African Journal of Food Science Vol. 5(7), pp. 436 - 445, July 2011
Available online http://www.academicjournals.org/ajfs
ISSN 1996-0794 ©2011 Academic Journals

Full Length Research Paper

Characterization of the Southern African sorghum varieties for mineral contents: Prospects for breeding for grain mineral dense lines

Dickson Ng'uni[1,2]*, Mulatu Geleta[1], Eva Johansson[3], Moneim Fatih[4] and Tomas Bryngelsson[1]

[1]Swedish University of Agricultural Sciences, Department of Plant Breeding and Biotechnology, SE-230 53 Alnarp, Sweden.
[2]Zambia Agriculture Research Institute, National Plant Genetic Resources Centre, Private Bag 7, Chilanga, Zambia.
[3]Swedish University of Agricultural Sciences, Department of Agriculture Farming Systems, Technology and Product Quality, SE-230 53 Alnarp, Sweden.
[4]Swedish Biodiversity Centre, Pomonavägen 2, SE-230 53 Alnarp, Sweden.

Accepted 6 June, 2011

Sorghum is a staple crop and source of energy and minerals for people in semi-arid tropics of Africa and Asia. Thirteen improved and twenty seven farmer varieties of sorghum from southern Africa were analyzed for grain macro- and micronutrient content to identify germplasm with potential for breeding for mineral dense varieties. Improved sorghum varieties ELT-1-17, MMSH-1040, MMSH-1257 and MMSH-1324 exhibited higher grain macronutrient contents than farmer varieties and ranked high for grain K, Mg, S and P contents. Grain K content ranged from 278.3 to 717.8 mg/100 g, Mg (109 to 224.1 mg/100 g), S (112.5 to 275.3 mg/100 g), and grain P content ranged from 195.1 to 468.5 mg/100 g. Farmer varieties showed superiority for grain Fe content that ranged from 2.74 to 8.18 mg/100 g (ZMB5788, MW734, TZ4255) and grain Zn content ranging from 2.03 to 5.53 mg/100 g (TZ4031, TZ3966 and ZMB7111).Sorghum varieties with brown grains exhibited significant higher grain content for grain Ca, K and B than white grained varieties. Most promising improved varieties for high grain Mg, P, S and K contents and farmer varieties for high grain Fe and Zn contents are potential candidates for replicated and multilocational field experiments.

Key words: Sorghum, farmer varieties, improved varieties, macronutrients, micronutrients, semi-arid tropics, nutrition.

INTRODUCTION

Mineral elements are essential components of plant metabolism and often accumulate in seeds. Minerals can be classified as nutritionally essential macronutrients that are required in large amounts such as calcium (Ca), chlorine (Cl), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P) and sulphur (S); and nutritionally essential micronutrients, which are needed in relatively small amount e.g. boron (B), iron (Fe), iodine (I), and silicon (Si); and those termed toxic or with the essential/toxic duality including cadmium (Cd), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se) and zinc (Ihnat, 2003).

Sorghum ranking the fifth most important cereal crop in the world in terms of total production (FAO, 2011), constitutes a major source of proteins, calories and minerals for millions of people particularly in the semi-arid tropical regions of Africa and Asia. Deficiencies of Fe and Zn have been identified as widespread worldwide (FAO/WHO, 2001) especially sub-Sahara Africa and South and Southeast Asia (Reddy Belum et al., 2005Reddy Belum et al., 2005). In its report, FAO (2008) singled out Sub-Sahara Africa as having the highest prevalence of under nutrition in the world, with one in

---

*Corresponding author. E-mail: dickson.nguni@gmail.com Tel: +46 40 41 5000. Fax: +46 40 46 55 19.

three people being chronically hungry. A large proportion of people in this part of Africa especially in the rural communities are poor and live on a diet composed primarily of staple foods prepared from cereals, including sorghum, tubers and plantains (Oniang'o et al., 2003). Sorghum is rich in minerals whose bioavailability range from low (less than 1% for some forms of Fe) to higher than 90% for Na and K. Compared with barley and rye, sorghum grains exhibit low profile for P, K, Mg, Ca, Na, Zn, Fe, Mn and, Cu (Ragaee et al., 2006). Preliminary studies observed similarity in mineral contents between sorghum and millet, but noted low Ca content in two sorghum varieties differing in grain colour (Hulse et al., 1980). K and P were reported to be dominant minerals in sorghum grain (Khalil et al., 1984). The grain mineral contents of crop species are influenced by the effects of genotypes and environments (Zhao et al., 2009; Hussain et al., 2010; Zhang et al., 2010) and that genotype-environment interactions (GxE) complicate the development of improved genotypes for a crop in a targeted environment (Mgonja et al., 2008). The quality characters of improved varieties such as micronutrient contents vary greatly in their performance in a wide range of environments although some varieties are able to perform well in a wide range of environments. Multi-location trials of different genotypes provide an opportunity to assess the effects of GxE in order to discern the pattern of genotypic adaptation over sampled environments and evaluate stability of quality parameters across end user locations.

Southern Africa possesses substantial diversity of sorghum that has been selected by local farmers over the years and they continue to do so to fulfill a wide spectrum of users' criteria. The high genetic differentiation exhibited among some cultivated sorghum genotypes (Ng'uni et al., 2010) may suggest the potential for genetic differences in grain mineral content. Screening of local germplasm for identification of superior source materials for breeding in the sorghum varieties is a crucial step in the genetic enhancement for grain mineral contents. To our knowledge, the southern Africa sorghum germplasm have not been investigated for variation in grain mineral contents and thus their potential use in crop improvement remains less understood. Hence, the objectives of the present study were to analyze the mineral composition of sorghum farmer and improved varieties from southern Africa and evaluate their potential for varietal improvement in various macro and micronutrients.

