	BAJIM-06-1	22.22

45.50 mg/kg, Zn: 22.22 mg/kg) were identified to be the most promising genotypes (Table not presented).

The present study revealed no significant correlation between kernel Fe and Zn concentration among the genotypes grown during 2006-08. This suggests that different sets of genes/QTLs could be involved in accumulation of kernel Fe and Zn, and genetic improvement could be undertaken independent of each other [14]. On the contrary, significant and positive association between the kernel Fe and Zn concentration was observed by various researchers [11, 13, 17, 20]. This contrast could be attributed to the inherent nature of the specific type of germplasm used in the study and may not be a general phenomenon.

The stability of a genotype for a target trait is important particularly when a set of promising genotypes are to be utilized as donor or directly used as parent in the breeding programme. Menkir [13] reported no significant genotype x location interaction for kernel Fe (except one out of eight trials) and Zn concentration in maize, although significant G x E were reported for other kernel micronutrients such as Mn, Ca, Mg, K and S. Keeping in view, stability analysis has been carried out among 17 common genotypes those were grown during 2006-08. Interestingly, the study revealed significant effects of genotype x environment interaction (G x E) for both kernel Fe and Zn concentration, suggesting genotypes in general behaved differently under three growing seasons (table not presented). The sum of square for G x E for kernel Fe concentration was 38.62% of the total sum of square, while for the kernel Zn concentration, it was 27.67%. This trend also showed that kernel Fe is more likely to change due to environmental fluctuation than kernel Zn concentration. Significant effect of genotype x year interactions for both kernel Fe and Zn concentration in maize has been reported by Prasanna *et al.* [14] while experimenting with a set of maize genotypes.

Since the G x E interaction was found to have significant effects on kernel Fe and Zn concentration, AMMI (Additive Main effect and Multiplicative Interaction) stability model was applied for further partitioning of various variance components [21]. However the AMMI analyses revealed that present data set was not of multiplicative type. Interestingly, Oikeh *et al.* [12] reported the presence of multiplicative type of G x E interaction for both the target traits in maize. The present data set was further analyzed using model as suggested by Eberhart and Russell [22]. The analyses revealed that, variance due to environment (linear) and pooled deviation were found to be significant for both the kernel micronutrient traits, while genotype x environment (linear) was non-significant for both the traits (Table 4).The sum of square for pooled deviation for kernel Fe was found to be 32.38% of the total sum of square, while it was 14.92% for kernel Zn concentration. This further suggested that kernel Fe was more affected by change of environmental conditions, while it was of much less extent for kernel Zn concentration. The environmental indices for kernel Fe concentrations were –1.02, –1.29 and 2.30 during *Kharif* 2006, 2007 and 2008, respectively. In case of kernel Zn concentration, the environmental index during *Kharif* 2006 was 2.69, while the indices for *Kharif* 2007 and 2008 were found to be –2.99 and 0.31, respectively. This suggested that *Kharif* 2008 was the richest environment for the expression of kernel Fe concentration, while *Kharif* 2006 was identified as the

Table 4. Analysis of variance and variance components (Eberhart and Russell model)

Source of Variation	df	Kernel Fe		Kernel Zn	
		SS	MSS	SS	MSS
Replications within Env.	3	326.11	108.70*	106.24	35.41*
Genotypes	16	576.35	36.02	223.06	13.94
Env. + Gen. x Env.	34	848.46	24.95	569.31	16.74*
Env (linear)	1	136.39	136.39*	277.82	277.82**
Gen. x Env (linear)	16	250.57	15.66	173.26	10.82
Pooled deviation	17	461.49	27.14**	118.23	6.95*
Pooled Error	48	214.02	4.45	172.12	3.58
Total	50	1424.81	28.49	792.37	15.85

*Significance at P = 0.05; **Significance at P = 0.01; df: Degrees of freedom; SS: Sum of square; MSS: Mean sum of squares

Table 5. Mean performance of 17 genotypes in each environment for kernel Fe and Zn content (mg/kg) and mean estimates of stability parameters based on Eberhart and Russell model

