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Assessment of grain minerals of Turkish sorghum (*Sorghum bicolor* L.) landraces by GT biplot analysis

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RESEARCH ARTICLE

Abstract

This study was conducted to determine grain micro (Zn, Fe, B, Cd, Cr, Cu, Mn, Ni, Pb) and macro (K, Mg, P, S, Ca, Na) elements of 164 Turkish sorghum landraces and cultivars. Sorghum grains were sown in incomplete blocks design in Kayseri in 2016. Correlation and genotype-trait (GT) biplot analyses were used to identify correlations among the traits and to identify the prominent genotypes. The highest positive correlations were observed among the micro elements of Fe, Zn, and Mn and between the macro elements of Mg and P and between K and Ca. The GT biplot graph generated for macro elements was able to explain 66.3% of total variation and the graph for micro elements explained 82.2% of total variation. Based on GT biplot analysis, 8 genotypes were selected for macro elements and 14 genotypes were selected for micro elements. Present findings clearly revealed that GT biplot analysis could reliably be used in selection of prominent genotypes.

Keywords: Turkey, macro element, micro element, correlations, breeding

1. Introduction

Sorghum is a significant food crop and thus directly used as a food source in several Asian (India and China) and African countries (Algeria, Kenya, Nigeria, Uganda, etc.) (Li *et al.*, 2010; Moraes *et al.*, 2012). Sorghum is used in food industry either in fermented or non-fermented forms in breads, cookies, breakfasts, cereals, alcoholic beverages and beers, pancakes, couscous and appetizers (Yousif *et al.*, 2012). Sorghum is a gluten-free foodstuff with quite slow digestibility. It is also used to reduce cholesterol levels and to inhibit cell growth in oesophageal and colon cancer patients (Awika *et al.*, 2009; Carr *et al.*, 2005; Moraes *et al.*, 2012). Therefore, its popularity is always increasing throughout the world. Such an intense utilisations makes sorghum a great carbohydrate, protein, oil, and mineral source (Hill *et al.*, 2012).

Abiotic and biotic stressors highly limit crop production. Sorghum is quite resistant to such stressors and thus commonly used in problematic regions where low-input agriculture is practiced (Rooney, 2004; Zulfiqar and Asim, 2002). Sorghum can easily be grown at quite low precipitation levels or excessively wet conditions because of high photosynthetic activity and mineral uptake under harsh conditions (Gosse, 1995; Woods *et al.*, 1995). Sorghum is also well-adapted to various soil pH ranges (5.0-8.5), saline conditions and can easily be cultured at high temperatures and in poor soils (Kimber, 2000).

Minerals are essential elements of life and required for the function of enzymatic systems (Ozlu *et al.*, 2012). Plant-originated foodstuffs constitute the primary mineral sources of low-income groups living in rural and urban places (Monasterio *et al.*, 2007). Sorghum is a significant mineral source of people living in arid and saline regions where low-input agriculture is practiced. Although iron, zinc, and iodine are commonly deficient human nutrients, Ca, Mg, Cu, and Se may sometimes are deficient in some human diets (Paiva *et al.*, 2017). Low-cost and relatively simple strategies are recommended and accepted to reduce mineral deficiencies in foodstuffs (Davidsson and Nestel, 2004). Present researches mostly focus on improvement of nutritional composition of basic foodstuffs through cultural practices and genetic selections (White and Broadley, 2005). Besides new technologies, new cultivars should also be developed to meet food and feed demands of ever increasing human and animal population. Sorghum has a high genetic diversity to be used in bio-fortification studies. Genetic resources and relevant information provide significant contributions in cultivar breeding programs. Plant gene sources are the best assistants of the researchers in cultivar breeding programs (Sehirali and Ozgen, 1987).

GT biplot analysis graphically presents several attributes of the genotypes, and allows visual comparison of several genotypes and attributes. Therefore, it is commonly used in sociology, medicine, engineering, genetics and agriculture (Yan *et al.,* 2001). GT biplot technique aids in identification of genotypes with superior characteristics (Yan and Kang, 2003; Yan, 2014).