MATERIALS AND METHODS

Plant materials

Forty sorghum accessions including twenty seven accessions of farmer varieties and thirteen accessions of improved varieties were used in this study (Table 1). The farmer varieties were obtained from national gene banks of Malawi (7 accessions), Tanzania (5 accessions) and Zambian (15 accessions). The geographical distribution of the sorghum accessions was such that accessions from Zambia were originally from the north and south regions of the country (Figure 1). The Malawian accessions were collected from the southern and parts of central regions of the country. Four of the sorghum accessions obtained from Tanzania were collected from the northern region and one accession was collected from the southern region of that country. All the improved varieties used in this study were obtained from the sorghum and millet improvement program of Zambia. The improved varieties did not have information related to latitude, longitude and nearest town.

Measurement of one thousand kernel weight (TKW) and seed density

For each sorghum accession, thousand kernel weights was determined based on weight of 100 dry grains weighed using a 10-4 precision balance and seed density was determined by dividing the weight by constant volume of the representative sample of each accession. These measurements were made in two replicates for each accession.

Sample drying and digestion

About 50 g of grains of each accession was milled to flour using a laboratory mill (Yellow line, A10, IKA-Werke, Staufen, Germany). Following milling before digestion, samples were freeze dried to constant dry weight over a period of four days. About 0.5 g of each flour sample was digested with 10 ml of concentrated nitric acid (HNO3) using a microwave digester (microwave labstation Mars 5, CEM Corporation, Mathews, NC, USA). The digested samples were diluted to 100 ml with distilled water and thoroughly mixed before analysis.

Mineral content analysis

The digested samples were analyzed for mineral contents at the ICP laboratory, Department of Ecology, Lund University, Sweden using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES; Perkin-Elmer, OPTIMA 3000 DV). The atomic spectrometry standards from Perkin-Elmer, SPEX, AccuStandard and Merck were used during the analysis. The ICP-AES instrument was calibrated using a mixed multi-component standard at three contents within the factor of 50. Mineral elements determined in this assay were B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S, Se and Zn.

Data analysis

Significant differences among samples for different minerals were evaluated by analysis of variance (ANOVA) using InfoStat (Di Rienzo et al., InfoStat version 2010). The means were separated using Tukey tests.

The Pearson correlations were also estimated among various macro and micronutrients and between the nutrients and thousand seed weight and seed density.

RESULTS

Grain macronutrient contents of sorghum varieties of the minerals analyzed in this study, Ca, K, Mg, P, Na and S were nutritionally macronutrients in sorghum. The study

Table 1. (a) Sorghum varieties used in this study and their specific grain colour, thousand grain weight and seed density. (b) The farmer varieties have collection location data and nearest town to collection site in their countries of origin.

Accession	Latitude	Longitude	Nearest town	Country	Grain colour	1000SW (g)	SD (g/cm^3)
[Framida x 3845]F6-5[i]	-	-		Zambia	Brown	31.2	0.6
ELT-1-17[i]	-	-		Zambia	White	13.1	0.4
Kuyuma[i]	-	-		Zambia	White	25.4	0.8
Maci[i]	-	-		Zambia	White	13.9	0.5
MMSH-1040[i]	-	-		Zambia	White	14.2	0.4
MMSH-1257[i]	-	-		Zambia	White	14.8	0.6
MMSH-1324[i]	-	-		Zambia	White	11.4	0.6
MMSH-1346[i]	-	-		Zambia	White	18.1	0.6
MMSH-1365[i]	-	-		Zambia	Brown	13.4	0.4
MMSH-375[i]	-	-		Zambia	Brown	15.8	0.5
MMSH-740[i]	-	-		Zambia	Brown	15.8	0.5
Sima[i]	-	-		Zambia	White	34.6	0.7
ZSV-15[i]	-	-		Zambia	White	22.3	0.5
MW1781[f]	15°39'00.0"	35°39'60.0"	Ngozi TC	Zambia	White	24.0	0.8
MW1788[f]	13°46'60.0"	34°29'00.0"	Salima	Malawi	Brown	24.6	0.8
MW1798[f]	13°41'60.0"	34°15'59.7"	Chitala Res	Malawi	Brown	15.7	0.8
MW409[f]	16°21'60.0"	34°41'00.0"	Chikwakwa	Malawi	White	24.2	0.8
MW467[f]	16°01'59.9"	35°25'59.9"	Mulanje	Malawi	White	23.1	0.8
MW679[f]	16°07'12.0"	35°07'59.9"	Majiga	Malawi	White	28.4	0.8
MW734[f]	14°52'00.1"	35°02'60.0"	Machinga	Malawi	White	26.7	0.7
TZ3866[f]	10°07'12.0"	38°28'12.0"	Nachingwea	Tanzania	White	19.0	0.9
TZ3938[f]	1°31'55.9"	34°30'36.0"	Serengeti	Tanzania	Brown	14.8	0.4
TZ3966[f]	1°42'09.0"	34°32'54.9"	Serengeti	Tanzania	Brown	14.4	0.7
TZ4031[f]	2°22'40.9"	32°26'27.9"	Ukerewe	Tanzania	Brown	11.2	0.6
TZ4255[f]	1°58'40.9"	31°32'42.7"	Muleba	Tanzania	Brown	12.0	0.6
ZMB3947[f]	12°16'60.0"	33°09'60.0"	Lundazi	Zambia	Brown	22.5	1.1
ZMB4859[f]	11°8'60.00"	24°18'0.00"	Mwinilunga	Zambia	White	32.9	0.7
ZMB5076[f]	13°10'60.0"	30°19'60.0"	Serenje	Zambia	White	34.3	0.7
ZMB5395[f]	13°36'00.0"	29°22'60.0"	Mkushi	Zambia	Brown	27.2	0.7
ZMB5788[f]	16°22'60.0"	23°2'34.0"	Shangombo	Zambia	White	28.0	0.7
ZMB6733[f]	12°58' 23"	27°54' 36"	Lufwanyama	Zambia	Brown	16.5	0.7
ZMB6847[f]	16°29' 43"	27°59' 16"	Gwembe	Zambia	White	35.9	0.6
ZMB6956[f]	11°6'4.44"	33°6'56.52"	Chama	Zambia	Brown	24.1	0.7
ZMB6986[f]	11°0'58.74"	33°1'52.80"	Chama	Zambia	Brown	16.0	0.7
ZMB7104[f]	15°4'19.06"	29°37'14.2"	Chongwe	Zambia	White	32.3	0.7
ZMB7105[f]	15°4'19.06"	29°37'14.2"	Chongwe	Zambia	Brown	19.2	0.6
ZMB7111[f]	15°9'40.07"	30°12'39.2"	Luangwa	Zambia	Brown	17.6	0.6
ZMB7198[f]	17°17'31.1"	24°39'33.2"	Sesheke	Zambia	Brown	18.6	0.7
ZMB7202[f]	17°32'28.6"	25°11'42.3"	Kazungula	Zambia	Brown	17.0	0.6
ZMB7207[f]	17°13'28.9"	27°23'19.6"	Sinazongwe	Zambia	White	22.5	0.8
Mean						21.17	0.65
CV (%)						33.58	22.02

