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Genetic Variation and Trait Associations of Yield, Protein and Grain Micronutrients for Identification of Promising Sorghum Varieties

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Sorghum is, globally, the fifth most important cereal after maize, rice, wheat and barley. The crop is tolerant to semi-arid and arid climatic conditions. Twenty-five sorghum varieties grown in South Africa were evaluated in the field at two locations with the objective of identifying high yielding, micronutrient dense genotypes. Two clusters were formed based on measured traits. Tx430 (G13), CIMMYT entry 49 (G12), E35-1 (G16), Framida (G19), IS1934 (G7) and IS14380 (G14) formed cluster A. The rest of the sorghum entries formed cluster B. Wide variation was exhibited for grain yield, ranging from 1.12 t ha^{-1} to 3.96 t ha^{-1} with a mean grain yield of 2.83 tha^{-1}. Analysis of variance also revealed significant differences among the varieties for protein, total starch, amylose and mineral content. Two varieties, Tx430 and AR-3048 exhibited very high protein content. Fe content ranged from 43.7 mg kg^{-1} (Kuyuma) to 61.2 mg kg^{-1} (IS14380) with an average of 50.5 mg kg^{-1}. Zn content ranged from 13.7 mg kg^{-1} (Macia) to 23.4 mg kg^{-1} (Tx430) with a mean of 17.4 mg kg^{-1}. Grain yield was significantly positively correlated with plant height, panicle weight and thousand kernel weight. Significant positive correlations were observed between Fe content and Zn, Cu, Mn and P. This data indicated that simultaneous genetic improvement of sorghum varieties for Fe and other important minerals, and starch content in the same genetic background was possible, without a penalty to grain yield.

Keywords: sorghum, yield, protein, minerals, starch

Introduction

Sorghum bicolor L. (Moench), ranks fifth as a global cereal crop after maize, rice, wheat and barley (FAO 2012) providing multiple uses such as food, feed, fodder, building material and fuel. The crop has wide adaptation and has the ability to thrive in hostile enviroments, especially in the tropics and semi-tropics, with unreliable rainfall, poor soils, pests, diseases and parastic weeds, where maize performs poorly.

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The crop is cultivated in many countries mainly spread over Africa, Asia, Oceania and the Americas with the area under its cultivation and realized total crop production in 2010 at 40.9 million ha and 55.7 million metric tonnes, respectively. The top nine major sorghum-producing countries in the world are the United States of America, Mexico, India, Nigeria, Argentina, Ethiopia, Sudan, Burkina Faso and China (FAO 2012). Sorghum is a staple food crop for millions of smallholders particularly in rain-fed areas of Africa and Asia, with the potential to serve as a source of micronutrients in their diets. Sorghum is comparable to other elite cereals from a nutritional quality point of view. Its grain is rich in protein and micronutrients such as iron (Fe) and zinc (Zn). Earlier studies at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) point to sorghum as one of the cheapest sources of energy, protein, Fe and Zn for people, especially those in Asia and Africa (Rao et al. 2006).

Successful crop improvement through breeding depends on the existence of genetic variation for the target traits in the gene pool. Crop species, including sorghum, often exhibit genetic variation in micronutrient content, which is essential for plant breeding programmes to improve the levels of micronutrients (Hirschi 2009). Genotypes differ in their ability to extract minerals from different soil depths. Grain mineral contents of crop species are influenced by the effects of genotypes and environments (Hussain et al. 2010; Zhang et al. 2010). Multi-location evaluation of new cultivars plays an important role in crop breeding programmes. However, in this process, there is usually more emphasis on the agronomic superiority of the new cultivars over existing cultivars in terms of grain and/or fodder yield. Breeders need information on the genetic variation for a given trait as well as the determinants, i.e. genetic and environmental factors in the collection of germplasm to justify selection for that trait (Oikeh et al. 2003). Genetic as well as environmental factors can significantly affect, for example, Fe and Zn levels in cereal grains as was indicated in maize and wheat (Baenzinger and Long 2000).