The objectives of the present study were to: (1) scan mineral contents of Turkish sorghum landraces (164 genotypes); (2) put forth genetic variation in sorghum landraces; (3) use GT biplot technique to compare genotypes; and (4) identify genotypes with superior mineral contents.

2. Material and methods

Plant materials and soil characteristics

A total of 164 sorghum genotypes supplied from National Plant Germplasm System (USDA), International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Aegean Agricultural Research Institute (ETAE) and sorghum cultivating provinces were used as the plant material of this study. Seed samples used as research material were obtained from the experiments conducted in incomplete blocks design with 3 replications over the experimental fields of Erciyes University Agricultural Faculty in 2016. Based on soil analyses, 120 kg/ha P_2O_5 and 200 kg/ha N were supplied to experimental soils. All of the phosphorus and half of the nitrogenous fertilizer were supplied at sowing and the remaining half of the nitrogen was applied when the plants reached to a height of 30-40 cm. Earthing up and hoeing were performed again when the plants reached to a height of 30-40 cm. Throughout the growth stages of the plants, two hoes and one herbicide treatment were practiced. Plants were irrigated with sprinkler irrigation throughout the emergence and initial growth stages and irrigated with drip irrigation when they reached to a height of 30-40 cm. Plants were irrigated weekly as to bring the deficient moisture level to field capacity in each time. Plants were harvested at hard-dough stage and ground to make them ready for mineral element analyses.

Soil samples were taken from 0-30 cm soil profile. Analyses revealed that experimental soils were slightly alkaline (pH 7.9) and sandy-clay in texture. Soils were unsaline, non-limy, poor in organic matter and rich in phosphorus and potassium.

Mineral analyses

About 0.5 g dry samples were taken from the plants to determine nutrient elements. Samples were supplemented with 10 ml nitric + perchloric acid mixture and subjected to wet digestion until a final volume of 1 ml. Following the digestion procedure, resultant solutions were diluted with distilled water and readings were performed in an ICP-OES spectrophotometer (Inductively Couple Plasma spectrophotometer) (Perkin-Elmer, Optima 4300 DV, ICP/OES, Shelton, CT, USA) to determine P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, and B content of the samples (Mertens, 2005).

Data analysis

Resultant data were subjected to variance analysis. Following the variance analysis, mean values were determined for macro and micro elements of the genotypes. A correlation analysis was performed by using these mean values to investigate the relationships between investigated macro and micro elements. SAS statistical software was used in statistical analyses. Then GT (genotype-trait) biplot graphs were generated to identify which genotype/genotypes were prominent with which trait/traits (Yan, 2014).

3. Results

Macro elements

Six different macro elements [potassium (K), magnesium (Mg), phosphorus (P), sulphur (S), calcium (Ca), sodium (Na)] of 164 sorghum genotypes were investigated. Descriptive statistics for investigated macro elements are provided in Table 1. Potassium showed the highest contents and varied between 2,785-12,832 mg/kg with an average value of 7,181 mg/kg. Na showed the lowest contents with an average of 186 mg/kg.

Genotype-macro element biplot explained 66.3% of total variation (PC1 43.4% and PC2 22.9%) (Figure 1). Present explanation ratios comply with the findings of earlier studies investigating genotype-trait relationships (Dehghani *et al.*, 2012; Mohammadi and Amri, 2011; Rubio *et al.*, 2004). However, Akcura (2011) and Akcura and Kokten (2017) investigated quality traits and macro element contents of wheat genotypes with GT biplot method and reported lower ratios.

Genotype-trait (GT) biplot analysis allows visual interpretation of the relationships between the traits and between the genotypes and provides aids in identifying which genotype/genotypes are prominent with which attribute/attributes (Yan and Kang 2003).

Table 1. Basic statistics for investigated elements.

