Protein content, in-vitro protein digestibility (IVPD), anti-nutritional factor and mineral content and bioavailability of sixteen sweet sorghum (*Sorghum bicolor* L Moench) grain genotypes grown in Sudan

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Abstract

The objective of this study was to evaluate the protein content, in vitro protein digestibility (IVPD), tannin content, phytic acid content, total polyphenol content and total and bioavailability of minerals of sixteen genotypes of sweet sorghum grains grown in Sudan. The protein content of the samples ranged from a high of 15.1% for S6 genotype to a low of 6.0% for AD13 genotype. The IVPD investigation showed that there was no significant differences among the most of the genotypes, except AD7, $ADS_2$6 and $ADS_1$6 which revealed the lower values of the IVPD. Most of the sweet sorghum genotypes contain low levels of antinutritional factors. The profile of mineral content and bioavailability indicated that sweet sorghum grains are rich source of essential minerals with high bioavailability rate. These, results showed that sweet sorghum grains from different genotypes have the potentiality to develop new value-added products for grains biofortification.

Keywords: Sweet sorghum, genotypes, protein, antinutritional factors, minerals bioavailability

1. Introduction

Sweet sorghum (*Sorghum bicolor* L. Moench) received extensive attention as feedstock for bio-ethanol production (Goff et al., 2010; Ratnavathi et al., 2010). It is known as a C4 species with high photosynthetic capacity and inherent high biomass yield potential. Compared to other sorghum species, sweet sorghum produces less grain, however, it has high photosynthetic efficiency and capacity to produce high biomass and sugar yield (Zhao et al., 2009). Its stalk contains an appreciable amount of sugar (16–23°Brix) similar to sugarcane (Smith et al., 1987; Bennett and Anex, 2009; Ratnavathi et al., 2011). The juice from the fresh stems of sweet sorghum contains sucrose, glucose and fructose, which can be directly fermented to produce bio-alcohol (Tew et al., 2008; Sipos et al., 2009). Economically, the cultivation cost of sweet sorghum is three times less than that of sugarcane (Reddy et al., 2005) since it matures and harvested in a single season (Grassi, 2001).

Sweet sorghum, is considered a multipurpose crop (food, feed, fodder and fuel), it has the potential as an alternative biofuel feedstock without affecting food and fodder security (Rooney et al., 2007). Several studies

reported that sweet sorghum's grain and stem can be used for sugar, alcohol, syrup, jaggery, fodder, fuel, bedding, roofing, fencing, paper and chewing in many areas of the world (Doggett, 1988; Laopaiboon et al., 2007; Liu et al., 2008). The bagasse produced from sweet sorghum is also used as forage or as raw material for the paper industry (FAO, 2009).

Sweet sorghum grain can be considered as one of an industrial crop with significant benefits particularly for bio-butanol production (Whitfield et al., 2012). It offers all the required elements for acetone-butanol-ethanol production (Mirfakhar et al., 2017). Such as other cereal grains its grain is rich in macro and micronutrients, it contains a high amount of starch content 72%, fat (2.3–2.8%) and protein (8.9–11.02%)(Udachan et al., 2012). Heidari et al., (2016), reported that some varieties of sweet sorghum grain have noticeable amounts of antinutritional factors such as tannins. However, some varieties are not acceptable as food due to dark color, sharp flavor, high fiber content, and very low gluten content, which make it unsuitable for bread and pastries production (Mehboob et al., 2015).

Throughout the world, India, Nigeria and Sudan are the leading countries in cultivation of sweet sorghum, with an area estimated as 7.5, 7.6 and 6.6 m ha, respectively (Dar et al., 2018). In Sudan, it is traditionally grown in many regions particularly in the middle-eastern and western parts of Sudan. It is cultivated mainly for animal feeding purpose, the vegetative part is used as forage and the grains are used as feed for livestock and birds (Sir ElKhatim, 2003). Our previous studies, on Sudanese local sweet sorghum genotypes showed promising findings on high yielding ability, high juice contents and good resistance to drought (Hud et al., 2017). Most of the investigation conducted on sweet sorghum was mainly as a source of biofuel. However, little attention has been paid to the nutritional quality of the grain. Therefore, the objective of this study was to study the compositional variation in mineral elements and protein contents of the grain of sweet sorghum genotypes and determine the association between them.

2. Material and methods

2.1. Plant materials and field experiments

In this study, 16 local sweet sorghum genotypes out of forty genotypes were used (table 1). These genotypes were selected based on their yielding rate, juice content and drought resistance. The field experiments were carried out at demonstration farm of the Faculty of Agriculture and Natural Resources, University of Bakht Al-Ruda, El-Dueim, White Nile State, Sudan during the season 2015. The climate is characterized as a short - humid air during the summer season and cold - dry during the winter season. The soil of the farm is non-saline and non-sodic clay soil. The soil particles proportions follow the order: clay> silt > sand. It has pH (paste) about 6.6, electrical conductivity (0.34 dSm-1) and nitrogen (0.022%). The experiments were designed as randomized complete block design (RCBD) with three replications. Each genotype was planted in 4 ridges 4 meters length with 70 cm between ridges. Seed rate was three seeds per hole spaced at 20 cm between holes. Sowing was carried out in the first week of July 2015. All cultural practices were done according to the recommendation of Agricultural Research Corporation, Sudan. In addition, thinning was carried out one week after sowing to raise two plants/hill. Weeding was done twice using the hand hoeing.

