Combating micronutrient malnutrition: Identification of commercial sorghum cultivars with high grain iron and zinc

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Introduction

Sorghum (*Sorghum bicolor*) is the fifth most important cereal crop grown on 47 million ha in 104 countries in Africa, Asia, Oceania and the Americas. The United States, Nigeria, India, Mexico, Sudan, China and Argentina are the major sorghum producers globally (http://faostat.fao.org/site/567/default.aspx#ancor accessed on 14 September 2010). Sorghum, a heat and drought tolerant C_4 plant, is a widely consumed cereal staple in subtropical and semi-arid regions of Africa and Asia (Kresovich et al. 2005, Reddy et al. 2009). It is the second cheapest source of energy and micronutrients [after pearl millet (*Pennisetum glaucum*)]; and a vast majority of the population in Africa and central India depend on sorghum for their dietary energy and micronutrient requirement (Parthasarathy Rao et al. 2006). Limited studies indicated that mineral concentrations and bioavailability are limited in cooked sorghum grain (Kayode et al. 2006); but this needs to be further validated.

Micronutrient malnutrition, primarily the result of diets poor in bio-available vitamins and minerals, causes blindness and anemia (even death) in more than half of the world's population, especially among women of reproductive age, pregnant and lactating women and pre-school children (Underwood 2000, Sharma 2003, Welch and Graham 2004) and efforts are being made to provide fortified foods to the vulnerable groups of the society. Biofortification, where possible, is the most cost-effective and sustainable solution for tackling micronutrient deficiencies as the intake of micronutrients is on a continuing basis with no additional costs to the consumer in the developing countries in arid tropics and subtropics. Biofortification of sorghum by increasing mineral micronutrients [especially iron (Fe) and zinc (Zn)] in the grains is of widespread interest (Pfeiffer and McClafferty 2007, Zhao 2008, Ashok Kumar et al. 2009).

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is working on sorghum biofortification for enhancing the grain Fe and Zn contents. Preliminary studies by Reddy et al. (2005) indicated limited variability for grain Fe and Zn contents in sorghum hybrid parents, advanced breeding lines and germplasm accessions. A field study conducted at ICRISAT farm in Patancheru, India to enhance the grain Fe and Zn under balanced nutrient application [nitrogen (N), phosphorus (P), potassium (K) along with sulfur (S), boron (B), Fe and Zn were applied to the soil] did not increase the grain Fe and Zn contents probably because the inherent availability of these nutrients in the soil was not limiting. Genetic enhancement is in progress to develop high Fe and Zn containing cultivars with desired agronomic background. While it is in progress, an attempt was made to assess the variability in the commercial sorghum cultivars that are currently being cultivated by the farmers in India. Identification of high grain Fe and Zn commercial cultivars would help in expanded dissemination of the cultivars to complement the on-going efforts for combating the micronutrient malnutrition.

Material and methods

In total, 20 commercial sorghum cultivars developed in India by the Indian NARS (national agricultural research system) in partnership with ICRISAT or NARS alone (17 hybrids contributed by seven private sector seed companies, one hybrid by the Marathwada Agricultural University, Parbhani and two varieties by the Regional Agricultural Research Station, Acharya NG Ranga Agricultural University, Palem) were evaluated along with two controls (CSH 16 and PVK 801) during postrainy season in 2008 and 2009 at the ICRISAT farm in Patancheru. The cultivars along with controls were evaluated in a randomized block design (RBD) with three replications under high fertility conditions (80N : 40P) on Vertisols at ICRISAT farm in Patancheru, located at an altitude of 545 m above mean sea level, latitude of 17.53° N and longitude of 78.27° E. Each cultivar was grown in four-row plots of 2 m length with 75 cm spacing between the rows. Irrigation (4–5) was applied as required during the cropping season. Utmost care was taken to raise a healthy crop and to get clean grain for lab analysis for grain Fe and Zn contents. Data were recorded for the agronomic traits, time to 50% flower (days), plant height (m), grain yield (t ha^{-1}) and grain size (g 100^{-1}), following the standard procedure. The panicles (4–5) were bagged with Kraft paper bags prior to flowering in each replication to avoid pollen contamination and to harvest pure seed for grain Fe and Zn analysis.

