Genetic variability and plant character association of grain Fe and Zn in selected core collection accessions of sorghum germplasm and breeding lines

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Abstract

Sorghum is the third most important food crop in India after rice and wheat and is the staple food in Central India. It is also the staple for large tribal populations across the country. The poor and vulnerable groups in the society depend upon sorghum for their calorie and micronutrient requirement and in the absence of access and affordability to nutrient-rich foods like vegetables, fruits and animal products, biofortification of sorghum helps in enhancing the nutritional security of this group. Research efforts at ICRISAT and elsewhere showed that there is considerable genetic variability and high heritability for grain Fe and Zn contents and it is possible to genetically enhance the grain micronutrient content (Fe and Zn) in sorghum and other major staples. However, limited information is available on the extent of variability in the sorghum germplasm accessions and breeding lines and the character association between grain Fe and Zn contents and with other agronomic traits. The main aim of this study was to identify promising donors in the core collection of sorghum germplasm accessions and breeding lines with the objective to use those with high grain Fe and Zn contents in the genetic enhancement program to develop biofortified sorghum cultivars. Significant positive correlation was observed between grain Fe and Zn contents (r=0.75) in the study. The five accessions, IS 5427, IS 5514, IS 55, IS 3760 and IS 3283, identified from the study with high grain Fe (>50 mg kg^{-1}) and Zn (>37 mg kg^{-1}) contents can be utilized to increase the diversity and micronutrient density of sorghum hybrid parents in the future.

Introduction

Sorghum (*Sorghum bicolor*) is an important food staple for millions of poor people in Africa and Asia; and these regions together produce 70% of world's sorghum. Sorghum is tolerant to drought, well adapted to the semi-arid and arid climatic conditions of Africa and Asia. To highlight the importance of sorghum in the human diets, Kayode (2006) stated that a multidisciplinary approach is needed to evaluate the contribution that sorghum can make to grain Fe and Zn intake by poor people in the world, especially in Asia and Africa. Earlier work at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in this direction indicated per capita sorghum consumption in India in the major sorghum producing areas was 75 kg yr^{-1} and share of sorghum in Fe intake was as high as 50% in the low income group population in India; sorghum is also one of the cheapest sources of energy, protein, Fe and Zn (Parthasarathy Rao et al. 2006).

Sorghum is comparable to other elite cereals from the nutritional quality point of view, and its grain is rich in protein and micronutrients. Iron (Fe) and zinc (Zn) deficiencies are the major public health threats worldwide. The magnitude of Fe and Zn deficiency is particularly alarming among the children, women of reproductive age, and pregnant and lactating women (Sharma 2003); and efforts are underway to provide fortified foods to the vulnerable groups of the society. Introduction of crop cultivars with increased grain Fe and Zn concentrations can complement these efforts. Biofortification, wherever possible, is the most cost effective and sustainable solution for tackling the micronutrient deficiencies as the intake of micronutrients is on a continuing basis.

Preliminary studies by Reddy et al. (2005) indicated limited variability for grain Fe and Zn contents in hybrid parents, advanced breeding lines and released sorghum cultivars. The attempts to enhance the grain Fe and Zn through exogenous application of macronutrients [nitrogen (N), phosphorus (P) and potassium (K) as per the need] and micronutrients [Fe, Zn, boron (B) and sulfur (S)] did not increase the grain Fe and Zn. In this study, the genetic enhancement route is attempted for higher grain Fe and Zn contents. The main aim of this work was to identify promising donors in the core collection of sorghum germplasm accessions and breeding lines with the objective to use those with high grain Fe and Zn contents in the genetic enhancement program to develop biofortified sorghum cultivars.

Material and methods

In all, 29 accessions selected from core collection of the sorghum germplasm and breeding lines along with two check cultivars ICSR 40 (an ICRISAT-developed restorer line) and 296B (Directorate of Sorghum Research (DSR)-Hyderabad developed hybrid parent) were evaluated. Accessions that belonged to different races and different geographical origins were selected from the core collections of sorghum germplasm accessions and were used in the study. The material was grown in the field during 2007 and 2008 postrainy seasons under high fertility conditions (N80:P40:K0) in a replicated trial in a randomized complete block design (RCBD) with three replications (4 rows of 2 m length plots) at ICRISAT farm, Patancheru, India (located at an altitude of 545 m above mean sea level, latitude 17.53° N and longitude 78.27° E). Care was taken to raise a healthy crop. The data were recorded for the agronomic traits: time to 50% flower (days), plant height (m), glume coverage (%), grain yield (t ha^{-1}) and grain size (g 100^{-1} grains) as per the standard procedure. Three to five panicles were bagged with Kraft paper bags prior to flowering in each replication to avoid pollen contamination and to harvest pure seed for grain analysis.