2.2. Sample preparation and milling

The sweet sorghum grains were cleaned from the extraneous materials. The samples were milled using laboratory miller and passed through 0.4 mm sieve. The sample flours were kept in a polyethylene bags at the room temperature. The obtained flours were used for biochemical analysis. Three independent replicates of each sample were used for biochemical analysis. All chemicals used in this study were of analytical grade.

2.3. Protein content and in vitro protein digestibility determination

The protein content of milled samples was determined using the micro-Kjeldahl method according to AOAC (1995). The in vitro protein digestibility (IVPD) was estimated in the samples using pepsin enzyme by the method of Maliwal (1983) cited from Monjula and John (1991).

Protein digestibility % = (digestible protein)/ (total protein) *100

Table 1: Sweet sorghum genotypes used in the current study

Genotypes code	Genotypes
G1	AD5
G2	$ADS_1$6
G3	$ADS_2$6
G4	AD7
G5	AD13
G6	$SDS_1$8
G7	$SDS_1$9
G8	$SDS_1$11
G9	$SDS_1$13
G10	ADS_{13}6
G11	S1
G12	S6
G13	SS8
G14	S14
G15	S17
G16	SS21

2.4. Phytic acid determination

The phytic acid content was measured by spectrophotometer according to the method defined by Wheeler and Ferrel (1971). A standard curve was prepared and results were shown as $Fe(NO_3)_3$ equivalent. Phytate phosphorus was calculated from the standard curve assuming a 4:6 iron to phosphorus molar ratio.

2.5. Tannin determination

Quantitative determination of tannins was carried out according to Price and Butler (1978) using the spectrophotometric vanillin-HCl method. A standard curve (R^2 = 0.9906) was prepared and results were expressed as catechin equivalents (mg per g).

2.6. Polyphenols determination

Polyphenols were performed according to Purssion Blue spectrophotometric method at 720 nm (Price and Butler, 1977). Sixty milligrams of ground sample were shaken manually for 1 min in 3.0 ml methanol. The mixture was filtered. The filtrate was mixed with 50 ml distilled water and analyzed within an hour. About 3.0 ml of 0.1 M $FeCl_3$ in 0.1 M HCl were added to 1.0 ml of the filtrate followed immediately by timed addition of 3.0 ml of freshly prepared $K_3Fe(CN)6$. The absorbance was monitored on a spectrophotometer at 720 nm after 10 min from the addition of 3.0 ml of 0.1 M FeCl3 and 3.0 ml of 0.008 M $K_3Fe(CN)6$.

2.7. Total mineral determination

Total minerals content of sweet sorghum grains were measured using atomic absorption spectrophotometer following the method of Chapman and Pratt (1982). Samples were charred in a muffle furnace at 550 °C and then the extract was dissolved in 5 ml of 5N HCl. The extracts were stored in bottles for further analysis. Fe and Zn content were determined using atomic absorption spectrophotometer.

2.8. HCl extractability of mineral

Minerals HCl extractability of the samples were determined according to Chauhan and Mahjan (1988). One gram of sample flour was dissolved and extracted in 10 mL of 0.03 M HCl for 3 h at 37 °C. The clear extract obtained was oven-dried at 60 °C and then acid digested following the method of Chapman and Pratt (1982). The HCl extractability (%) of the mineral was determined as follows:

HCl extractability % = (mineral extractable in 0.03 N HCl ÷ total mineral) × 100

2.9. Statistical analysis

Each determination was carried out on three separate samples and analyzed in triplicate on the dry weight basis; the figures were then averaged. Data were assessed by the analysis of variance (Snedecor and Cochran, 1987). Comparisons of means for treatments were made using Duncan's multiple range tests. Significance was accepted at $P < 0.05$.

3. Results

3.1. Protein content and in vitro protein digestibility (IVPD) of sweet sorghum genotypes grains

The percentage of the protein content of 16 sweet sorghum genotypes grains was shown in figure 1. The protein content of these genotypes exhibited significant ($P < 0.05$) genetic variation. It was ranged from 6.0 to 15.1%. Among these genotypes, S6 cultivar grains show the highest percentage of protein content (15.1%) followed by SS8 and S1 one (13.9 and 13.6), whereas, AD13 and $ADS_1$13 showed the lowest percentages of protein content which was found 6.0 and 6.6%, respectively.

Figure 2 shows the results of IVPD of the 16 genotypes. $ADS_3$6 genotype showed significantly high in vitro protein digestibility (25.75%), while $ADS_2$6 and AD7 $ADS_1$6 showed significantly ($P < 0.05$) low IVPD, 6.82, 17.65 and 17.99, respectively. There were no significant ($P < 0.05$) variation among the rest of sweet sorghum genotypes in their IVPD.

3.2. Antinutrients content of sweet sorghum genotypes grains

Phytic acid, tannin and total polyphenol content of sweet sorghum genotypes grains are presented in figures 3, 4 and 5. Phytic acid content (fig.3) in the sweet sorghum genotypes was ranged between 1.67 to 0.16 mg/g. Among the genotypes, the lowest phytic acid value was found in the $ADS_1$6 genotype, while the highest one was found in SS8 sample. However, the analysis of variance showed that there were no significant ($P < 0.05$) differences in phytic acid content among the rest of sweet sorghum genotypes.

As shown in figure 4, tannins content of grains showed significant ($P < 0.05$) differences among the genotypes, and it was ranged from 12.97 to 1.58 mg/g. The genotypes AD13 and AD7 showed the highest values of tannin content which were found to be 11.27 and 12.97 mg/g, respectively, whereas the lowest value 1.58 mg/g was found in the SS8 genotype.