At maturity, the panicles were harvested and the grain was threshed carefully without any contact with metal containers to avoid contamination. The cleaned seeds were collected in cloth bags and used for micronutrient analysis in the Analytical Laboratory at ICRISAT, Patancheru. The grain Fe and Zn contents were determined in the ground grain samples by using the triacid digestion method (Sahrawat et al. 2002). The data on agronomic traits along with grain Fe (mg kg^{-1}) and Zn (mg kg^{-1}) were statistically analyzed using GENSTAT 9.1 to assess the significant differences among the cultivars for mean performance for grain Fe and Zn contents, agronomic traits and to estimate the correlations among traits.

Results and discussion

ANOVA indicated that there were significant differences (P <0.01) among the cultivars for all the traits studied (Table 1). Mean squares for years differed significantly for time to 50% flower, plant height, grain size, grain Fe and grain Zn contents and cultivar × year interactions were significant for grain yield, grain size, grain Fe and Zn contents.

The mean performance of the cultivars over two years (2008 and 2009) is presented in Table 2. The performance of cultivars in 2008 is presented in Table 3 and in 2009 is presented in Table 4. Based on the mean performance over two years, the grain Fe content among the genotypes varied from 29.8 to 44.2 mg kg^{-1} and grain Zn content from 22.2 to 32.9 mg kg^{-1} (Table 2). Among the 18 hybrids tested, five hybrids showed >38.8 mg kg^{-1} grain Fe and >27.2 mg kg^{-1} grain Zn well above the trial means for grain Fe and Zn contents. The controls PVK 801 and CSH 16 had 42.6 and 41.2 mg kg^{-1} grain Fe and 30.4 and 27.9 mg kg^{-1} grain Zn, respectively. Four hybrids (NSH 703, GK 4035, Mahabeej 703 and NSH 702) were superior to the control CSH 16 for grain Fe content that ranged from 42.9 to 44.2 mg kg^{-1}, while six genotypes had grain Zn content ranging from 28.9 to 32.9 mg kg^{-1} and were superior to the control CSH 16 (Zn content 28 mg kg^{-1}). The hybrids GK 4035 and Mahabeej 703 showed higher Fe contents in both the years (Tables 3 and 4) indicating their stability for this trait. Among the varieties, PVK 801 showed higher grain Fe (42.6 mg kg^{-1}) and Zn contents (30.4 mg kg^{-1}) than the other varieties. PVK 801 is a white-grained, high-yielding, grain mold resistant variety and also has high grain Fe and Zn contents (Ashok Kumar et al. 2009). The range for Fe and Zn contents in the commercial cultivars in the present study was numerically higher than that of hybrid seed parents or advanced breeding lines assessed earlier (Reddy et al. 2005); but this comparison may have limited value considering significant genotype × environment interactions. In the cultivars evaluated, time to flower ranged from 66 to 79 days, plant height varied from 1.5 to 2.3 m, grain yield ranged from 1.3 to 4.9 t ha^{-1} and grain size ranged from 2.36 to 3.74 g 100^{-1}. All these cultivars are from white grain background and are preferred for food use in India; and most of the cultivars are in the early to medium maturity group.

Highly significant positive correlation between grain Fe and Zn content (r=0.853; P <0.01) was observed (Table 5), indicating that either genetic factors for Fe and Zn contents are linked, or physiological mechanisms were interconnected for Fe and Zn uptake/translocation in the grains. These results point to the potential of simultaneous genetic improvement for both the micronutrients. The weak association of grain Fe and Zn with the other traits studied – time to 50% flower, plant height, grain yield and grain size – indicates that there is no penalty for enhancing the grain Fe and Zn contents in

Table 1. Mean sum of squares (ANOVA) of the sorghum commercial cultivars evaluated for grain Fe and Zn contents and agronomic traits during postrainy season in 2008 and 2009 at ICRISAT, Patancheru, India[1].