Over decades, a large pool of sorghum genetic resources has been mobilised through collective international effort. The value of germplasm is realised only when characterised for morpho-agronomic and other useful traits to unearth new gene combinations for use in crop improvement programmes. Previous investigations by Reddy et al. (2005, 2010), and Ng'uni et al. (2011, 2012) have shown variability for grain micronutrients such as grain Fe and Zn contents in sorghum germplasm. The present study assessed sorghum varieties for grain yield, protein, and micronutrient contents at two locations in South Africa. The main aim of the study was to evaluate sorghum varieties for high yield and micronutrient dense grain for advancement in the breeding programme.

Materials and Methods

Germplasm and field experiments

A total of 25 sorghum varieties were planted in field experiments at Potchefstroom and Taung in South Africa during the 2011/12 planting season. Twenty-two of these varieties were grain types from the South African germplasm collection and the Agricultural

Research Council Grain Crops Institute (ARC-GCI) breeding programme while the remaining three entries (23, 24, 25) were of the sweet stem type (Table 1). The research site of the ARC-GCI at Potchefstroom (26° 74' S; 27° 8' E) is located at an altitude of 1344 metre above sea level and is characterised by sandy clay loam soils. The other research site, Taung (27° 31' S; 24° 47' E) which is 1111 meters above sea level, is also located in the North West province. The site is predominantly characterised by sandy soils. The average total annual rainfall at Potchefstroom and Taung are 620 and 522 mm, respectively.

The experimental design used was a 5×5 lattice square with three replications. Each experimental plot size was 4 rows of 5 m long with inter-row and intra-row spacing of 1 m and 0.2 m, respectively, at both sites. At Potchefstroom, the plots were machine planted, using a two-row planter, while at Taung the plots were planted by hand. Plants were hand-thinned equally at both sites to the desired population density. Commercial fertilisers 3:2:1 (32) + 0.5 Zn and LAN (28) were applied at a rate of 150 kg ha^{-1} and 100 kg ha^{-1}, respectively. 3:2:1 (32) + 0.5 Zn was applied at planting time, while LAN (28) was applied as a side dressing at 45 days after planting.

Data were collected on days to 50% flowering (DTF), plant height (PH), panicle weight (PWt), thousand-kernel weight (TKW) and grain yield (GYD) at both locations according to the IBGR/ICRISAT sorghum descriptors (IBGR and ICRISAT, 1993). TKW was recorded as the weight of 1000 kernels from pooled seeds from heads from each plot. Grain yield was recorded as the total weight of the grain harvested from two rows of 4.5 m long or 9 m^2 in each plot. Data on grain yield, TKW and PWt were adjusted to 12.5% moisture for statistical analysis.

The extraction steps of mineral elements (Ca, K, Fe, Mg, Mn, Na, P and Zn) were done according to the dry-ashing method outlined by the AOAC (2000). Sorghum seed samples were ground to a fine powder using a 1KA analysis grinder, A10 Yellowline (Merck Chemicals Pty Ltd., South Africa) with a 1 mm sieve. Approximately 2 g of maize flour was then weighed into glazed, high-form porcelain crucibles and ashed in a furnace at 550 °C for 3 h. A few drops of nitric acid (HNO_3) (55%) were added to the samples for digestion. The samples were then placed in a hot sand-bath until they were completely dry, after which they were returned to the oven for 1 h at 550 °C for further ashing. After cooling, 10 ml of 1:2 HNO_3 was added to the samples for further digestion. The samples were returned to the hot sand-bath until they became warm. The samples were then transferred to 100 ml volumetric flasks and filled to the mark with distilled water. Ca, K, Fe, Mg, Mn, Na, P and Zn content were measured in triplicate using an Atomic Absorption Spectrophotometer (Spectra AA 300).