The panicles were harvested at maturity and the grain was threshed carefully without any contact with metal or dust to avoid contamination. The cleaned seeds were collected into cloth bags and used for micronutrient analysis in the ICRISAT Central Analytical Services Laboratory (CASL) at 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 the GENSTAT 9.1 package.

Results and discussion

The ANOVA showed significant differences among the genotypes and years for all the traits studied except for grain Fe contents among years (Table 1). Significant genotype × year interactions existed for time to 50% flower, plant height, grain yield, grain size and grain Fe and Zn contents. Over the two years, mean grain Fe content ranged from 26 to 61 mg kg^{-1} and Zn content ranged from 21 to 57 mg kg^{-1} (Table 2). Both the checks, 296 B and ICSR 40 had grain Fe content of 40 and Zn content of 24 mg kg^{-1} (Table 2). Twelve lines were significantly superior to both the checks for grain Fe content ranging from 48 to 61 mg kg^{-1}, while 27 accessions were superior for grain Zn content ranging from 32 to 57 mg kg^{-1}.

In earlier studies also, the superiority of landraces over controls for grain Fe and Zn contents in sorghum were reported (Reddy et al. 2005, Sreeramaiah et al. 2007). In the top five entries for grain Fe contents, the two accessions (IS 5427 and IS 5514) were from India, two accessions (IS 55 and IS 3283) were from USA and one accession (IS 3760) was from USSR. The grain Fe content in these accessions was >50 mg kg^{-1}, which is 25% higher than that recorded in the best check ICSR 40 (grain Fe 40 mg kg^{-1}). All these lines are early to medium for time to 50% flower (65–71 days) with good plant height (1.0 to 2.0 m). Grain yield in these lines ranged from 1.3 to 2.2 t ha^{-1} and the grain size varied from 2.23 to 2.97 g 100^{-1} grains. The grain Zn content in these lines ranged from 37 to 57 mg kg^{-1} compared to the best check 296 B with grain Zn content of 24.0 mg kg^{-1}.

The correlations of grain Fe and Zn with grain yield and plant traits are presented in Table 3. Significant positive correlation existed between grain Fe and Zn contents (r= 0.75) for the lines under evaluation (Table 3). Both grain Fe (–0.36) and Zn (–0.46) contents showed significant negative relation with grain yield but numerically low indicating that genetic enhancement for grain Fe and Zn contents does not have yield penalty.

Table 1. Mean squares (ANOVA) of sorghum landraces evaluated for iron and zinc estimations in postrainy season 2007 and 2008 at ICRISAT, Patancheru, India.

Source	df	Time to 50% flower (days)	Plant height (m)	Glume coverage (%)	Grain yield (t ha^{-1})	Grain size (g 100^{-1} grains)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})
Replication	2	22.129	0.38517	658.6	0.819	0.130	4.350	42.02
Genotype (G)	30	246.375**	0.726**	2130.2**	2.346**	4.376**	235.870**	287.650**
Year (Y)	1	685.210**	0.944**	2449.6**	1.516**	5.734**	87.330	4643.930**
G × Y	30	38.943**	0.0648*	227.4	1.432**	0.264**	54.020**	86.070**
Error	122	2.752	0.0411	160	0.212	0.091	23.27	24.660
Total	185							

Table 2. Mean performance of selected sorghum germplasm lines evaluated for grain iron and zinc contents at ICRISAT, Patancheru, India in postrainy season 2007 and 2008.