[i] sorghum improved variety. [f] sorghum farmer variety.

revealed significant differences ($p < 0.0001$) among the investigated sorghum accessions for the macronutrients (Table 2). The grain Ca contents ranged from 5.2 to 38.1 mg/100 g with an average value of 15.4 mg/100 g. Values for Mg ranged from 109.8 to 224.1 with an average of 163.9 mg/100 g. Grain K ranged from 278 to

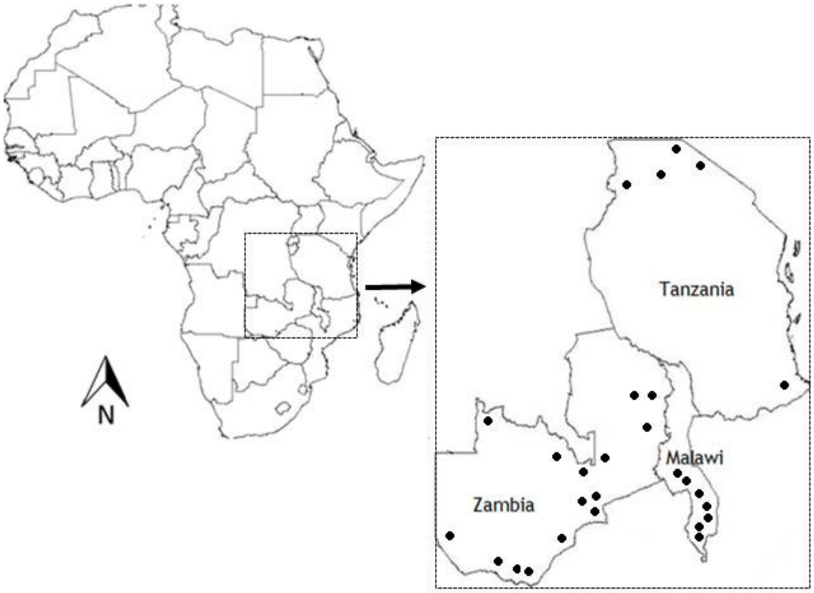

Figure 1. Map showing the localities of origin of sorghum farmer varieties in the three countries for the gene bank accessions in this study.

717.8 mg/100 g with a mean of 436.9 mg/100 g. Grain P was wide in range from 195 to 468 mg/100 g with an average of 343.8 mg/100 g. Similarly, S ranged from 112 to 275 mg/100 g with a mean of 149.4 mg/100 g.

Improved sorghum varieties exhibited higher profiles for grain macronutrient contents than farmer varieties. Among the improved varieties, ELT-1-17, Macia, MMSH-1040, MMSH-1257, MMSH-1324, MMSH-1365 and MMSH-740 ranked high for K, Mg and P grain contents. Comparatively, MMSH-1365 (25 mg/100 g) and ELT-1-17 (20 mg/100 g) had higher Ca content among the improved sorghum varieties. Although, MMSH-1040 was low in Ca content (15 mg/100 g), it exhibited high content in K (582 mg/100 g), Mg (217 mg/100g), Na (199 mg/100 g), P (456 mg/100 g) and S (265 mg/100 g). Kuyuma and Sima had the lowest grain contents for K, Mg and P among the improved varieties (Table 2).