Figure 5 illustrates the total polyphenol of the sweet sorghum genotypes. There was significant differences in total polyphenol content among the genotypes grain. The genotypes AD7 and $AD_3$6 have the highest values of total polyphenols 12.35 and 12.98 mg/g, respectively, while the genotype $S_1$4 has the lowest value of 0.89 mg/g total polyphenols.

3.3. Macro- and micro-elements content and extractability of sweet sorghum genotypes grains

The total content and extractability of major elements Ca, Mg, Na, K and P of 16 sweet sorghum genotypes is shown in tables 2a and 2b. The results revealed that most of the studied genotypes grains are rich source of the macro elements. There was significant ($P < 0.05$) variation in the total and available contents (table 2). The Ca content was ranged from 80.2 mg/100g for $SS_2$1 genotype to 15.8 mg/100g for the $SDS_1$11 genotype. Whereas, its extractability was varied from 75.4 to 23.7% for the genotypes AD5 and S1, respectively (table 2).

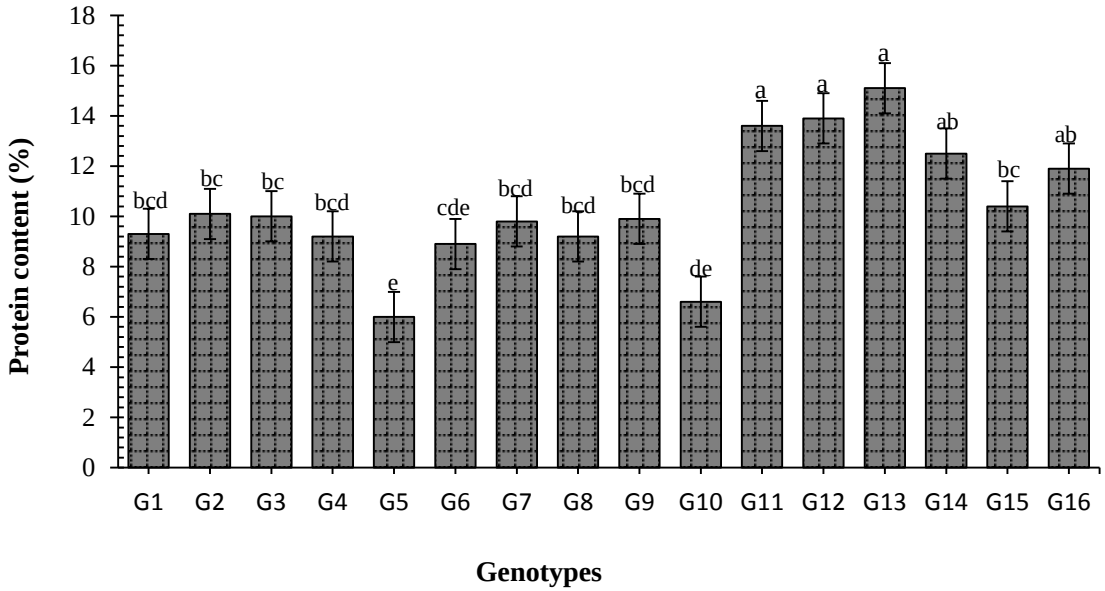

Fig.1 Protein content (%) of 16 local sweet sorghum genotypes grains. Values are means (±SD) of triplicate samples. Values followed by the same letter are not significantly different (P < 0.05) as assessed by LSD

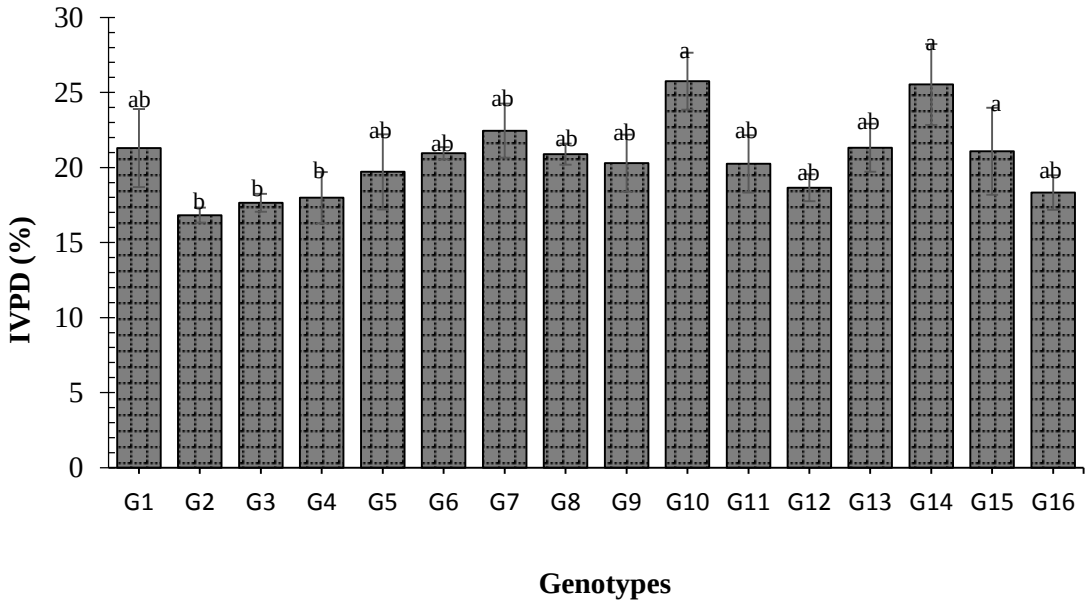

Fig. 2 In vitro protein digestibility (%) of 16 local sweet sorghum genotypes grains. Values are means (±SD) of triplicate samples. Values followed by the same letter are not significantly different (P < 0.05) as assessed by LSD