Variable		Mean	Minimum	Maximum	Significance degree	Least significant difference
Macro elements (mg/kg)	K	7,181	2,785	12,832	*P*≤0.01	386.741
	Mg	1,401	512	2,426	*P*≤0.01	94.548
	P	5,632	2,257	9,401	*P*≤0.01	364.683
	S	2,004	20	4,508	*P*≤0.01	155.181
	Ca	5,157	1,103	16,387	*P*≤0.01	0.922
	Na	186	4.18	504	*P*≤0.01	13.701
Micro elements (mg/kg)	Fe	33.07	8.21	53.58	*P*≤0.01	2.459
	Zn	27.18	11.04	68.00	*P*≤0.01	2.554
	B	1.55	0.13	7.87	*P*≤0.01	0.095
	Cu	15.79	2.42	26.09	*P*≤0.01	0.922
	Mn	16.18	4.25	30.96	*P*≤0.01	3.753

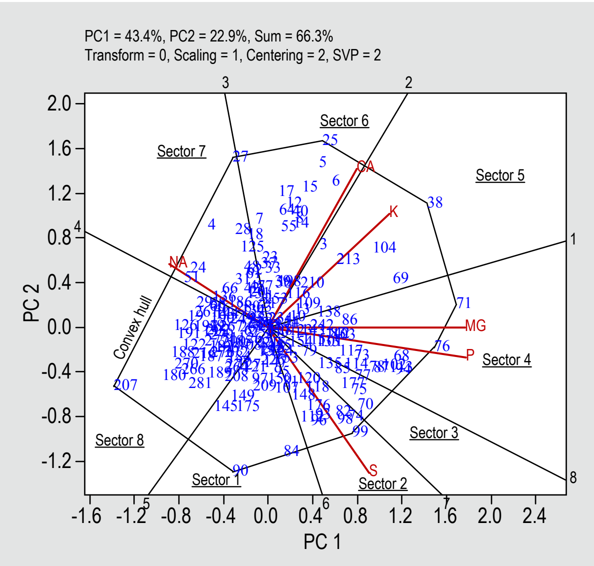

Figure 1. Genotype by traits (GT) biplot of 164 sorghum genotypes for six macro elements.

GT biplot graphs can be created in different ways. A polygon is formed through connecting the furthest genotypes from the origin of the graph. A graph can also be formed through the lines drawn from the origin to perpendicular to polygon edges. These two types of graph as presented in Figure 1 are the most efficient ones (Yan, 2014). Vectors are also formed for each one of the investigated elements in this graph to assess the relationships between the elements.

Within 8 sectors of the polygon created for macro elements, 9 genotypes formed a diagonal. These genotypes were genotypes 90 and 84 in the first sector, 99 in the second, 76 and 71 in the fourth sector, 38 in the fifth sector, 25 in the sixth sector, 27 in the seventh sector and 207 in the eighth sector. Diagonal genotypes were prominent with the relevant attribute/attributes (Mohammadi and Amri, 2011).

With the same GT biplot graph, the relationships between the genotypes can be visually assessed. The cosine of the angle between two vectors (r=cos0°=1, cos90°=0, and cos180°=-1) indicates the correlation between these two traits. The highest positive correlations were observed between Mg – P and between K – Ca. There were also significant correlations between K and Mg – P, between S and P – Mg (Figure 1). Correlation analysis results for these relationships are provided in Table 2. Correlation coefficients verified the visual relationships in biplot graph.

In GT biplot graph generated with the best 8 genotypes among 164 genotypes, axis values explained 80.4% of the total variation (Figure 2). As it can be seen from the figure, the genotypes 12 and 38 were prominent with K, genotypes 71 and 76 with S, genotype 76 with Mg and P and the genotypes 5 and 6 were prominent with Ca and Na. Average macro element contents of the genotypes are provided in Table 1.

Table 2. Correlation matrix for macro elements.[1]

	Mg	P	S	Ca	Na
K	0.34**	0.40**	0.01	0.40**	-0.11
Mg		0.92**	0.30**	0.34**	-0.32**
P			0.46**	0.18*	-0.25**
S				-0.16*	-0.25**
Ca					-0.07

[1] ** = *P*<0.01.