Farmer varieties also exhibited differences among them for the macronutrient content. Analysis of Ca content revealed higher variation among farmer varieties than among improved varieties, as both the lowest and highest grain Ca content were obtained from farmer varieties. MW409, farmer variety from Malawi had the lowest (5 mg/100 g) whereas TZ3938, a farmer variety from Tanzania had the highest (38 mg/100 g) Ca content among sorghum accessions analyzed in this study. Among the Zambian sorghum accessions, ZMB6956 had the highest (30 mg/100 g) Ca content and was the second highest among all the accessions analyzed (Table 2). Magnesium content of farmer varieties from the three countries ranged from 118 mg/100 g (MW467) to 190 mg/100 g (MW734) (Table 2). Substantial differences in the K content were observed among the farmer varieties. MW467 had the lowest (291 mg/100 g) while TZ4031 had the highest (537 mg/100 g) K content ranking highly among improved sorghum varieties used in this study.

Nutritionally essential grain micronutrient contents of sorghum varieties

Sorghum accessions exhibited significant differences in grain micronutrient content for all micronutrients analyzed except for Se (P < 0.001) (Table 3). Grain Fe content ranged from 2.74 to 8.2 mg/100 g with a mean of 4.11 mg/100 g. A narrow range of 2.03 to 5.5 with the average of 2.79 mg/100 g was observed for grain Zn content. Comparatively, the average grain micronutrient content of 4.11 mg/100 g (Fe) and 2.97 mg/100 g (Zn), respectively occur in substantially higher levels in sorghum (Table 3).

Other micronutrients such as Cu ranged from 0.3 to 0.8 with an average of 0.46 mg/100 g and grain Mn ranged from 0.87 to 3.94 with a mean of 2.1 mg/100 g. The highest mean grain Fe content was obtained from ZMB5788 (8.03 mg/100 g) followed by MW734 (6.33 mg/100 g). This was followed by three accessions from Tanzania, TZ4255, TZ3966 and TZ4031 with grain Fe content of 5.78 mg/100 g, 5.41 mg/100 g and 5.27 mg/100 g, respectively. Grain Zn content was higher in farmer varieties than in improved varieties (Tables 3 and 4). The highest grain Zn content (5.5 mg/100 g) was obtained from TZ4031. This was followed by TZ3966 (4.51 mg/100 g), MW734 (3.89 mg/100 g) and ZMB7111 (3.89 mg/100 g). Analysis of grain Cu content revealed that ZMB4859, a Zambian accession, was the highest in

Table 2. Nutritionally essential grain macronutrient contents of sorghum varieties in mg/100 g[a].

Accession	Ca	K	Mg	Na	P	S
[Framida x 3845]F6-5[i]	11	428	132	158	311	122
ELT-1-17[i]	20	684	209	164	429	185
Kuyuma[i]	11	372	111	194	258	127
Macia[i]	16	579	189	161	385	197
MMSH-1040[i]	15	582	217	199	456	265
MMSH-1257[i]	14	554	218	174	460	159
MMSH-1324[i]	17	664	214	194	445	166
MMSH-134[i]	14	470	184	198	359	190
MMSH-1365[i]	25	545	196	193	417	146
MMSH-375[i]	14	540	166	156	378	136
MMSH-740[i]	17	494	193	195	412	159
Sima[i]	10	398	124	194	310	129
ZSV-15[i]	10	510	179	196	413	155
MW1781[f]	13	345	157	177	288	156
MW1788[f]	17	370	153	174	274	155
MW1798[f]	13	424	182	174	339	160
MW409[f]	5	315	148	168	315	141
MW467[f]	11	291	118	168	201	148
MW679[f]	8	331	129	174	254	157
MW734[f]	12	381	190	173	392	188
TZ3866[f]	14	304	159	146	324	139
TZ3938[f]	38	500	144	171	338	116
TZ3966[f]	14	490	185	146	442	147
TZ4031[f]	16	537	171	161	412	153
TZ4255[f]	20	435	157	147	284	119
ZMB3947[f]	12	380	141	193	282	129
ZMB4859[f]	19	397	173	204	322	149
ZMB5076[f]	14	373	154	202	305	144
ZMB5395[f]	11	349	181	202	355	148
ZMB5788[f]	14	375	165	193	330	143
ZMB6733[f]	17	389	184	196	354	141
ZMB6847[f]	14	373	139	195	293	124
ZMB6956[f]	30	427	136	193	280	119
ZMB6986[f]	20	439	167	170	344	127
ZMB7104[f]	12	329	158	199	342	152
ZMB7105[f]	19	395	156	169	328	139
ZMB7111[f]	22	459	157	171	378	149
ZMB7198[f]	13	387	136	197	274	144
ZMB7202[f]	15	497	135	195	318	124
ZMB7207[f]	11	364	151	194	348	129
Mean	15.4	436.9	163.9	180.7	343.8	149.4
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
CV (%)	3.69	3.31	2.11	2.58	1.81	1.98

[a] Values are means ± SD. [i] sorghum improved variety. [f] sorghum farmer variety.

grain Cu content (0.80 mg/100 g), which was closely followed by another Zambian accession, ZMB5788 with 0.72 mg/100 g. ZMB7198 (0.52 mg/100 g) and TZ4031 (0.45 mg/100 g) exhibited superiority in grain B content of the sorghum accessions analyzed.