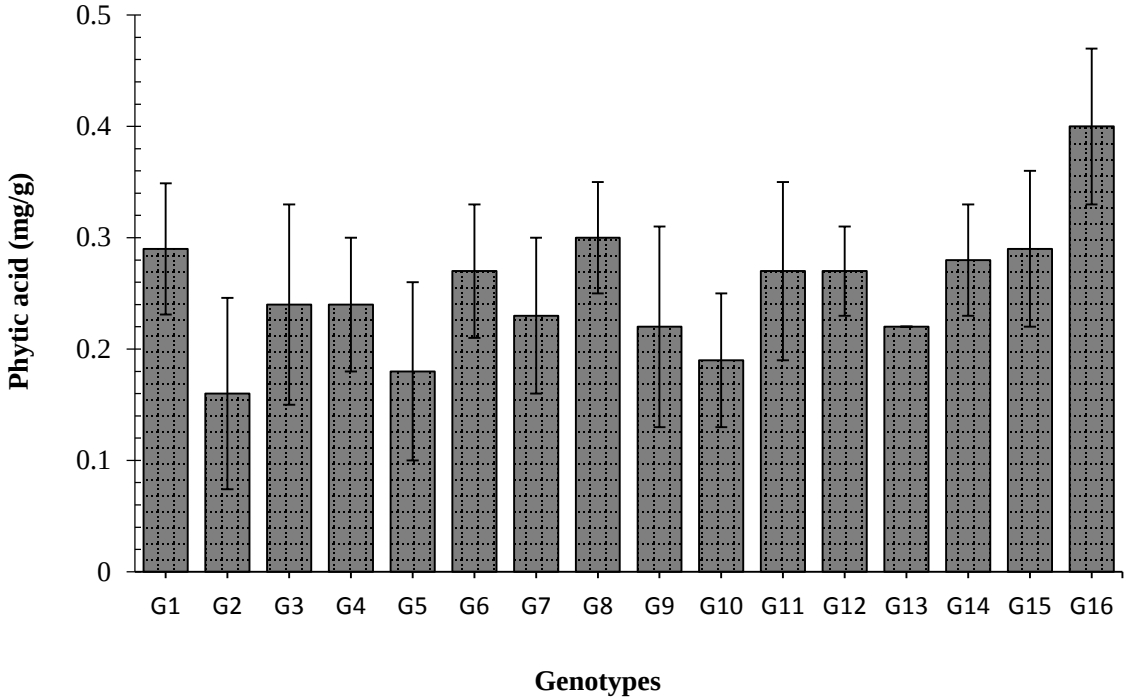

Fig. 3 Phytic acid content (mg/g) of 16 local sweet sorghum genotypes grains. Values are means (±SD) of triplicate samples. Values without letters are not significantly different (P < 0.05) as assessed by LSD

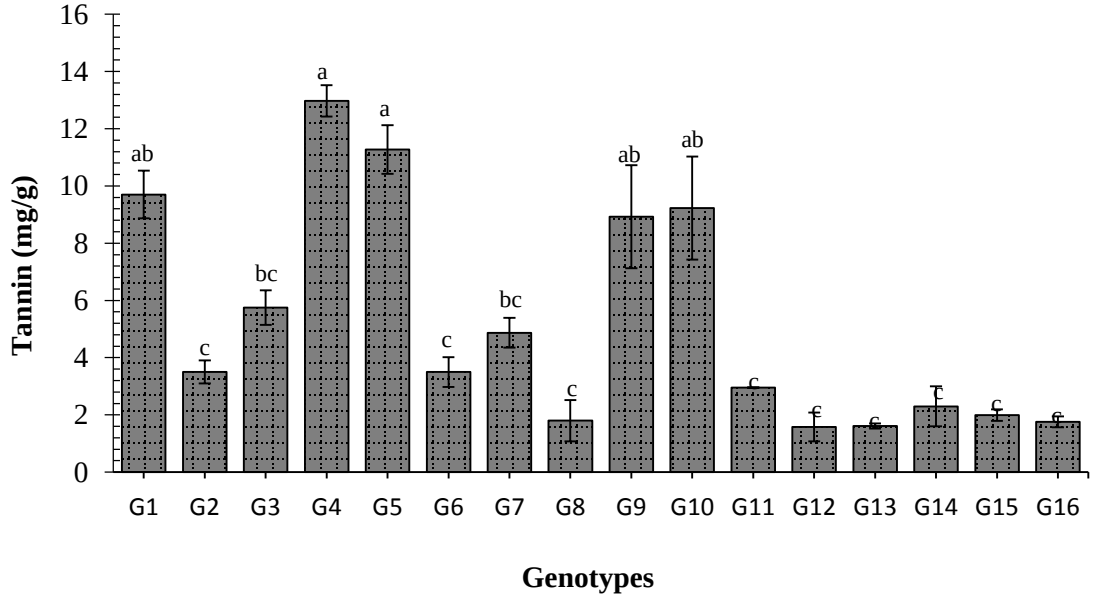

Fig. 4 Tannin content (mg/g) of 16 local sweet sorghum genotypes grains. Values are means (±SD) of triplicate samples. Values followed by the same letter are not significantly different (P < 0.05) as assessed by LSD.