Approximately 3 mg of sorghum flour was weighed into glass tubes and dried overnight at 95.5 °C. The samples were then placed in a desiccator (room temperature) to cool. The dried samples were removed from the desiccator and transferred to foils (which had their mass individually recorded) and immediately weighed in triplicate. The total protein content was determined using the combustion method with a Leco FP-528 nitrogen analyser. Protein concentration was estimated from the nitrogen value as: % Protein = % Nitrogen×6.25, the conversion factor for sorghum as recommended by Merrill and Watt (1973).

Table 1. Field mean performance for 25 entries of sorghum for yield, plant height, and number of days to flowering during the 2011/12 season at Taung and Potchefstroom

Entry	Type	YLD Potch (ton ha^{-1})	YLD Taung (ton ha^{-1})	Average	PHt Potch (cm)	PHt Taung (cm)	Average	DtF Potc (days)	DtF Taung (days)	Average
SA1785	Grain	3.98	1.68	2.83	333.33	200.67	267.00	88	82	85.33
SA1794	Grain	4.83	1.57	3.20	246.67	132.33	189.50	86	69	77.83
2426 DCDB Bop Nonoeba	Grain	5.10	2.26	3.66	205.00	129.00	167.00	74	62	67.67
2426 DCDB Bop Welgeval	Grain	5.09	1.85	3.47	201.67	107.33	154.50	79	65	72.33
SDS1594	Grain	4.73	1.59	3.16	208.33	131.00	169.67	92	84	88.00
CY917/1	Grain	5.70	2.22	3.96	118.33	100.67	109.50	73	64	68.50
IS1934	Grain	4.03	0.62	2.32	155.00	112.33	133.67	86	102	93.83
Transk RED No. 2	Grain	4.65	2.18	3.42	223.33	125.67	174.50	87	74	80.33
IS10364	Grain	4.05	1.66	2.86	130.00	95.67	112.83	66	63	64.33
AR-3048	Grain	3.26	1.32	2.29	96.67	77.00	86.83	82	68	75.17
OK11	Grain	3.91	1.09	2.50	111.67	82.67	97.17	82	69	75.83
CIMMYT Entry 49	Grain	2.64	1.81	2.22	106.67	104.33	105.50	61	62	61.50
Tx2880	Grain	3.98	1.18	2.58	128.33	84.00	106.17	70	64	66.83
IS14380	Grain	2.99	1.15	2.07	323.33	186.00	254.67	103	98	100.50
IS14384	Grain	3.63	0.71	2.17	323.33	153.33	238.33	86	97	91.17
E35-1	Grain	5.22	0.55	2.89	186.67	134.33	160.50	93	98	95.00
Sima	Grain	5.98	0.68	3.33	225.00	159.00	192.00	87	101	94.17

Table 1 (cont.)

Entry	Type	YLD Potch (ton ha^{-1})	YLD Taung (ton ha^{-1})	Average	PHt Potch (cm)	PHt Taung (cm)	Average	DtF Potc (days)	DtF Taung (days)	Average
Kuyuma	Grain	5.31	2.20	3.76	143.33	94.00	118.67	79	67	73.00
Framida	Grain	5.77	0.41	3.09	223.33	152.33	187.83	75	90	82.17
Macia	Grain	5.16	2.11	3.64	138.33	93.00	115.67	72	65	68.67
Tx430	Grain	3.07	1.00	2.03	108.33	85.00	96.67	78	69	73.33
ICSV112	Grain	4.95	0.78	2.87	220.00	157.33	188.67	87	99	93.00
SSP004	Sweet stem sorghum	1.94	0.30	1.12	308.33	191.00	249.67	101	70	85.50
SSP013	Sweet stem sorghum	5.22	1.55	3.38	193.33	108.00	150.67	89	80	84.50
SSP019	Sweet stem sorghum	2.89	1.08	1.98	295.00	147.33	221.17	85	86	85.33
Mean		4.32	1.34	2.83	198.13	125.73	161.93	82	78	80.15
Min		1.94	0.30	1.12	96.67	77.00	86.83	61	62	61.50
Max		5.98	2.26	3.96	333.33	200.67	267.00	103	102	100.50
CV%		12.35	41.33	19.22	6.05	10.50	7.79	3.36	6.21	4.92
LSD		7.30	7.60	5.22	16.40	18.09	12.09	3.79	6.63	3.78
SE		4.36	4.53	3.14	9.78	10.78	7.28	2.26	3.95	2.28

YLD = yield, PHt = plant height, DTF = days to 50% flowering.