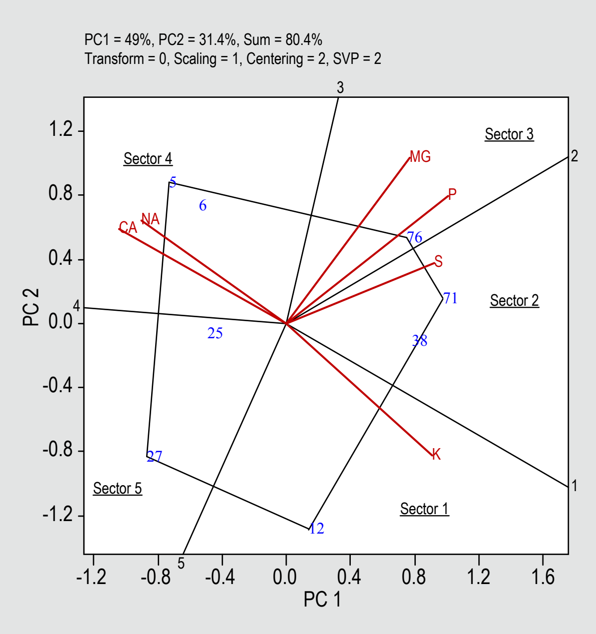

Figure 2. Genotype by traits (GT) biplot of 8 winner genotypes for six macro elements.

Micro elements

Fe, Zn, B, Cu, and Mn contents were investigated as the micro elements. Basic statistics for these micro elements are provided in Table 1. Among the investigated elements, Fe had the highest concentration (33.07 mg/kg), and it was respectively followed by Zn (27.18 mg/kg), Mn (16.18 mg/kg), Cu (15.79 mg/kg) and B (1.55 mg/kg).

GT biplot graph generated to visually assess the relationships among the micro elements explained 82.2% of total variation. There were 11 sectors over the graph. Micronutrients were placed only in three sectors. There were 15 diagonal genotypes (5, 10, 3, 87, 153, 99, 176, 148, 149, 115, 180, 197, 18, 42, and 20) over the polygon generated from the furthest genotypes from the origin of the graph (Figure 3). The diagonal genotypes are prominent with the relevant attribute/attributes of the same sector. Genotype 3 was prominent with Fe, Zn, and Mn and the genotypes 18, 42 and 20 were prominent with B (Figure 3).

As it can be seen from Figure 3, positively correlated elements were placed close to each other over the graph. There were significant positive correlations among Fe, Zn, and Mn. Cu and B were placed into separate sectors. There were significant correlations between Mn, Fe, Zn, and Cu, B (Figure 3). Correlation analyses proved these relationships (Table 3).

The GT biplot generated with the best 14 genotypes selected through 10% selection intensity for all micro elements is presented in Figure 4. GT-biplot graph was able to explain

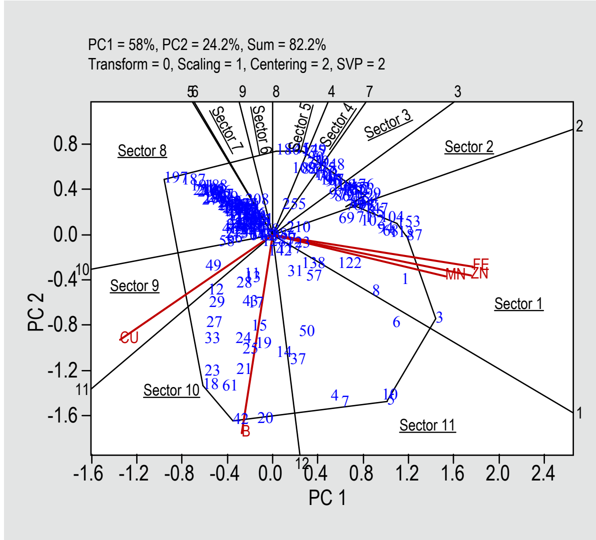

Figure 3. Genotype by traits (GT) biplot for five micro elements of 164 sorghum genotypes.

Table 3. Correlation matrix for micro elements.[1]

	Fe	B	Cu	Mn
Zn	0.92**	0.02	-0.51**	0.67**
Fe		-0	-0.54**	0.68**
B			0.39**	0
Cu				-0.39**
Mn				

[1] ** = *P*<0.01.