IS no./ Pedigree	Race	Origin	Time to 50% flower (days)	Plant height (m)	Glume coverage (%)	Grain yield (t ha^{-1})	Grain size (g 100^{-1} grains)	Iron (mg kg^{-1})	Rank[1]	Zinc (mg kg^{-1})
5427	*Durra*	India	65	2.0	54	2.0	2.75	60.5	1	56.8
5514	*Guinea-bicolor*	India	68	1.7	71	1.4	2.97	56.2	2	44.6
55	*Durra-caudatum*	US	71	1.0	75	1.3	2.64	54.1	3	38.3
3760	*Caudatum-bicolor*	USSR	68	1.9	67	2.2	2.23	52.8	4	37.1
3283	*Bicolor*	US	66	1.8	71	1.9	2.70	50.2	5	42.0
17580	*Caudatum*	Nigeria	66	1.9	79	1.6	2.09	49.9	6	40.5
15952	*Guinea*	Cameroon	81	2.4	38	2.5	3.35	49.3	7	41.3
3813	*Durra*	India	79	2.2	83	1.4	1.73	49.2	8	38.1
15266	*Caudatum*	Cameroon	70	1.4	54	2.7	2.65	48.6	9	43.6
2939	*Kafir*	US	69	2.0	63	3.6	3.94	48.4	10	37.2
4159	*Durra*	India	65	1.9	50	1.5	3.30	47.6	11	37.6
3929	*Kafir-durra*	US	75	2.0	79	2.2	2.09	47.6	12	39.5
3443	*Guinea-caudatum*	Sudan	68	1.7	63	3.3	3.47	47.4	13	39.3
3925	*Durra-caudatum*	US	78	2.0	67	2.4	1.95	47.2	14	38.5
5460	*Durra-bicolor*	India	66	1.5	79	1.4	2.68	46.9	15	46.4
12452	*Caudatum-bicolor*	Sudan	64	1.9	79	3.2	4.34	46.8	16	33.2
2801	*Caudatum*	Zimbabwe	71	1.8	71	2.3	3.11	45.5	17	45.0
2536	*Kafir-caudatum*	US	72	1.8	83	2.3	2.36	45.2	18	37.0
5429	*Durra*	India	66	1.7	79	2.8	2.99	44.4	19	30.0
356	*Durra*	US	84	1.1	46	2.2	2.71	44.2	20	32.9
2265	*Durra-bicolor*	Sudan	75	2.2	71	1.8	1.69	44.2	21	40.9
12695	*Bicolor*	South Africa	68	1.9	100	2.8	2.58	44.1	22	38.9
5538	*Durra*	India	65	1.4	33	1.7	2.22	43.9	23	36.9
5476	*Durra*	India	69	1.5	75	2.1	2.69	40.8	24	35.5
16337	*Caudatum*	Cameroon	80	1.7	38	2.4	3.03	40.5	25	34.0
5853	*Guinea-durra*	India	65	1.7	29	2.4	5.91	40.5	26	31.5
14318	*Bicolor*	Swaziland	79	2.1	79	2.2	2.25	39.3	29	38.0
10674	*Durra-caudatum*	China	65	2.1	46	1.9	4.04	38.5	30	37.6
22215	*Durra-bicolor*	USSR	80	2.1	71	2.9	2.39	26.3	31	21.4
Controls										
ICSR 40			70	1.2	33	3.3	3.19	40.1	27	23.5
296B			86	1.1	29	2.7	2.77	39.5	28	24.0
Mean			71	1.76	63	2.26	2.87	45.92		37.49
SE±			0.96	0.12	7.30	0.26	0.17	2.67		2.75
CV (%)			2.32	11.51	20.06	20.12	10.38	10.07		12.69
CD (5%)			2.68	0.33	20.44	0.74	0.49	7.80		8.03

1. Based on grain iron content.

Table 3. Correlation coefficients for morphological traits of sorghum landraces evaluated for iron and zinc estimations in postrainy season 2007 and 2008 at ICRISAT, Patancheru, India[1].

Trait	Iron content	Zinc content	Time to 50% flower	Plant height	Glume coverage	Grain yield
Iron content	1.00					
Zinc content	0.75**	1.00				
Time to 50% flower	–0.35	–0.35	1.00			
Plant height	0.02	0.28	–0.01	1.00		
Glume coverage	0.19	0.27	–0.17	0.31	1.00	
Grain yield	–0.36*	–0.46**	0.10	0.01	–0.14	1.00
Grain size	–0.12	–0.17	–0.37*	–0.06	–0.43*	0.37*

1. df (n–2)=29 and r=0.36 at 5% and 0.46 at 1%.

However, there was no significant negative association of grain Fe and Zn with the other traits studied. As expected, the grain size showed significant positive correlation with grain yield.

In the light of the limited variability observed in the sorghum hybrid parents and advanced breeding lines for grain Fe and Zn contents (Reddy et al. 2005) and no appreciable increase in grain Fe and Zn contents with soil application of macronutrients (N) and micro-fertilizers (Fe, Zn, B and S) as the response to applied micronutrients in terms of yield and grain Fe and Zn depends on the soil available status relative to these nutrients, genetic enhancement for grain Fe and Zn contents assumes high importance. Identification of suitable donors is the first step in the process and the present results assume significance in this regard. The superior lines identified in this study can be used as parents in developing sorghum varieties and hybrid parents that in addition to high grain yields will be dense in grain Fe and Zn, thus providing a low-cost solution to the micronutrient deficiencies in sorghum-eating populations.

Currently, the grain Fe and Zn contents in selected sorghum hybrids and varieties commercially cultivated in India are being analyzed to establish the current levels of grain Fe and Zn contents to develop the breeding strategies for further improvement. Also, the grain Fe and Zn contents of the entire set (nearly 3000 lines) of the core collections of sorghum germplasm are being analyzed and the inheritance and stability of the trait are being studied at ICRISAT, Patancheru. The five accessions, IS 5427, IS 5514, IS 55, IS 3760 and IS 3283, identified from the study with high grain Fe (>50 mg kg^{-1}) and Zn (>37 mg kg^{-1}) contents (Table 2) can be utilized to increase the diversity and micronutrient density of sorghum hybrid parents in the future.

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