A 2.5 g sample of each entry was weighed in duplicate and transferred to a 100 ml Erlenmeyer flask. To each sample, 50 ml of 32% HCl solution was added and placed in a boiling water bath for 15 min, stirring with a glass rod every 5 min. Afterward, the samples were placed in a water bath to cool at about 20 °C. Each sample was then quantitatively transferred to a 100 ml volumetric flask with a 55 mm ∅ funnel to which 5 ml of Tungstophosphoric acid was added and made up to the mark with distilled water. The mixtures were shaken gently before double filtration with Whatman no 4 or M&N

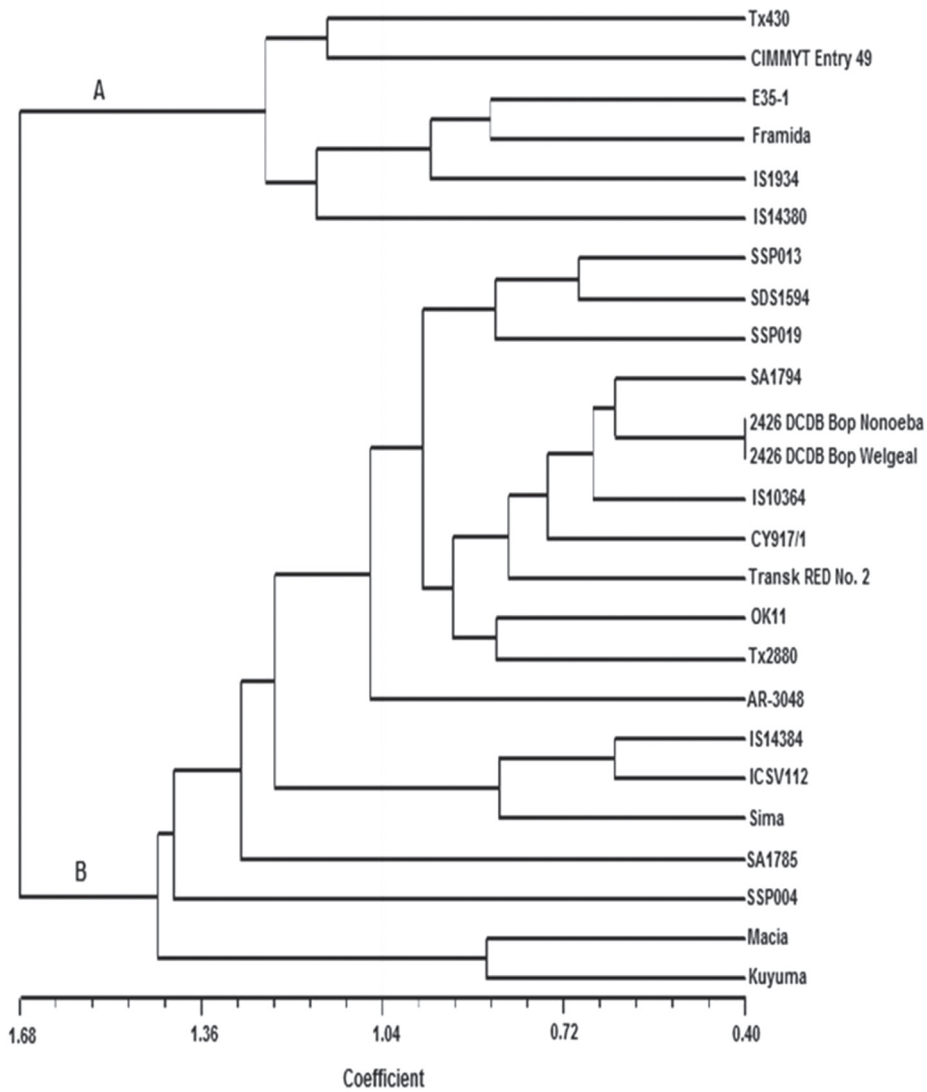

Figure 1. UPGMA dendrogram of 25 sorghum varieties based on Jaccard similarity coefficients