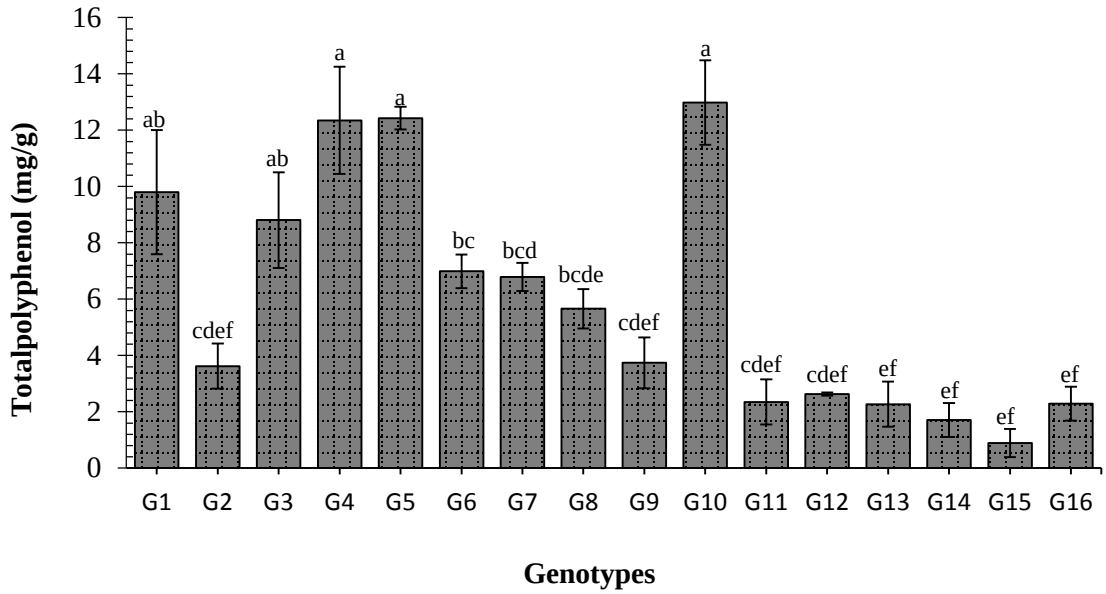

Fig. 5 Total polyphenol (mg/g) of 16 local sweet sorghum genotypes grains. Values are means (±SD) of triplicate samples. Values followed by the same letter are not significantly different ($P < 0.05$) as assessed by LSD.

Similarly, the content of Mg was significantly ($P < 0.05$) among the genotypes and ranged from 68.1.4 to 41.5 mg/100g. The highest Mg value was observed in the genotype ADS16 and the lowest was found in the AD13 genotype. The extractability rate of Mg was also varied among the genotypes. It was ranged between 59.1 and 23.2% in the grains of S17 and ADS16, respectively. Among the sweet sorghum genotypes, SS21 and S17 showed highest content of Na 68.5 and 66.2 mg/100g respectively, while the SDS_18, SDS_19 and SDS_111genotypes had the lowest Na content 30.8, 30.6 and 28.0 mg/100g, respectively (tables 2a and 2b). Similar to Ca and Mg, Na extractability showed significant variation among sweet sorghum genotypes. AD7, SS8 and S6 genotypes showed the highest values of the Na extractability 83.5, 89.7 and 56.7%, respectively. While AD5 genotypes had the lowest extractability (35.9%).

The total amount of potassium of the sweet sorghum genotypes was found to be in the range of 17.5 to 30.8 mg/100g. SDS_111genotyp record the highest K amount while the lowest amount was shown in the SDS_18 and SDS_19 genotypes. K extractability was significantly ($P < 0.05$) varied among the genotypes. It was ranged between 83.2 (ADS_16) and 19.22% (S14). Table 2a and 2b shows the content of P of sweet sorghum genotypes. The result revealed small variation among the genotypes but no significant ($P < 0.05$) differences were observed between the genotypes. In contract, there was significant in P extractability among sweet sorghum genotypes. The highest P extractability 60.0% was found in SS21 genotypes and the lowest value 11.5 % was found in SDS_111 genotype.

Microelements ($P < 0.05$) genetic variation for total and extractable Fe and Zn among the genotypes (table 3). Fe & Zn analysis in sweet sorghum grains, showed a significant variation. The total content of Fe is varied from 2.3 to 5.1 mg /100g. The AD13 genotype showed significantly ($P < 0.05$) higher content iron compared to the AD5 genotype with lowest Fe content. There was no significant differences in Fe content among the rest of the genotypes (table 3). The Fe extractability of the sweet sorghum genotypes showed significant ($P < 0.05$) variation among the genotypes. The highest Fe bioavailability 94.4 and 89.7% recorded in S17 and SS21 genotypes, respectively.

The content of Zn in grains of different sweet sorghum genotypes is shown in table 3. Most of the genotypes contained relatively high Zn content. Grains of the sweet sorghum accessions S14, ADS26, SDS18, ADS36 and SS8 demonstrated significantly higher total zinc contents than other genotypes, whereas AD5 and Ads16 genotypes showed the lowest Zn content among the genotypes (table 3). The bioavailability of Zn showed significant ($P < 0.05$) differences among the genotypes. It is varied from 28.6% for the sweet sorghum SS8 to 76.2% for the genotype ADS16 (table 3).