Source of variation	df	Time to 50% flower (days)	Plan height (m)	Grain yield (t ha^{-1})	Grain size (g 100^{-1})	df	Fe (mg kg^{-1})	Zn (mg kg^{-1})
Replication	2	13.64	0.02	1.77	0.36	2	516.78	494.03
Genotype (G)	21	50.06**	0.13**	3.66**	0.67**	21	74.21**	1221.63**
Year (Y)	1	1624.01**	0.46**	0.045	20.09**	1	11632.52**	6224.83**
G × Y	21	9.63	0.01	2.76**	0.21**	21	37.24**	965.55**
Error	86	6.23	0.01	0.14	0.09	84 (2)	23.33	1029.36
Total	131					129 (2)		

1. ** = Significant at 1% level.

Table 2. Mean performance of commercial sorghum cultivars for grain Fe and Zn contents and agronomic traits at ICRISAT, Patancheru, India during postrainy season in 2008 and 2009.

Cultivar	Seed source	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Time to 50% flower (days)	Plant height (m)	Grain yield (t ha^{-1})	Grain size (g 100^{-1})
NSH 703	Nuziveedu Seeds Pvt Ltd, Hyderabad	44.2	32.2	74	1.6	3.1	3.5
GK 4035	GK Seeds, Hyderabad	44.2	32.9	70	1.6	2.2	3.7
Mahabeej 703	MSSCL, Akola	43.3	28.9	69	1.6	3.0	3.1
NSH 702	Nuziveedu Seeds Pvt Ltd, Hyderabad	42.9	32.2	77	1.6	3.5	3.0
8562	Bayer Bio Sc., Hyderabad	41.1	29.8	70	1.5	1.8	3.5
Mahabeej 704	MSSCL, Akola	39.5	26.3	66	1.6	3.7	3.4
KDSH 1179 (Sudama)	Krishidhan Seeds, Jalna	39.4	26.5	73	1.6	3.8	3.3
BSH 45	Biostadt, Aurangabad	38.6	26.6	72	1.5	4.0	3.5
Madhura-SS hyb	Nimbkar Seeds, Paltan	38.5	32.2	71	2.3	3.5	3.2
Mahabeej 7	MSSCL, Akola	38.5	25.8	70	1.6	4.1	3.4
GK 4009	GK Seeds, Hyderabad	38.2	26.7	73	1.6	3.6	3.3
Hi-jowar 52	Biostadt, Aurangabad	37.7	24.9	73	1.7	3.1	3.4
PSV 2	ARS, Palem	37.5	26.1	79	1.7	1.3	2.4
CSH 25 (Parbhani Sainath)	MAU, Parbhani	37.4	25.2	73	1.7	2.9	2.8
8340	Bayer Bio Sc., Hyderabad	36.8	24.6	72	1.6	3.3	3.6
KDSH 209	Krishidhan Seeds, Jalna	36.4	26.3	74	1.7	3.4	3.3
PSV 1	ARS, Palem	36.3	23.9	69	1.7	2.2	2.9
BSH 47	Biostadt, Aurangabad	34.7	22.8	71	1.7	3.0	3.6
GK 4044	GK Seeds, Hyderabad	32.7	22.2	73	1.5	3.1	2.8
8568	Bayer Bio Sc., Hyderabad	29.8	23.1	70	1.5	3.0	3.2
PVK 801 (control)		42.6	30.4	76	1.5	2.7	3.2
CSH 16 (control)		41.2	27.9	71	1.6	4.9	3.7
Mean		38.76	27.19	72	1.64	3.14	3.26
SE±		2.76	2.00	1.44	0.05	0.21	0.18
CD (5%)		7.84	5.68	4.05	0.14	0.60	0.50

Table 3. Performance of commercial sorghum cultivars for grain Fe and Zn contents and agronomic traits at ICRISAT, Patancheru, India during 2008 postrainy season.