(Machery and Nagel) 617 filter paper into 150 ml beakers. The angle of optical rotation of filtrate was measured for each sample using the polarimeter, Atago Automatic Polarimeter AP-300 (Labex Pty, Ltd., South Africa).

Amylose content was analysed in the flour of sorghum varieties according to Deja Cruz and Khush (2000) with modifications. Flour samples (0.1 g) were placed into 15 ml tubes, and 1 ml of 95% ethanol and 9 ml of 1M NaOH solution were added. As a control, a tube without a flour sample having all reagents, was included. To gelatinise the samples, the tubes were boiled in a water bath for 30 min. The tubes were capped and cooled for 1 hour, and then centrifuged at 1000 G sec^{-1} for 5 min. From the supernatants, 0.1 ml was pipetted into a 10 ml glass tubes. To each glass tube, 0.2 ml 1M acetic acid – Iodine solution and 9.5 ml distilled water, were added. The samples were mixed and sedimented for 20 min before reading the arbsorbance at 620 nm using a Spectrophotometer. Standard samples with known values of high, medium and low AC were used for a standard AC curve and on this basis the AC values of samples were computed.

A dendrogram and matrix plot were compiled using NTSYSpc 2.2 (Rohlf 2008). The collected data on agronomic traits along with all the grain quality characteristics were subjected to analysis of variance (ANOVA) and estimation of the correlations among traits using Genstat Ver 15 (Payne et al. 2009).

Results

Sorghum varieties exhibited genetic differences for the traits evaluated and broadly grouped into two clusters, A and B which at a coefficient of 1.68 (Fig. 1). Tx430, CIMMYT entry 49, E35-1, Framida, IS1934 and IS14380 formed similarity cluster A. The rest of the sorghum varieties grouped in cluster B.

There was significant variation among sorghum varieties for days to flower, plant height and grain yield on avergae but also for the two locations separately ($P < 0.05$; Table 1). Plant height ranged from 86.8 cm (AR-3048) to 267.0 cm (SA1785) with an average of 161.9 cm. The shortest and tallest sorghum varieties were grain sorghum types. With respect to days to flowering, the sorghum varieties ranged from 62 days (CIMMYT entry 49) to 101 days (IS14380) with a mean value of 80 days. Wide variation was also exhibited by sorghum varieties in terms of grain yield, ranging from 1.12 t ha^{-1} (SSP004) to 3.96 t ha^{-1} (CY917/1) with a mean grain yield of 2.83 t ha^{-1}.

The summary statistics revealed a wide range between the minimum and maximum values for the grain quality characteristics (Table 2). Protein content ranged from 10.0% (Macia) to 13.9% (AR-3048) with an average of 12.1%. Three sorghum genotypes, Tx430, AR-3048 and IS10364 had significantly higher protein content than the rest of the varieties. Amylose content ranged from 15.8% (IS1934) to 22.6% (Kuyuma) with an avearge of 19.0%. The sorghum varieties exhibited wide variation for Fe content, ranging from 43.7 mg kg^{-1} (Kuyuma) to 61.2 mg kg^{-1} (IS14380) with an average of 50.5 mg kg^{-1}. The other nutritionally equally important micronutrient, Zn ranged from 13.7 mg kg^{-1} (Macia) to 23.4 mg kg^{-1} (Tx430) and a mean of 17.4 mg kg^{-1}. Sorghum line, IS14380, followed by Tx430, SA1785 and Framida exhibited significantly higher levels of Zn con-

Table 2. Mean, minimum, maximum values of protein, starch, amylose and mineral composition of 25 sorghum varieties at Taung and Potchefstroom