Table 2a: Total (mg/100g) and available (%) Ca, Mg and Na of sweet sorghum genotypes

genotypes	Ca		Mg		Na	
	Total	available	Total	available	Total	available
G1	28.5±0.00^{efg}	75.4±0.00^{a}	60.8±7.57^{bc}	28.2± 3.32^{fgh}	49.1±4.62^{bc}	35.5±4.06^{g}
G2	38.0±0.00^{de}	52.1±9.87^{bcd}	68.1±4.04^{b}	23.2±2.35^{h}	35.3±5.48^{de}	52.3±0.00^{ef}
G3	26.3±5.48^{fg}	51.2±9.86^{cd}	47.3±2.88^{ef}	35.5±6.70^{cdefg}	36.2±2.13^{de}	52.6±2.91^{ef}
G4	28.1 ±0.20^{efg}	49.3±6.64^{cd}	64.7±3.10^{b}	26.5 ±1.78^{gh}	47.2±2.40^{bcd}	83.5±0.00^{a}
G5	23.2±2.02^{gh}	54.4±4.56^{bc}	41.5±5.76^{f}	24.1±5.25^{h}	37.8±8.50^{cde}	45.2±5.97^{f}
G6	31.3±3.78^{efg}	32.9±9.21^{ef}	50.7±0.28^{def}	40.1±5.69^{cde}	30.8±2.88^{e}	53.5±0.00^{def}
G7	38.0±0.00^{de}	39.0±6.49^{de}	48.1±1.52^{def}	31.1±3.59^{defgh}	30.6±3.17^{e}	48.3±5.24^{f}
G8	15.8±1.92^{h}	35.0±0.18^{ef}	58.5±4.33^{bcd}	39.6±3.45^{cde}	28.0±4.09^{e}	44.8±6.59^{f}
G9	35.0±0.00^{def}	67.4±8.41^{ab}	61.0±1.80^{bc}	37.9±1.89^{cdef}	33.8±4.16^{e}	63.0±5.97^{bc}
G10	38.0±4.33^{de}	33.7±0.76^{ef}	52.6±5.50^{cde}	38.9±7.16^{cdef}	46.6±6.17^{bcd}	49.6±1.63^{f}
G11	55.8±4.90^{b}	23.8±1.03^{f}	51.1±4.07^{cde}	41.6±1.12^{cd}	37.8±2.25^{cde}	68.7±0.00^{bc}
G12	51.7±4.93^{bc}	35.4±5.33^{ef}	44.8±1.15^{ef}	55.0±0.64^{ab}	37.1±0.28^{cde}	89.7±1.64^{a}
G13	43.7±7.50^{cd}	55.1±2.77^{bc}	45.1±2.02^{ef}	57.5±0.00^{a}	39.6±1.03^{cde}	86.2±2.91^{a}
G14	32.8±7.00^{defg}	45.6±6.97^{cde}	46.7±3.51^{ef}	59.1±3.96^{a}	66.2±6.54^{a}	60.3±1.36^{cde}
G15	80.2±6.35^{a}	33.0±3.24^{ef}	79.6±0.29^{a}	29.5±2.70^{efgh}	68.5±8.66^{a}	72.9±2.62^{b}
G16	42.0±3.12^{cd}	57.5±0.68^{bc}	63.1±4.25^{b}	46.1±7.30^{bc}	56.0±1.73^{ab}	62.6±4.81^{c}

Means carrying same letters in a column are not significantly different from each other's

Table 2b: Total (mg/100g) and available (%) K and P of sweet sorghum genotypes

genotypes	K		P	
	Total	available	Total	available
G1	25.3±2.88^{abc}	67.02 ± 0.71^{bc}	116± 0.23^{a}	34.5 ± 0.00^{abc}
G2	27.5±1.73^{abc}	55.03 ± 4.67^{cde}	189±0.28^{a}	24.7 ± 3.06^{bc}
G3	21.9±0.98^{abc}	83.18 ± 0.43^{a}	169±0.13^{a}	27.6 ± 3.41^{bc}
G4	24.5±7.11^{abc}	67.80 ± 5.69^{bc}	178±0.69^{a}	18.7 ± 9.01^{bc}
G5	17.9±3.28^{c}	52.57 ± 0.53^{de}	209±0.12^{a}	33.0 ± 13.38^{abc}
G6	17.5±0.00^{c}	59.08 ± 3.20^{cde}	192±0.57^{a}	16.3 ± 0.60^{bc}
G7	17.5±0.00^{c}	73.87 ± 3.78^{ab}	193±0.28^{a}	19.0 ± 2.99^{bc}
G8	30.8±0.00^{a}	39.61 ± 6.02^{fg}	185±0.03^{a}	11.5 ± 3.51^{c}
G9	29.8±8.08^{a}	47.08 ± 8.61^{ef}	182±0.09^{a}	11.7 ± 4.44^{c}
G10	29.3±5.22^{ab}	66.94 ± 7.73^{bc}	180±0.19^{a}	18.5 ± 6.41^{bc}
G11	28.5±3.50^{ab}	61.92± 3.57^{bcd}	162±0.48^{a}	27.9 ± 5.73^{bc}
G12	21.3±3.75^{abc}	38.70 ± 1.040^{g}	192±0.23^{a}	38.8 ± 5.89^{ab}
G13	17.8±2.30^{c}	34.92 ± 3.71^{g}	157±0.62^{a}	43.2 ± 2.26^{ab}
G14	20.0±2.17^{abc}	29.28 ± 5.65^{gh}	187±0.35^{a}	34.4 ± 3.33^{abc}
G15	19.1±3.78^{bc}	33.13 ± 6.91^{g}	121±0.74^{a}	60.0 ± 4.84^{a}
G16	25.5±5.63^{abc}	19.22 ± 2.56^{h}	227±0.32^{a}	55.6 ± 8.66^{a}