Cultivar	Seed source	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Time to 50% flower (days)	Plant height (m)	Grain yield (t ha^{-1})	Grain size (g 100^{-1})
GK 4035	GK Seeds, Hyderabad	57.2	46.4	73	1.6	1.4	3.3
Mahabeej 703	MSSCL, Akola	53.4	35.9	72	1.5	3.6	2.8
CSH 25 (Parbhani Sainath)	MAU, Parbhani	53.3	35.0	77	1.6	1.8	2.6
Madhura-SS hyb	Nimbkar Seeds, Paltan	51.9	43.2	74	2.1	2.5	2.7
Mahabeej 7	MSSCL, Akola	51.8	33.4	75	1.6	4.8	3.1
8562	Bayer Bio Sc., Hyderabad	51.0	36.9	73	1.5	1.9	3.1
NSH 703	Nuziveedu Seeds Pvt Ltd, Hyderabad	50.1	36.0	78	1.6	3.8	2.9
KDSH 1179 (Sudama)	Krishidhan Seeds, Jalna	48.7	30.9	78	1.5	3.8	2.7
NSH 702	Nuziveedu Seeds Pvt Ltd, Hyderabad	48.6	36.5	82	1.6	3.4	2.5
BSH 45	Biostadt, Aurangabad	48.2	31.6	76	1.5	4.4	3.0
Mahabeej 704	MSSCL, Akola	47.9	33.6	66	1.5	4.7	3.2
PSV 2	ARS, Palem	47.3	35.8	83	1.7	0.6	1.6
PSV 1	ARS, Palem	46.8	30.7	70	1.6	1.2	2.9
8340	Bayer Bio Sc., Hyderabad	46.6	29.0	75	1.6	3.6	3.2
GK 4009	GK Seeds, Hyderabad	46.3	36.0	76	1.6	4.1	2.8
KDSH 209	Krishidhan Seeds, Jalna	44.7	30.6	76	1.6	3.8	2.9
GK 4044	GK Seeds, Hyderabad	42.7	31.8	77	1.5	2.5	2.7
Hi-jowar 52	Biostadt, Aurangabad	42.5	27.7	77	1.6	3.6	2.8
BSH 47	Biostadt, Aurangabad	41.7	26.4	75	1.6	2.9	3.4
8568	Bayer Bio Sc., Hyderabad	37.1	29.0	73	1.4	2.9	3.1
PVK 801 (control)		54.6	41.2	82	1.5	1.8	2.7
CSH 16 (control)		50.0	33.6	75	1.6	5.8	3.2
Mean		48.30	34.18	76	1.58	3.12	2.87
SE±		2.86	2.09	1.74	0.04	0.15	0.17
CV (%)		10.27	10.60	4.00	4.00	8.45	9.98
CD (5%)		8.39	6.13	4.98	0.10	0.43	0.47

Table 4. Performance of commercial sorghum cultivars for grain Fe and Zn contents and agronomic traits at ICRISAT, Patancheru, India during 2009 postrainy season.