Sorghum entry	Protein (%)	Starch (%)	Amylose (%)	Ca (mg kg^{-1})	Cu (mg kg^{-1})
Tx430 (21)	13.8a	47.6m	17.6fghij	351abcd	4.5a
SSP013 (24)	11.2fg	55.3cde	18.9cdefgh	200ij	2.6hi
E35-1 (16)	11.9bcdefg	49.4klm	17.8efghij	342abcde	4.5a
SA1785 (1)	12.1bcdefg	58.4ab	17.0ghij	230fghij	4.2abc
SA1794 (2)	12.6bcd	54.6def	17.6fghij	257cdefghij	2.9fghi
IS1934 (7)	11.9bcdefg	56.0cde	15.8j	357abc	3.7cde
SDS1594 (5)	11.3efg	56.7bc	16.0ij	241efghij	3.2efgh
CY917/1 (6)	11.9bcdfeg	54.2efg	18.7cdefghi	309bcdefgh	3.3defg
Transk RED No. 2 (8)	12.1bcdefg	59.8a	19.8bcdef	232fghij	3.5def
Framida (19)	12.3bcdef	48.2lm	18.3defghij	428a	4.3ab
AR-3048 (10)	13.9a	55.1cde	20.4abcde	227ghij	2.8ghi
IS10364 (9)	12.9ab	55.9cde	19.0bcdefgh	235fghij	3.3defg
OK11 (11)	12.0bcdefg	54.5def	20.9abcd	222ghij	2.5i
CIMMYT Entry 49 (12)	12.6bcd	48.0m	18.9cdefgh	367ab	4.2abc
Tx2880 (13)	12.4bcde	48.2lm	21.1abc	277bcdefghij	3.5def
IS14380 (14)	12.6bc	48.2lm	19.4bcdefg	336abcdef	3.8bcd
IS14384 (15)	11.9bcdef	47.7m	20.3abcdef	258cdefghij	3.4defg
2426 DCDB Bop Nonoeba (3)	12.5bcd	52.3ghi	18.4cdefghij	262bcdefghij	2.5i
2426 DCDB Bop Welgeval (4)	12.6bcd	55.6cde	18.2efghij	254cdefghij	2.7hi
Macia (20)	10.0h	52.7fgh	21.0abcd	272bcdefghij	3.5def
ICSV112 (22)	11.6cdefg	50.2jkl	20.9abcd	317bcdefg	3.8bcd
Sima (17)	11.9bcdefg	54.9cde	21.7ab	289bcdefghi	4.3ab
Kuyuma (18)	11.0gh	56.3cd	22.6a	247defghij	2.9fghi
SSP019 (25)	11.5defg	51.5hij	17.7fghij	205hij	2.7hi
SSP004 (23)	11.0gh	50.6ijk	16.9hij	182j	3.3defg
Mean	12.1	52.9	19.0	279	3.4
Min	10.0	47.6	15.8	182	2.5
Max	13.9	59.8	22.6	428	4.5
Potchefstroom	11.48b	52.66a	18.50b	193.73b	3.49a
Taung	12.72a	53.18a	19.58a	365.42a	3.40a

Different letters within the column indicates significant differences ($P<0.05$).

Table 2 (cont.)