Comparison between improved versus local sorghum varieties

Comparatively, improved sorghum varieties showed significantly higher grain contents of Mg, K, P and S than

Table 3. Nutritionally essential grain micronutrient contents of sorghum varieties in mg/100 g[ab].

Accession	B	Fe	Cu	Mn	Se	Zn
[Framida x 3845]F6-5[i]	0.35	3.5	0.35	1.08	0.17	2.49
ELT-1-17[i]	0.23	4.21	0.41	2.08	0.12	2.73
Kuyuma[i]	0.33	4.61	0.31	1.12	0.13	2.71
Macia[i]	0.18	3.51	0.53	1.92	0.03	2.75
MMSH-1040[i]	0.03	4.51	0.42	2.13	0.16	3.29
MMSH-1257[i]	0.23	5.05	0.51	1.47	0.13	2.96
MMSH-1324[i]	0.13	3.79	0.49	1.67	0.19	2.55
MMSH-134[i]	0.13	3.61	0.41	1.85	0.08	2.97
MMSH-1365[i]	0.40	4.25	0.40	1.55	0.02	2.73
MMSH-375[i]	0.19	3.46	0.32	1.47	0.20	2.91
MMSH-740[i]	0.16	3.97	0.36	1.52	0.31	2.95
Sima[i]	0.30	3.23	0.36	0.96	0.01	2.04
ZSV-15[i]	0.29	3.93	0.47	1.22	0.12	2.23
MW1781[f]	0.18	3.70	0.51	2.63	0.03	2.99
MW1788[f]	0.12	3.20	0.38	2.29	0.29	2.55
MW1798[f]	0.14	3.85	0.38	2.81	0.16	2.97
MW409[f]	0.09	2.83	0.36	1.89	0.01	2.62
MW467[f]	0.03	3.35	0.52	1.29	0.18	2.32
MW679[f]	0.13	3.90	0.37	1.33	0.04	2.49
MW734[f]	0.08	6.33	0.65	2.22	0.19	3.89
TZ3866[f]	0.19	3.90	0.52	1.77	0.07	3.42
TZ3938[f]	0.38	4.67	0.46	1.47	0.11	2.73
TZ3966[f]	0.10	5.41	0.67	1.93	0.02	4.51
TZ4031[f]	0.45	5.27	0.44	2.63	0.06	5.51
TZ4255[f]	0.24	5.78	0.57	2.71	0.08	2.72
ZMB3947[f]	0.20	4.51	0.36	2.67	0.06	2.63
ZMB4859[f]	0.19	4.12	0.80	3.58	0.22	3.26
ZMB5076[f]	0.19	3.40	0.33	3.87	0.12	2.61
ZMB5395[f]	0.12	4.04	0.56	2.91	0.21	3.47
ZMB5788[f]	0.19	8.03	0.72	2.48	0.19	3.31
ZMB6733[f]	0.29	3.72	0.47	3.21	0.10	3.58
ZMB6847[f]	0.19	2.93	0.55	2.30	0.16	2.42
ZMB6956[f]	0.28	2.79	0.45	2.22	0.09	2.44
ZMB6986[f]	0.23	4.38	0.37	2.60	0.14	2.82
ZMB7104[f]	0.25	3.44	0.33	1.96	0.21	2.85
ZMB7105[f]	0.30	3.55	0.46	3.50	0.23	3.50
ZMB7111[f]	0.40	4.81	0.61	1.91	0.03	3.89
ZMB7198[f]	0.52	4.11	0.37	1.46	0.36	2.50
ZMB7202[f]	0.26	3.18	0.63	1.24	0.03	2.79
ZMB7207[f]	0.25	3.56	0.41	1.31	0.21	2.84
Mean	0.22	4.11	0.46	2.06	0.13	2.97
P-value	<0.0001	<0.0001	<0.0001	<0.0001	Ns	<0.0001
CV%	27.18	10.73	2.74	1.92	83.01	2.92

[ab] Values are means ± SD. [i] sorghum improved variety. [f] sorghum farmer variety.

farmer varieties suggesting that sorghum varietal improvement had resulted in a significant increase in these macronutrients. The average grain Mg, K, P and S contents of improved sorghum varieties were 179.4 mg/100 g, 524.7 mg/100 g, 387.4 mg/100 g and 164.4 mg/100 g, respectively (Table 4). On the contrary, farmer varieties exhibited significantly higher ($p \leq 0.05$) grain contents of micronutrients for Zn (3.1 mg/100 g), Cu (0.5 mg/100 g) and Mn (2.3 mg/100 g (Table 3). The results have also demonstrated superiority of farmer varieties for

Table 4. Comparison of mean grain mineral content (g/100 g) in sorghum accessions based on variety type, grain colour (brown and white) and country of origin. Only farmer varieties were used for mean mineral content comparisons based on country of origin.