Means carrying same letters in a column are not significantly different from each other's

Table 3: Total (mg/100g) and available (%) iron and zinc of sweet sorghum genotypes

genotypes	Fe		Zn	
	Total	**Available**	**Total**	**Available**
G1	2.3±0.38^{c}	54.9±7.42^{ef}	0.37±0.01^{c}	58.9±7.45^{abc}
G2	3.2±0.14^{bc}	74.1±8.00^{bcd}	0.41±0.03^{c}	76.2±4.43^{a}
G3	3.8±0.42^{b}	71.1±9.04^{bcd}	0.65±0.13^{a}	33.3±1.34^{ef}
G4	4.1±0.35^{ab}	67.3±5.07^{cde}	0.51±0.05^{abc}	40.2±10.5^{def}
G5	5.1±0.25^{a}	67.4±8.09^{cde}	0.66±0.11^{a}	36.2±8.38d^{ef}
G6	3.6±0.64^{b}	55.3±8.31^{ef}	0.62±0.02^{a}	49.2±1.85^{bcde}
G7	3.6±0.10^{b}	70.9±0.00^{bcd}	0.55±0.09^{abc}	52.8±2.76^{bcd}
G8	3.8±0.57^{b}	84.1±2.86^{ab}	0.59±0.07^{ab}	48.3±7.76^{bcde}
G9	3.7±0.31^{b}	83.1±2.64^{ab}	0.59±0.09^{ab}	42.1±9.49^{cdef}
G10	3.3±0.32^{bc}	66.4±5.68^{cde}	0.62±0.06^{a}	38.2±7.87^{def}
G11	3.3±0.63^{bc}	47.9±6.77^{f}	0.60±0.06^{ab}	47.5±7.94^{bcde}
G12	3.2±0.16^{bc}	80.6±3.17^{abc}	0.62±0.05^{a}	28.6±7.72^{f}
G13	3.0±0.57^{bc}	74.8±0.00^{bcd}	0.49±0.07^{abc}	42.6±10.8^{cdef}
G14	4.0±0.01^{ab}	94.4±2.46^{a}	0.59±0.06^{ab}	36.8±7.66^{def}
G15	4.0±0.41^{b}	89.7±2.02^{a}	0.57±0.05^{ab}	64.5±3.99^{ab}
G16	3.3 ±0.25^{b}	65.0±0.00^{de}	0.66±0.10^{a}	51.5±1.75^{bcd}

Means carrying same letters in a column are not significantly different from each other's

3.4. Phenotypic correlation among nutrients

Correlation analysis of sweet sorghum quality parameters is an essential to understand the associations between nutrition and quality characteristics and their interacted influence on each other, and therefore proper assessment of the overall quality of sweet sorghum genotypes. Correlation coefficients between the quality parameters of sweet sorghum genotypes are shown in Table 4. The results showed varied correlation (positive, negative and week) among all the nutritional quality of sweet sorghum genotypes. The analysis revealed that there were no significant correlation among IVPD, available Ca, available Na, total K, available P and total Zn with all nutritional parameters of all studied genotypes.

Analysis of correlation among protein and other nutrients showed negative and highly significant correlations (R= -0.79 and –0.68**) among total polyphenol and tannin content. Availability of Mg, Na and P were significant and positively correlated (R=0.72, 0.68 and 0.43*) While Fe availability showed positive but not significantly correlated with crud protein (table 4). On the other hand, phytic acid, tannin, total polyphenol, total Ca, total Mg, available Mg, total Na, available Na, total P and available Fe exposed significant positive correlation with available P (R = 0.46), total polyphenol and available K (R= 0.84, 0.58), available K (R= 0.69), total Na, available Na & available P (R = 0.47, 0.53, 0.64), available Zn (R = 0.71), available P (R = 0.69), total Zn (R = 0.55) and total Zn (R = 0.56), respectively (table 4).

The significant positive correlation between the studies nutritional parameters has implicated for the possibility of combine selection for these nutrients in a single agronomic background. Genetic mapping in different wheat populations confirmed QTL co-localization conferring high Protein, high Zn and high Fe (Peleg et al., 2009). Likewise, co-localization of QTLs for Zn and Fe concentrations has been reported in rice (Garcia-Oliveira et al., 2009).

Table 4: Phenotypic correlations among quality parameters of selected Sudanese Sweet sorghum genotypes