Cultivar	Seed source	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Time to 50% flower (days)	Plant height (m)	Grain yield (t ha^{-1})	Grain size (g 100^{-1})
NSH 703	Nuziveedu Seeds Pvt Ltd, Hyderabad	38.3	28.3	70	1.7	2.5	4.1
NSH 702	Nuziveedu Seeds Pvt Ltd, Hyderabad	37.2	27.9	71	1.7	3.5	3.4
Mahabeej 703	MSSCL, Akola	33.1	21.9	66	1.8	2.5	3.4
Hi-jowar 52	Biostadt, Aurangabad	33.0	22.0	69	1.7	2.7	4.0
8562	Bayer Bio Sc., Hyderabad	31.3	22.6	67	1.6	1.8	3.9
GK 4035	GK Seeds, Hyderabad	31.2	19.4	67	1.7	3.1	4.1
Mahabeej 704	MSSCL, Akola	31.0	19.0	66	1.6	2.6	3.6
GK 4009	GK Seeds, Hyderabad	30.1	17.4	70	1.7	3.1	3.7
KDSH 1179 (Sudama)	Krishidhan Seeds, Jalna	30.0	22.0	67	1.7	3.8	3.9
BSH 45	Biostadt, Aurangabad	29.0	21.6	68	1.6	3.5	4.1
KDSH 209	Krishidhan Seeds, Jalna	28.0	22.0	71	1.8	3.0	3.8
PSV 2	ARS, Palem	27.7	16.4	75	1.7	2.0	3.1
BSH 47	Biostadt, Aurangabad	27.6	19.2	67	1.7	3.1	3.9
8340	Bayer Bio Sc., Hyderabad	27.1	20.1	69	1.7	3.0	3.9
CSH 25 (Parbhani Sainath)	MAU, Parbhani	26.9	18.6	69	1.8	4.0	3.1
GK 4044	GK Seeds, Hyderabad	26.0	15.8	68	1.5	3.8	2.8
PSV 1	ARS, Palem	25.8	17.1	67	1.8	3.2	3.0
Mahabeej 7	MSSCL, Akola	25.2	18.1	66	1.6	3.4	3.6
Madhura-SS hyb	Nimbkar Seeds, Paltan	25.1	21.1	68	2.4	4.4	3.7
8568	Bayer Bio Sc., Hyderabad	22.6	17.2	68	1.6	3.1	3.3
CSH 16 (control)		32.5	22.1	67	1.6	3.9	4.1
PVK 801 (control)		30.5	19.5	71	1.6	3.6	3.7
Mean		29.50	20.42	69	1.69	3.16	3.65
SE±		1.85	1.44	0.91	0.06	0.26	0.18
CV (%)		10.85	12.20	2.31	6.11	14.18	8.76
CD (5%)		5.27	4.10	2.60	0.17	0.74	0.53

Table 5. Correlation coefficients for commercial sorghum cultivars grown at ICRISAT, Patancheru, India during postrainy season in 2008 and 2009[1].

Trait	Fe	Zn	Time to 50% flower (days)	Plant height (m)	Grain yield (t ha^{-1})
Zn	0.853**	1.000			
Time to 50% flower (days)	0.087	0.158	1.000		
Plant height (m)	–0.039	0.224	–0.017	1.000	
Grain yield (t ha^{-1})	0.020	–0.045	–0.223	0.023	1.000
Grain size (g 100^{-1})	0.279	0.221	–0.464	–0.133	0.456*

1. df (n–2)=20; * = Significant at 5% level; ** = Significant at 1% level.

sorghum along with other agronomic traits such as grain size and grain yield in varied maturity backgrounds. As expected, the grain size showed significant positive correlation with grain yield (r=0.456).

In order to realize the potential impact of the micronutrient-dense cultivars, the micronutrient-rich cultivars must be delivered in high-yielding backgrounds with farmers' preferred traits such as early maturity and large seed size.

Conclusions

The biofortification program complements the on-going efforts in combating the micronutrient malnutrition. In the present study, the grain Fe and Zn contents in commercially grown sorghum cultivars in India were used to identify suitable cultivars for large-scale promotion, and for developing the breeding strategies for further improvement. These results suggest that there is considerable variability for grain Fe and Zn contents in the elite commercial sorghum cultivars grown in India for food purposes and the four hybrids NSH 703, GK 4035, Mahabeej 703 and NSH 702 identified in the study can form part of the on-going efforts for combating micronutrient malnutrition through their large-scale promotion. The correlation studies indicated that it is possible for simultaneous improvement of grain Fe and Zn contents in sorghum and there is no penalty in the agronomic traits when combined with high Fe and Zn contents. Also, the study showed that it is possible to deliver high Fe and Zn contents in cultivars with farmers' preferred traits such as early maturity, high yield potential and bold grain.

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