Group	Ca	Mg	K	Na	P	S	Zn	B	Cu	Fe	Mn
Level of genetic improvement											
Improved variety (n=13)	15.0a	179.4b	524.7b	182.8a	387.4b	164.4b	2.7a	0.2a	0.4a	3.9a	1.5a
Farmer variety (n=27)	15.6a	156.6a	394.7a	179.6a	322.8a	142.2a	3.1b	0.2a	0.5b	4.2a	2.3b
Grain colour											
Brown (n=19)	17.9b	161.7a	446.7b	176.9a	343.2a	138.5a	3.1a	0.3b	0.5a	4.2a	2.2a
White (n=21)	13.1a	165.9a	428.1a	184.1a	344.3a	159.2b	2.8a	0.2a	0.5a	4.1a	2.0a
Country of origin of farmer varieties											
Malawi (n= 7)	11.4a	153.9a	350.9a	172.4b	294.8a	158.0b	2.8a	0.1a	0.4a	3.9a	2.1a
Tanzania (n=5)	20.4c	163.1a	453.2c	154.4a	360.1b	134.8a	3.8b	0.3b	0.5a	5,0b	2.1a
Zambia (n=15)	16.1b	155.6a	395.6b	191.4c	323.5a	137.3a	2.9a	0.3b	0.5a	4.0a	2.5a

Means with the same letters within a column and under the same subheading (mineral element) do not differ significantly (Tukey Test at $p \leq 0.05$).

grain Fe and Zn contents when compared with improved varieties. This is clearly evidenced by the superiority of five accessions of farmer varieties TZ4031, TZ3966, TZ4255, MW734 and ZMB5788 for grain Fe (5.27 to 8.03 mg/100 g) and five accessions ZMB7105, ZMB6733,MW734, ZMB7111 and TZ4031 for grain Zn contents (3.5 to 5.51 mg/100 g (Table 3).

Sorghum grain colour and mineral contents

A significant relationship was found between grain colour and mineral contents. Sorghum varieties with brown grain exhibited significantly higher grain content for Ca (18.3 mg/100 g), K (431.9 mg/100 g) and B (0.3 mg/100 g) than varieties with white grains (Table 4). However, white sorghum varieties exhibited significantly higher grain S content (159.2 mg/100 g) as compared to those with brown grains.

Comparison of countries of origin of farmer varieties for grain mineral contents

Analysis of variance for grain mineral contents of farmer varieties grouped according to country of origin showed some significant differences in grain mineral content for Ca, K, Na, P, S, Zn, B and Fe (Table 4). Sorghum accessions from Tanzania had significantly higher grain mineral content of Ca (20.4 mg/100 g), K (453.6 mg/100 g), P (360.1 mg/100 g), Zn (3.8 mg/100 g) (Table 4). However, ANOVA indicated no significant difference between countries for grain Mg, Cu and Mg contents.

Association of grain macro and micronutrient TSW

The Pearson correlation of grain macro and micronutrients with thousand seed weight and seed density are presented in Table 5. There was a significant positive correlation between grain Fe and Zn contents (r = 0.46), Fe and Cu (r = 0.45), Zn and Cu (r = 0.39), Zn and P (r = 0.43), K and Mg (r = 0.67), K and P (r = 0.77), K and S (r = 0.42), Mg and P (r = 0.88), Mg and S (r = 0.66), S and P (r = 0.53). Grain Ca, K, Mg, P, S and Zn showed negative correlations with TSW r = -0.39, -0.66, -0.53, -0.53, -0.26 and -0.32, respectively

DISCUSSION

Variation among sorghum accessions for grain mineral contents

Genetic biofortification through plant breeding is a widely accepted, cost effective and the most sustainable approach to minimize the extent of mineral nutrient deficiencies, especially micronutrient deficiencies such as Fe and Zn

Table 5. Estimates of correlation coefficients between mineral elements, thousand seed weight (TSW) and seed density (SD).

	TSW	SD	Ca	Cu	Fe	K	Mg	Mn	P	S	Zn
TSW	1.00										
SD	0.45**	1.00									
Ca	-0.39**	-0.45**	1.00								
Cu	0.01	-0.08	0.14	1.00							
Fe	-0.20	-0.08	0.09	0.45**	1.00						
K	-0.66**	-0.72**	0.39**	0.01	0.13	1.00					
Mg	-0.53**	-0.52**	0.14	0.20	0.28	0.67**	1.00				
Mn	0.12	0.16	0.14	0.27**	0.12	-0.17	0.21	1.00			
P	-0.53**	-0.61**	0.15	0.14	0.27**	0.77**	0.88**	-0.04	1.00		
S	-0.26*	-0.39**	-0.15	0.05	0.12	0.42**	0.66**	0.07	0.53**	1.00	
Zn	-0.32**	-0.09	0.05	0.39**	0.46**	0.11	0.34**	0.36**	0.43**	0.20	1.00

** = Significant correlation at $P<0.05$, 0.01 (2 tailed).

(Cakmak, 2008). This strategy is not only potentially a conveyor belt reaching out even to the remotest areas but, it is also affordable by people especially in the developing world. Identifying the sources of desirable genetic variants is critical for the success of genetic biofortification. This study has demonstrated a significant variation in mineral content among the sorghum varieties. However, grain mineral contents are influenced by genotypes, environments and probably by genotype-environment interactions (House, 1999). For example, genetic as well as environmental factors have been shown to significantly affect Fe and Zn levels in maize and wheat (Graham et al., 1999; Bänzinger and Long, 2000) and the same is expected in sorghum.

Similarly, Ficco et al. (2009) reported that there were about two-fold differences in Fe, Zn and Mn grain contents for durum wheat grown under different environments which was mainly attributed to the genetic effect. Therefore, part of the significant variation obtained in this study is due to genotypic variation among varieties in relation to grain mineral contents and suggests the existing genetic potential in the studied genetic material for the improvement of sorghum varieties in macro and micronutrients. ll the improved sorghum varieties in this study except Kuyuma and Sima showed superiority in grain macronutrient content, but the latter two improved varieties are perhaps the most popular and commonly cultivated in Zambia (Chisi, 2007). The Zambian sorghum and millet improvement programme has focused on the development of sorghum varieties with different agro-ecological adaptation and high yielding (Chisi, 2007) but has not targeted the improvement of grain mineral contents.