	Crude Protein	IVPD	Phytic acid	Tannin	Total pp	Total Ca	A. Ca	Total Mg	A. Mg	Total Na	A. Na	Total K	A. K	Total P	A. P	Total Fe	A. Fe	Total Zn	A. Zn
Crude Protein																			
IVPD	-0.11																		
Phytic acid	0.35	-0.03																	
Tannin	-0.68	-0.02	-0.44																
Total pp.	-0.79	0.06	-0.41	0.84															
Total Ca	0.46	0.03	0.18	-0.43	-0.59														
A. ca	-0.1	-0.23	-0.03	0.43	0.17	-0.38													
Total Mg	-0.12	-0.25	0.24	0	-0.2	0.39	0.11												
A. Mg	0.72	0.35	0.36	-0.6	-0.54	0.14	-0.18	-0.46											
Total Na	0.14	0.31	0.4	-0.08	-0.24	0.47	0.08	0.41	0.16										
A. Na	0.68	-0.23	0.1	-0.26	-0.44	0.53	-0.22	0.03	0.48	0.2									
Total K	-0.13	-0.08	0.05	0.15	0.06	-0.18	0.07	0.36	-0.13	-0.15	-0.19								
A. K	-0.5	-0.03	-0.49	0.58	0.69	-0.35	0.02	-0.13	-0.6	-0.4	-0.45	0.07							
Total P	-0.12	-0.16	0.02	-0.06	0.06	-0.39	-0.09	-0.37	0.17	-0.31	-0.03	0.01	-0.21						
A. P	0.43	-0.1	0.46	-0.4	-0.47	0.64	0.09	0.23	0.24	0.69	0.36	-0.39	-0.58	-0.22					
Total Fe	-0.43	-0.04	-0.22	0.26	0.24	-0.16	-0.2	-0.13	-0.24	0.04	-0.01	-0.29	-0.01	0.39	-0.09				
A. Fe	0.14	0.21	-0.01	-0.28	-0.4	0.12	0.06	0.19	0.27	0.35	0.2	-0.09	-0.52	-0.04	0.17	0.28			
Total Zn	-0.1	0.08	0.23	-0.14	0	0.02	-0.43	-0.37	0.3	-0.03	0.09	-0.11	-0.19	0.55	0.03	0.56	0.03		
A. Zn	-0.07	-0.18	0.03	-0.2	-0.27	0.28	0.09	0.71	-0.5	0.11	-0.29	0.14	0.03	-0.3	0.16	-0.32	-0.06	-0.61	1

4. Discussion

In this study, 16 out of 40 local sweet sorghum genotypes were used. These genotypes were selected based on their yielding rate, juice content and drought resistance (Hud et al., 2017). The grains collected from these genotypes were subjected for nutritional evaluation in order to investigate genetic variation among genotypes which might help to produce sorghum cultivars with high nutritional quality through breeding in the available gene pool. Protein is an essential element of the food of animals and humans which supplies the required amino acids (Okareh et al., 2015). From obtained results, most of the genotypes grain contained relatively high protein content, except G5 with 10 genotypes, with high digestibility rate. Several studies reported that most of the sorghum cultivars grown in Sudan contained only 9–11% protein content (Elbashir et al., 2008; Ahmed et al., 2014), which is critical for determining the nutritional value of foods. Therefore, sweet sorghums might offer a significant source of protein, and fortified ingredients for enhancing the nutritional value of other foods due to their high protein and mineral contents.

It was noted that phytic acid can complex with protein as well as with trace elements and lower their availability (Carnovale et al., 1988).The phytic acid content of the sweet sorghum is lower than that reported in sorghum cultivars, Gadambalia (3.19), Tabat (2.33) and wad Ahmed (2.65 mg/gm). The low phytic acid content in sweet sorghum grains might lead to high bioavailability rate of mineral particularly trace one. Similar to phytic acid, tannins reduce the bioavailability of protein and other macromolecules, since it can form cross-linkages with them (Griffiths, 1991). These inhibitory facets, in conjunction with an astringent taste, constitute the antinutritional characteristics of tannins (Petterson, 2000). Additionally, polyphenols are able to form a mineral complex and reduce mineral availability. Therefore, the low content of total polyphenols of sweet sorghum grains obtained in this study may also enhance its mineral bioavailability. Variations in total polyphenol, could be attributed to genetics, physiological/biochemical mechanisms, responses to climate variations, tolerance to pests and diseases, and responses to agronomic management practices. Genetic variations in plant acquisition of nutrients have been reported (Duncan and Carrow, 1999).

In the present study, high content of macro- and microelement were observed in sweet sorghum genotypes. The values of Ca content in this study of the sweet sorghum genotypes except Si genotype were higher than the value reported in Sudanese sorghum genotypes Wad Ahmed, Tabat and Gadambalia, which were found to be 10.6, 12.5 and 14.07 mg/100g for sorghum, respectively (Idris et al., 2005; Ahmed et al., 2014). In contrast, most of the sweet sorghum genotypes grains showed lower content and extractability of Mg, K and P than of some Sudanese sorghum genotypes. The Na content in sweet sorghum genotypes grains varied from 28.0 to 68.5 mg/100g. The obtained values were higher than those found in Wad Ahmed, Tabat and Gadambalia sorghum genotypes.

Inadequate dietary intake of Fe cause severe anemia for the people, particularly in developing countries. Therefore the fortification of cereal flour with Fe is widely used to solve the problem (Stein, 2010; Clemens, 2014). The concentration of Fe varied from 2.3 to 5.1 mg/100g with bioavailability ranged between 47.9 raise to 94.4% in the sweet sorghum genotypes grains. From these findings, the genotypes with high concentration and bioavailability of Fe could be selected as a potential source for biofortification through plant breeding program. In contrast, all studied sweet sorghum genotypes showed relatively low content of Zn compared to other sorghum cultivars, with high extractability.

5. Conclusion

In this study, there was considerable variation among the genotypes in all measured quality parameters. This variation might result from the genetic deviation between the genotypes. However, Sweet sorghum genotypes with a high concentration of total and available mineral and protein and less antinational factors are a potential genetic resource for development sorghum cultivars through breeding research to produce sorghum cultivars with sufficient quality and marketability. Generally, obtained results reveal that these genotypes are potentially considered as excellent materials to the plant breeders to produce high quality of grains. Therefore, intensive efforts are required to screen more sweet sorghum genotypes for macro and micro- nutritional traits.

Conflict of Interest: Authors declare that there is no conflict of interests.

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