S. No.	Genotypes	Kernel Fe						Kernel Zn					
		2006 (mg/kg)	2007 (mg/kg)	2008 (mg/kg)	Mean (mg/kg)	b_i	S^2_{di}	2006 (mg/kg)	2007 (mg/kg)	2008 (mg/kg)	Mean (mg/kg)	b_i	S^2_{di}
1	BAJIM-06-10	21.58	30.26	34.12	28.65	2.21	32.70 *	21.70	21.15	26.54	23.13	0.19	11.55
2	BAJIM-06-15	21.29	30.13	38.56	29.99	3.55	37.76 *	22.87	17.08	20.00	19.98	1.01	-5.33
3	BAJIM-06-20	28.01	28.15	32.35	29.50	1.23	-10.48	25.78	18.19	14.99	19.65	1.19	32.77*
4	BAJIM-06-6	27.95	33.33	35.70	32.33	1.36	6.02	29.88	13.52	19.83	21.08	2.81	1.29
5	BAJIM-06-7	25.93	31.12	35.43	30.83	1.90	5.80	26.13	19.46	20.90	22.16	1.13	-1.55
6	BAJIM-06-8	27.66	26.72	30.33	28.24	0.92	-10.35	16.87	17.11	19.91	17.96	0.01	0.25
7	CM128	31.31	42.01	34.11	35.81	0.92	44.23 *	18.92	15.41	20.15	18.16	0.67	-0.63
8	CM129	33.64	33.08	34.41	33.71	0.31	-10.47	21.70	19.03	23.70	21.47	0.53	0.97
9	CM139	37.93	34.48	31.45	34.62	1.31	-3.30	19.86	17.99	17.30	18.38	0.30	-3.37
10	CM140	43.79	23.23	33.33	33.45	0.30	199.95**	25.87	14.68	18.50	19.68	1.92	-0.70
11	CM145	42.38	33.07	37.51	37.65	0.10	32.70 *	20.09	19.40	18.43	19.31	0.10	-4.22
12	CM153	30.70	26.73	30.78	29.40	0.66	-3.36	21.46	7.01	20.26	16.24	2.63	10.14
13	CM212	36.10	33.46	49.24	39.60	4.21	-9.49	22.34	14.70	20.77	19.27	1.37	-3.70
14	V336	39.17	37.29	38.15	38.20	0.01	-8.83	28.40	22.01	23.88	24.76	1.09	-3.23
15	V340	33.13	29.42	34.41	32.32	0.97	-4.61	25.35	21.63	21.92	22.96	0.62	-3.15
16	VQL1	31.85	34.39	35.50	33.91	0.64	-6.88	23.27	18.34	21.27	20.96	0.87	-5.46
17	VQL5	34.14	35.03	37.69	35.62	0.88	-9.95	20.19	17.21	21.76	19.72	0.58	-0.21
	Mean	32.15	31.87	35.47	33.17	1.26	16.56	22.98	17.29	20.59	20.29	1.00	1.50
	SE	6.48	4.45	4.33	3.47	1.15	50.99	3.49	3.60	2.65	2.16	0.81	9.35

b_i: Regression coefficient; S^2_{di}: Deviation from regression; *: Significance at P = 0.05; **: Significance at P = 0.01

most favourable environment for the accumulation Zn concentration in the endosperm.

The genotype x environment interaction for kernel Fe and Zn are generally attributed to soil profile, which determines the accumulation of micronutrients in grain (Oikeh *et al.*, 2003). This logic is true when experiments are conducted under different locations with sufficiently different soil profile. However, in the present study, experiments were carried out at Hawalbagh Experimental Farm, VPKAS, Almora, under similar soil profile during 2006-08 (Table 2). Interestingly, *kharif* 2006 experienced 548.5 mm of total rainfall during the crop growth period, while it increased substantially during 2007 (613.5 mm) and 2008 (748.5 mm). It is important to note that kernel Fe reported highest mean during 2008, while 2006 experienced highest mean for kernel Zn (Table 2 & 5). Ferreira *et al.* [23] reported similar observation among 10 corn cultivars grown at Rolandia County, Parana State, Brazil during 2006 and 2007. Kernel iron concentration was significantly higher during 2007, a year that experienced higher rainfall than the preceding year (2006). Temporary water logging could have favoured reduction reactions thereby increasing available Fe to the plants during 2007 [23]. The same experiment also reported that Zn concentration in maize kernel was higher during 2006 which experienced comparatively less rainfall. The study emphasized significant effects of soil water availability on grain nutrient concentration. In fact, performance of a genotype is a function of genotypic constitution, its interaction with environment, and the possible involvement of a complex network of diverse factors related to soil dynamics and micro-climates [24-26]. Even minor changes in one factor in combination with other factors may also lead to significant variation in micronutrient traits. It is important to note that even micro-environmental variations, spatial and temporal variation, system variations caused by the differential management practices can have the significant effects on the accumulation of micronutrients [2].

In spite of genotype x environment interactions for kernel Fe and Zn concentration, it is possible to identify genotypes that show considerable stability in mineral concentration across environments and could be combined well with high yield [27]. Taking into consideration mean performance, regression coefficient and deviation from linearity, V336, VQL5, CM139, VQL1, CM129, and V340 were found to be stable and promising genotypes for kernel Fe concentration (Table 5). In case of kernel Zn, V336, BAJIM-06-10, V340, BAJIM-06-7, CM129, and VQL1 were identified as the stable genotypes. Considering both Fe and Zn concentration, V336, CM129, V340 and VQL1 were identified as stable and promising genotypes. The promising genotypes thus identified, could be utilized for the improvement of target traits in the breeding programme and further development of micronutrient rich cultivars.

The study thus revealed the presence of wide genetic variation for kernel Fe and Zn concentration in maize, suggesting the scope for genetic improvement of those traits. The genetic behaviour of the kernel Fe and Zn provided enough evidence that separate groups of genes control micronutrient concentration in these genotypes. Besides, it was also revealed that kernel Fe was more affected by environmental fluctuation than kernel Zn, which showed more stable nature across three years. Stable and promising inbreds identified in the study hold promise in maize biofortfication programme.

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