Therefore, the observed high grain mineral contents of K, Mg and P in improved varieties perhaps suggests some association between the targeted traits and the grain mineral contents. This study showed that P and K were the dominant grain macronutrients in sorghum varieties when compared with Ca, Mg, Na and S with Ca taking the lowest rank. In that sense, these sorghum varieties were comparable to other elite cereals from the point of view of their potential to accumulate grain minerals in their grain (Akundabweni et al., 2010; Mohammed et al., 2010). Micronutrient-enriched sorghum varieties will provide the nutritional needs of the poor small-scale farmers in semi arid regions of Africa as well as Asia, most of whom grow their crops such as sorghum under low external input system (Graham et al., 2001). The highest grain contents of Fe and Zn obtained in this study was 8 mg/100 g (ZMB5788) and 5 mg/100 g (TZ4031), respectively. The recommended intake level for Fe and Zn for an adult person aged 25 -to 50 years is 10 and 15 mg, respectively (FAO/WHO, 2000). This implies that an adult person who gets its Fe and Zn mainly from sorghum will need to consume about 400 g of grain of these sorghum varieties in order to satisfy the needs for these minerals.

Breeding for increased grain micronutrients should consider strategies that keep pace with rates of progress for value-added traits, such as yield that increase chances of adoption of varieties by farmers. In some cases, biofortification programmes are associated with problems of lack of association among the desired traits. Earlier studies demonstrated that grain yield related traits were weak or negatively correlated with grain Fe and Zn contents in maize (Bänzinger and Long, 2000) and sorghum (Ashok Kumar et al., 2010), which are commonly grown cereal staple crops in sub Saharan Africa. The results of the present study is also in line with these studies, as grain Fe and Zn contents were higher in farmer varieties than in the improved varieties. Thus, mutants that break this association should be searched for in the global sorghum gene pool.

The significant positive correlations observed between grain minerals e.g. Fe–Cu (r = 0.45), Zn-Fe (r = 0.46), Zn-P (r = 0.43) and S-Mg (r = 0.66). In this study (Table 5) indicates that either genetic factors for each pair of minerals are associated, or physiological mechanisms were interconnected for their uptake/translocation in the grains indicating that there is potential of simultaneous genetic improvement for two or more grain minerals (Ashok Kumar et al., 2010). Thousand seed weight, a parameter that is closely linked with grain size and yield was also negatively correlated with grain Fe and Zn contents among other minerals in this study. Thousand seed weight is one of farmer-preferred variety attributes and therefore one of the traits that have influence on farmer's selection pattern of varieties for cultivation and maintenance. Therefore, in order to realize increased impact of improved nutrient rich varieties, the macro and micronutrients should be packaged in high thousand seed weight sorghum varieties.

Grain colour and grain mineral contents in sorghum

This study has shown that grain Ca, K, S and B contents have some association with grain colour as Ca, K and Bare higher in brown grains than in white grains whereas findings suggest that seed colour needs to be taken into S is higher in white grains than in brown grains. The consideration when evaluating genetic materials for the content of these minerals. The present study has revealed no significant differences between brown and white sorghum grains for Fe and Zn contents. Our study is in agreement with Kayode et al. (2006) who also reported insignificant differences in grain Fe and Zn contents between grains of different colours (red, white, pink and yellow). Therefore, whereas high grain macronutrients of Ca, K and B seem to be associated with brown grained varieties, selection for high Fe or Zn grain content may not automatically translate into selection for a desired grain colour. However, further studies that involve large number of accessions of different seed colour should be conducted to establish the suggested association.

Conclusion

A significant variation among the sorghum varieties was evident for both macro- and micronutrients. Identification of sorghum genetic materials that have a potential of attaining desirable levels of macro and micronutrients from southern African countries is promising. Improved sorghum varieties ELT-1-17, MMSH-1040, MMSH-1257 and MMSH-1324 were more superior for grain macronutrient contents than farmer varieties and ranked highly for grain K, Mg, S and P contents. Farmer varieties, ZMB5788, MW734 and TZ4255 showed superiority for grain Fe content while TZ4031, TZ3966 and ZMB7111 were high in grain Zn content. However, this variation is due to both environmental and genetic factors and their interactions. To identify the best starting genetic material for breeding for desirable levels of macro and micronutrients, superior accessions identified in this study and other accessions that will be identified in the future should be further studied both under the same and different environmental conditions. This is necessary not only for the evaluation of the heritability of the traits and the maximum potential of the accessions but also to determine suitable environmental conditions under which these desirable levels can be attained. Such superior sorghum germplasm are the best starting material for the development or improvement of varieties for increased micronutrients and improved nutritional quality in semi-arid tropics where sorghum is a staple crop.

ACKNOWLEDGEMENTS

The authors would like to thank Swedish International Development Cooperation Agency (Sida) for providing financial support for this research. We are also thankful to Malawian, Tanzanian and Zambian gene banks for the provision of sorghum germplasm used in this study. We are indebted to Tommy Olsson from Lund University for his technical assistance during the chemical analysis.