Fe (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Mn (mg kg^{-1})	P (mg kg^{-1})	Zn (mg kg^{-1})
60.1ab	3683bcde	1500ab	22.0a	3697abc	23.4a
46.3d	2767gh	1283abcd	15.3efgh	3397cde	15.7hijk
53.0abcd	4575a	1617a	20.7ab	3906ab	17.7defghi
59.8ab	3142defgh	1550ab	16.3efgh	3494bcde	17.2defghij
51.7abcd	2900efgh	1358abc	14.7fgh	3412cde	15.7hijk
56.9abc	4200ab	1458abc	22.0a	3643abc	19.7bcd
45.6d	3075defgh	1458abc	15.4efgh	3160def	15.8ghijk
48.1cd	3192defgh	1258abc	18.0bcde	3506abcde	14.8jk
48.4cd	2950efgh	1483abc	16.2efgh	3548abcd	18.8cdef
60.1ab	4008abc	1475abc	20.7abc	3944a	21.2abc
46.9cd	2642h	1333abcd	17.2defg	3063ef	18.3defg
48.0cd	3033defgh	1467abc	15.3efgh	3444cde	16.3fghijk
46.9cd	3317cdefgh	1475abc	14.6fgh	3323cde	15.3ijk
45.7d	3775abcd	1383abc	22.2a	3458bcde	17.9defghi
48.9cd	3317cdefgh	1267abcd	17.1defg	3313cde	15.9ghijk
61.2a	3200defgh	1617a	21.5a	3654abc	21.6ab
51.3abcd	3267cdefgh	1208bcd	16.2efgh	3489bcde	18.2defgh
46.9cd	2867fgh	1442abc	17.5cdef	3609abcd	16.3fghijk
46.2d	2992defgh	1467abc	19.7abcd	3452cde	16.2fghijk
45.5d	2650h	975d	14.2gh	2736f	13.7k
50.8bcd	3558bcdefg	1117cd	14.2gh	3387cde	19.3bcde
53.6abcd	3600bcdef	1275abcd	16.5efgh	3753abc	17.1efghij
43.7d	3392cdefgh	1250abcd	13.4h	2842f	14.0k
46.3d	2892efgh	1267abcd	17.6cdefg	3096ef	17.3defghij
50.5bcd	3617bcdef	1350abcd	15.7efgh	3306cde	16.0ghijk
50.5	3321	1378	17.5	3427	17.4
43.7	2642	975	13.4	2736	13.7
61.2	4575	1617	22.2	3944	23.4
50.92a	2897.30b	1250.00b	14.81b	3378.14a	17.44a
50.05a	3715.30a	1502.78a	20.10a	3479.28a	17.32a

Table 3. Spearman's correlation coefficients among days to flowering, plant height, plant weight, yield, thousand-kernel weight, protein, starch, amylose and mineral concentration of 25 sorghum genotypes across two environments

	DTF	PHt	PWt	YLD	TKWt	Zn	Fe	Cu	Mn	Na	Ca	Mg	K	P	Protein	Starch
PHt	0.62**															
PWt	–0.03	0.39**														
YLD	–0.06	0.41**	0.98**													
TKWt	0.04	0.19**	0.29**	0.33**												
Zn	0.31**	0.16*	–0.06	–0.08	–0.03											
Fe	0.37**	0.29**	0.01	–0.01	0.12	0.52**										
Cu	0.25**	0.16	–0.01	–0.03	0.12	0.61**	0.47**									
Mn	–0.07	–0.35**	–0.62**	–0.64**	–0.26**	0.44**	0.25**	0.33**								
Na	–0.20*	–0.50**	–0.69**	–0.71**	–0.18*	–0.06	–0.07	–0.004	0.54**							
Ca	–0.10	–0.45**	–0.66**	–0.69**	–0.12	0.16	0.02	0.26**	0.66**	0.75**						
Mg	–0.01	–0.17*	–0.36**	–0.36**	–0.05	0.32**	0.04	0.15	0.51**	0.38**	0.39**					
K	0.1	–0.24**	–0.54**	–0.55**	–0.01	0.28**	0.08	0.35**	0.61**	0.45**	0.60**	0.72**				
P	0.25	0.15	–0.17*	–0.18*	0.13	0.60**	0.53**	0.46**	0.56**	0.09	0.26**	0.49**	0.46**			
Protein	–0.34*	–0.48**	–0.45**	–0.48**	–0.09	0.14	–0.04	0.02	0.46**	0.45**	0.47**	0.37**	0.27**	0.14		
Starch	–0.08	–0.05	0.09	0.14	0.05	–0.29**	–0.22**	–0.28**	–0.21*	0.08	–0.13	0.01	–0.21**	–0.21*	–0.03	
Amylose	–0.20	–0.22**	–0.05	–0.05	–0.09	–0.13	–0.18*	–0.06	–0.06	0.042	0.08	–0.001	0.04	–0.13	0.15	–0.17*