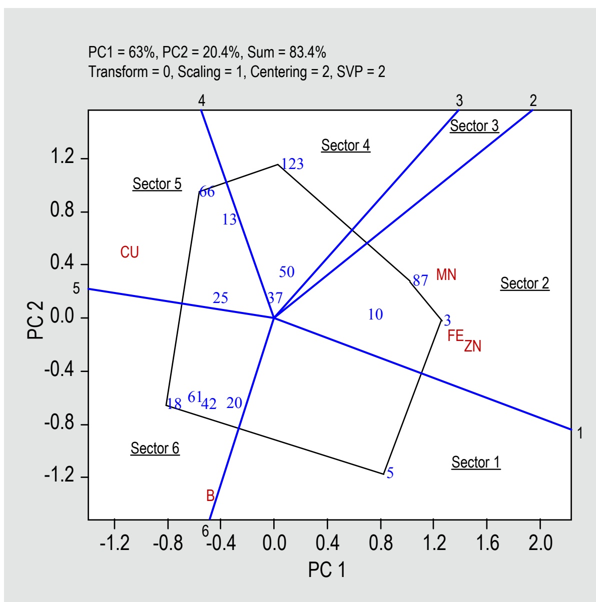

Figure 4. Genotype by traits (GT) biplot of 14 winner genotypes for five micro elements.

83.4% of total variation. There were 6 sectors in this graph. The genotypes 3, 10, and 87 prominent with Mn, Zn, and Fe were placed within the second sector. The genotypes 13, 25, and 66 prominent with Cu were placed in the fifth sector. The genotypes 18, 20, 42, and 61 prominent with B were placed within the sixth sector. There were not any elements in the first, third and fourth sectors.

The genotype 42 with the highest Cu and B contents and relatively higher Cu contents than the other genotypes was placed in the sixth sector. The genotype 50 with high B contents were placed in the fourth sector. The biplot allowing the selection of the best genotypes over the entire micro elements is presented in Figure 4. As it can be seen from the figure, 14 genotypes were selected as the best genotypes for all micro elements. Average micro element contents of the genotypes are provided in Table 2.

4. Discussion

Plants should be fortified with mineral elements. However, plant minerals are highly influenced by the environment in which they are produced. In most cases, plants experience deficiencies in Fe, Zn, Ca, Mg, and Cu (White and Broadley, 2005). Cereals are the primary food crops used in human nutrition in Turkey. Since nutritional composition of different genotypes varies highly, plant breeding programs should be supported to develop varieties with high nutritional values (Teixeira *et al.,* 2013). Thus, Fe and Zn deficiency is also evident in humans (Akcura and Kokten, 2017). Therefore, mineral elements of food crops should be determined (Paiva *et al.,* 2017). Then, micro and macro elements of 164 sorghum genotypes were investigated in this study.

K (7,181 mg/kg) and P (5,632 mg/kg) were the prominent macro elements. Present P and K values were higher than the values reported by Paiva *et al.* (2017) for K (4,080 mg/kg) and P (3,670 mg/kg). Calcium was the third and S was the fourth micro element. Present Ca and S contents were higher than the values reported by Martinol *et al.* (2012) for sorghum genotypes. Paiva *et al.* (2017) indicated K and Shegro *et al.* (2012) indicated P as the prominent macro elements in sorghum grains. Despite deficiencies in several elements, Turkish soils are quite rich in potassium. Therefore, plant seeds are highly rich in K (Akcura and Kokten, 2017).

Among the micro elements of sorghum grains, Fe (33.07 mg/kg), Zn (27.18 mg/kg) and Mn (16.18 mg/kg) had the highest concentrations. These elements (Fe, Zn, Mn) were reported as the most common micro elements encountered in sorghum genotypes (Pontieri *et al.,* 2014). The average values for these three elements were quite close to the values reported by Paiva *et al.* (2017) for Fe (31.94 mg/kg), Zn (26.59 mg/kg) and Mn (19.75 mg/kg). For the other micro elements considered in present study, there was not sufficient information in literature. Martinol *et al.* (2012) carried out a study with Brazilian sorghum genotypes and reported Mg contents as between 0.79-1.47 g/kg, Cu contents between 0.33-1.01 mg/kg, Fe contents between 4.7-14.9 mg/kg, Mn contents between 0.0-0.6 mg/kg and Zn contents between 13.2-27.0 mg/kg. Present findings were higher than those reported by Martinol *et al.* (2012). Pontieri *et al.* (2014) carried out a study under Mediterranean conditions and reported similar Fe contents (39.36-70.03 mg/kg) with the present study and lower Mn contents (8.93-19.44 mg/kg) and Zn contents (21.10-7.05 mg/kg) than the present values. Seed mineral contents are highly influenced by plant genetics, soil and climate conditions (Paiva *et al.,* 2017).