REFERENCES

Akundabweni LSM, Munene RW, Maina DM ,Bartilol SK (2010). Mineral Micronutrient Density in local cereals sampled from Bungoma, Maseno and Kibwezi areas. Afr. J. Food Agric. Nutr. Dev., 10(11): 4301-4319.

Ashok Kumar A, Reddy BVS, Sahrawat KL, Ramaiah B (2010). Combating micronutrient malnutrition: identification of commercial sorghum cultivars with high iron and zinc. J. SAT Agric. Res., P. 8.

Barikmo I, Ouattara F ,Oshaug A (2007). Differences in micronutrients content found in cereals from various parts of Mali. J. Food Compos. Anal., 20(8): 681-687.

Bänzinger M, Long J (2000). The potential for increasing the iron and zinc density of maize through plant breeding. Food Nutr. Bull., 21: 397-400.

Cakmak I (2008). Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant Soil, 302: 1-17.

Chisi M (2007). Impact assessment of sorghum research in Zambia. In Impact of science on African agriculture and food security CABI, Wallingford, UK, pp. 137-146.

Di Rienzo JA, Casanoves F, Balzarini MG, Gonzalez L, Tablada M, Robledo CW (InfoStat version 2010). InfoStat Group. College of Agricultural Sciences, Nacional University of Cordoba, Argentina.

FAO (2008). The state of food insecurity in the world: High food prices and food security - threats and opportunities. Rome, Italy.

FAO (2011). FAOSTAT. http://faostat.fao.org.

FAO/WHO (2000). Preliminary report on recommended nutrient intakes. Joint FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements, FAO, Bangkok, Thailand, September 21-30, 1998, revised July 13, 2000. Food and Agricultural Organization of the United Nations Rome, Italy and World Health Organization, Geneva, Switzerland.

FAO/WHO (2001). Human vitamin and mineral requirements, 2nd ed. Geneva, Switzerland.

Ficco DBM, Riefolo C, Nicastro G, De Simone V, Di Gesu AM, Beleggia R, Platani C, Cattivelli L, De Vita P (2009). Phytate and mineral elements concentration in a collection of Italian durum wheat cultivars. Field Crops Res., 111: 290-295.

Graham R, Senadhira D, Beebe S, Iglesias C, Monasterio I (1999). Breeding for micronutrient density in edible portions of staple food crops: Conventional approaches. Field Crops Res., 60: 57-80.

Graham RD, Welch RM ,Bouis HE (2001). Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods:

principles, perspectives and knowledge gaps. Adv. Agron., 70: 77-142.

House W (1999). Trace element bioavailability as exemplified by iron and zinc. Field Crops Res., 60: 115-141.

Hulse JH, Laing EM, Pearson OE (1980). Sorghum and millet: their chemical composition and nutritive value. New York: Academic Press.

Hussain A, Larsson H, Kuktaite R, Johansson E (2010). Mineral composition of organically grown wheat genotypes: Contribution to daily minerals intake. Int. J. Environ. Res. Pub. Health, 7: 3442-3456.

Ihnat M (2003). A survey of methods of analysis for minerals in feedstuffs. J. Anim. Sci., 81: 3218-3225.

Kayode APP, Linnemann AR, Hounhouigan JD, Nout MJR ,Van Boekel M (2006). Genetic and environmental impact on iron, zinc, and phytate in food sorghum grown in Benin. J. Agric. Food Chem., 54(1): 256-262.

Khalil JK, Sawaya WN, Safi WJ, AL-Mohammad HM (1984). Chemical-composition and nutritive quality of sorghum flour and bread. Plant Food Hum. Nutr., 34: 141-150.

Mgonja MA, Chandra S, Obilana AB, Monyo ES, Kudita S, Chisi M, Saadan HM, Chinhema E (2008). Stratification of sorghum hybrid testing sites in southern Africa based on grain yield. Field Crops Res., 108 193-197.

Mohammed NA, Ahmed IAM, Babiker EE (2010). Nutritional evaluation of sorghum flour (Sorghum bicolor L. Moench) during processing of Injera. Int. J. Biol. Life Sci., 6(1): 35-39.

Ng'uni D, Geleta M, Fatih M, Bryngelsson T (2010). Phylogenetic analysis of the genus Sorghum based on combined sequence data from cpDNA regions and ITS generate well-supported trees with two major lineages. Ann. Bot., 105: 471-480.

Oniang'o RK, Mutuku JM, Malaba SJ (2003). Contemporary African food habits and their nutritional and health implications. Asia Pac. J. Clin. Nutr., 12: 231-236.

Ragaee S, Abdel-Aal EM, Noaman M (2006). Antioxidant activity and nutrient composition of selected cereals for food use. Food Chem., 98(1): 32-38.

Reddy Belum VS, Ramesh S, Longvah T (2005). Prospects of breeding for micronutrients and carotene-dense sorghums. J. SAT Agric. Res., 1: 1-4.

Zhang Y, Song Q, Yan J, Tang J, Zhao R, Zhang Y, He Z, Zou C, Ortiz-Monasterio I (2010). Mineral element concentrations in grains of Chinese wheat cultivar. Euphytica, 174: 303-313.

Zhao FJ, Su YH, Dunham SJ, Rakszegi M, Bedo Z, McGrath SP, Shewry PR (2009). Variation in minerals micronutrient concentrations in grain of wheat lines of diverse origin. J. Cereal Sci., 49: 290-295.