*$P<0.05$, **$P<0.01$. DTF = days to flowering, PHt = plant height, PWt = plant weight, YLD = yield, TKWt = thousand-kernel weight.

tent than the rest of the sorghum varieties. Ca content ranged from 182 mg kg^{-1} (SSP004) to 428 mg kg^{-1} (Framida) and an average of 279 mg kg^{-1}.

Grain yield (YLD) was significantly positively correlated with plant height, plant weight and thousand-kernel weight (Table 3). On the contrary, yield showed significant negative correlations with Mn, Na, Ca, Mg, K, P and CP contents. There were significant positive correlations between Fe and Zn, Cu, Mn and P.

Discussion

Genetic biofortification through plant breeding is a widely accepted and most cost effective approach to minimize the micronutrient deficiencies such as Fe and Zn (Cakmak 2008). Populations in developing countries are at a risk of developing Zn and Fe deficiency due to their reliance on cereals as staple in the diet (Allen et al. 2006). Identifying sources of desirable genetic variants that are high yielding is critical for the success of genetic biofortification. Kumar et al. (2009) reported a lower range of grain yield of 1.3 to 2.2 t ha^{-1}, in a study with 29 sorghum accessions from ICRISAT, however, all the varieties involved in their study exhibited a narrow range of days to 50% flowering, ranging between 65–71 days. In another study, Kumar et al. (2010) reported slightly higher yield for commercial sorghum cultivars developed by the Indian National Agricultural Research Program in partnership with ICRISAT ranging between 1.3 to 4.9 t ha^{-1}. This study has demonstrated a significant variation among the sorghum entries for grain yield and mineral content. In fact, the range of grain Fe was far higher in this study than that obtained for sorghum evaluated at ICRISAT (Reddy et al. 2005; Kumar et al. 2010). However, it is important to bear in mind that such comparisons may be of limited significance, especially considering the large environment interactions reported by Kumar et al. (2010). A study of 20 commercial sorghum varieties reported that season influence (intepreted as environment) was larger for Fe, Zn, days to 50% flowering, plant height, and grain size, compared to genotype, which had a larger influence on grain yield (Kumar et al. 2010).

Sorghum is a staple crop for people living across water-stressed regions in Africa and serves as a source of protein (Klopfenstein and Hoseney 1995). The average protein content of sorghum usually varies but is often on average around 12% (Dendy 1995), which was also found in this study. Highly significant positive correlation between Fe and Zn content was observed in earlier evaluation studies (Reddy et al. 2010; Kumar et al. 2011). This was also seen in this study. This in itself provides an indication of a possibility of simultaneously genetic improvement of sorghum varieties for Fe with another or more grain quality characteristics in the same genetic background. In cases of significant negative correlations with grain yield, but numerically low values, provides an indication that genetic enhancement for such grain quality contents does not necessarily have a yield penalty (Kumar et al. 2009).

To conclude, sorghum varieties such as Tx430, IS1934, Transk RED No. 2, Framida, AR-3048, IS14384 and ICSV112 had Zn content above the average of 17.4 mg kg^{-1}. Similarly, sorghum varieties such as Tx430, E35-1, SA1785, SA1794, IS1934, Framida, IS14380, IS14384, ICSV112 and Sima exhibited grain Fe content of more than

50 mg kg^{-1}. Within these sorghum varieties, Sima, Framida and ICSV112 showed potential of yielding above a mean grain yield of 3.14 t ha^{-1}. The sorghum varieties exhibiting superiority for agronomic traits and micronutrient contents in this study could be selected and used as parents in the development of sorghum varieties. These sorghum varieties were only evaluated in the field for one season at two locations. Further field evaluation of these sorghum varieties is therefore recommended.

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