The highest significant positive correlations among the macro elements were observed between Mg and P and the highest significant positive correlations among the micro elements were observed between Fe and Zn (Figure 1 and Figure 2). Similar with the findings of the present study, previous researchers also reported significant positive correlations between Fe – Zn, between Mg – Zn, between Mg – Fe and between Mn – Zn (Paiva *et al.,* 2017; Pontieri *et al.,* 2014). Plant genetics play a significant role in mineral uptake from the soils, mineral transport and accumulation. Such positive correlations indicate potential improvements for one or more minerals (Ashok-Kumar *et al.,* 2010).

The relationships between the other elements can be seen visually from the biplot graphs. Biplot facilitates the visual assessment of two-way data. Genotype-trait interactions were investigated with GT biplot analysis for different plants (Akcura and Kokten, 2017; Rubio *et al.,* 2004). Besides the relationships between the traits, GT biplot analysis also allows the users to identify which genotypes is prominent with which trait or traits. In this way, genotype or genotypes to be used in further breeding studies can easily be selected. In present study, 8 genotypes were selected for macro elements and 14 genotypes were selected for micro elements (Table 4 and Table 5). An overview of all genotypes can be found in Table S1 and S2. Potential use of GT biplot method for selections was presented in detail by Yan and Fregeau-Reid (2008).

Present findings revealed sufficient variations in macro and micro elements of Turkish sorghum landraces. Within these variations, prominent genotypes were able to be selected easily with GT biplot analysis method. Selected genotypes could reliable be used in further sorghum breeding programs to be carried out to improve macro and micro elements of sorghum genotypes. It was concluded that sorghum with high mineral contents could reliably be used in regions with mineral deficiency-induced health problems.

Table 4. Selected genotypes for macro elements (mg/kg).

Genotypes	K	Mg	P	S	Ca	Na
5	6,984	2,100	6,964	507	15,845	504
6	7,320	2,120	7,041	664	15,303	380
12	12,832	1,177	4,922	605	5,585	129
25	9,137	1,633	6,119	136	16,387	165
27	8,532	858	3,155	416	15,402	114
38	12,832	2,416	9,401	299	6,903	122
71	11,590	2,228	9,401	4,445.54	9,970	17.17
76	8,543	2,426	8,633	4,508	10,253	14.67

Table 5. Selected genotypes for micro elements (mg/kg).

Genotypes	Zn	Fe	B	Cu	Mn
3	68.00	53.58	2.93	8.70	30.96
5	54.32	48.61	7.58	5.01	25.36
10	64.21	50.64	4.48	22.56	27.53
13	22.42	31.87	2.10	25.33	17.55
18	16.75	23.28	7.70	20.73	12.05
20	27.98	37.22	7.66	23.01	16.11
25	23.93	33.44	4.75	26.07	16.70
37	33.58	43.99	4.38	25.54	19.51
42	23.81	33.38	7.87	24.51	14.06
50	35.69	46.21	3.26	25.13	18.84
61	21.62	30.61	7.29	21.78	11.26
66	21.01	30.11	0.87	26.09	12.83
87	66.32	52.67	0.56	8.15	20.88
123	21.12	29.13	0.81	19.95	29.72

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Conflict of interest

The author declares that they have no conflict of interest.

Supplementary material

Supplementary material can be found online at https://doi.org/10.3920/QAS2018.1393

Table S1. Macro mineral contents in Turkish sorghum landrace.

Table S2. Micro mineral contents in Turkish sorghum landrace.

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