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Changes in total and extractable macroelements of grains of sorghum cultivars grown under different levels of micronutrients

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ABSTRACT: The grains of four sorghum cultivars (Tabat, Tetrom, WadAhmed and Gadambellia) were grown in a sandy clay soil with a pH 7.2 for two consecutive seasons under different levels (0, 2, 4, and 8 gm/5kg soil) of micronutrients fertilizer and a constant level of macronutrients (6 gm/5kg soil). After addition of the fertilizers and water to the soil, the pH dropped to 5.7. Macroelements (Ca, P, Mg, K and Na) content and extractability (bioavailability) of the harvested grains were investigated. The content of macro-elements of the grains harvested during both growing seasons was significantly ($p \leq 0.05$) increased with increase in micronutrients dose. However, the grains harvested during the second season for all cultivars had significantly ($p \leq 0.05$) higher amount of macroelements than that harvested during the first season. Calcium content of the cultivar Tabat and sodium content of the cultivar Tetron were increased by more than 100% as a maximum values during the second season. Macroelements extractability (bioavailability) was increased with micronutrients fertilization with very few exceptions. The maximum value of extractability recorded was 92.88% for Mg extracted from the grains of Tabat cultivars grown under 8 gm/5kg soil micronutrients. The results revealed that micronutrients fertilization of sorghum cultivars is an ideal method in improving macroelements contents. Moreover, the pH (5.7) is the suitable value for the acquisition of micronutrients by the plant.

KEYWORDS: Sorghum, grains, micronutrients, macroelements, extractability.

1 INTRODUCTION

Sorghum nutritional quality is dictated mainly by its chemical composition and one of the constraints on the utilization of sorghum grain as food or feed is the occurrence of anti-nutritional factors [1]. Cereal crops are inherently very low in grain Zn and Fe concentrations, and growing them on potentially Zn- and Fe-deficient soils further reduces Fe and Zn concentrations in grain [2]. It is evident that the nutritional importance of a given food/feed stuff depends not only on nutrient composition of raw foodstuff but also on the amount utilised [3].

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In the Sudan, sorghum comes first in volume of cereals produced and is the staple food for people in rural areas, particularly the low-income groups as food or sometimes processed to produce alcoholic or soft beverages or as feed for livestock [4]. Many soil factors such as pH, temperature, and moisture affect the availability of micronutrients to crop plants. The effects of these factors vary considerably from one micronutrient to another as well as in their relative degree of effectiveness [5]. Some of the adverse effects of micronutrient deficiency-induced stress in plants include low crop yield and quality. Plant factors such as root and root hair morphology (length, density, surface area), root-induced changes (secretion of H^+, OH^-, $HCO3^-$), root exudation of organic acids (citric, malic, tartaric, oxalic, phenolic), sugars, and non-proteinogenic amino acids (phytosiderophores), secretion of enzymes (phosphatases), plant demand, plant species/cultivars, and microbial associations (enhanced CO_2 production, rhizobia, mycorrhizae, rhizobacteria) have profound influences on plant ability to absorb and utilize micronutrients from soil [6].

Soil pH influences solubility, concentration in soil solution, ionic form, and mobility of micronutrients in soil, and consequently acquisition of these elements by plants [7, 5]. As a rule, the availability of B, Cu, Fe, Mn, and Zn usually decreases, and Mo increases as soil pH increases. The availability of most micronutrients tends to decrease at low temperatures and moisture contents because of reduced root activity and low rates of dissolution and diffusion of nutrients. The deficiency of essential micronutrients induces abnormal pigmentation, size, and shape of plant tissues, reduces leaf photosynthetic rates, and leads to various detrimental conditions [8]. Iron deficiency occurs not because of Fe scarcity in soil but because of various soil and plant factors that affect Fe availability to inhibit its absorption or impair its metabolic use [9].

Different approaches have been tried: germination [10], addition of malt [1], fermentation [11], addition of malt followed by fermentation [12], radiation [13] and conventional breeding [14] to improve minerals content and extractability of millet and sorghum seeds. Moreover, previous research focused only on the effect of micronutrients fertilization on yield. Therefore, in this study, we would like to investigate the effect of micronutrients fertilization on total and extractable macroelements of grains of four sorghum cultivars grown under controlled conditions during two consecutive seasons.

2 MATERIALS AND METHODS

2.1 MATERIALS

Grains of four sorghum (*Sorghum biocolor* L. Monech) cultivars (Tabat, Tetron, Wad Ahmed and Gadamblia) were obtained from the Department of Agronomy, Faculty of Agriculture, University of Khartoum, Shambat, Sudan. The grains were grown in pots under compound micronutrients (14% water soluble Mo + 0.3% water soluble Mn + 0.3% water soluble B + 1.2% FeS + 0.02% Cu_2SO_4 + 0.02% $ZnSO_4$ + 0.004% $(NH_4)_6[Mo_7O_{24}].4H_2O$) and compound macronutrients (N-P_2O_5-K_2O) fertilizers for two consecutive seasons (2010 and 2011). The experimental site lies at the Demonstration Farm of the Faculty of Agriculture, University of Khartoum, Shambat (latitude 15˚40'N and longitude 32˚32'E). The soil was sandy clay (82% sand and 18% clay) with pH of 7.2 and temperature between 20 and 25 ^oC. Four doses (0, 2, 4 and 8 g/5kg soil) of micronutrients were applied to each pot. Beside micronutrients, all treatments received compound macronutrients (N-P_2O_5-K_2O) at a constant dose (6 g/5kg soil). The pH of the soil dropped to 5.7 after addition of fertilizers and water to the soil. Each experiment was arranged in a factorial design with four replicates. At the end of each season, the grains were collected, sun dried, cleaned from dirt and broken grains and then ground to pass a 0.15 mm screen and stored at 4 ^oC.

2.2 TOTAL MINERALS DETERMINATION

Minerals were extracted from the samples by the dry ashing method described by Chapman and Pratt [15]. About 2.0 gm of sample was acid-digested with diacid mixture (HNO_3:$HClO_4$, 5:1, v/v) in a digestion chamber. The digested samples were dissolved in double-distilled water and filtered (Whatman No. 42). The filtrate was made to 50 ml with double-distilled water and was used for determination of total calcium, phosphorus and iron. Elements were determined by atomic absorption spectrophotometer (Perkin-Elmer 2380). Calcium was determined by a titration method. Phosphorus was determined spectrophotometrically using molybdovanadate method.

2.3 EXTRACTABILITY OF MINERALS (IN VITRO BIOAVAILABILITY)

Minerals in the samples were extracted by the method described by Chauhan and Mahjan [16]. About 1.0 gm of the sample was shaken with 10 mL of 0.03 M HCl for 3 h at 37 ^oC and then filtered. The clear extract obtained was oven-dried at 100 ^oC and then acid-digested. The amount of extractable minerals was determined by the methods described above. HCl extractability (%) was determined as follows:

$$\textit{Mineral extractability (\%)} = \frac{\textit{Mineral extractable in 0:03NHCl (mg/100g)}}{\textit{Total minerals (mg/100g)}} X100$$

2.4 STATISTICAL ANALYSIS

Each determination was carried out on three separate samples and analyzed in triplicate on dry weight basis; the figures were then averaged. Data were assessed by the analysis of variance [17]. Comparisons of means for treatments were made using Duncan's multiple range tests. Significance was accepted at P ≥ 0.05.

3 RESULTS AND DISCUSSION

Figure 1 shows total and extractable Ca of grains of four sorghum cultivars (Tabat, Tetron, WadAhmed and Gadambalia) grown under different levels of micronutrients (0, 2, 4 and 8 g/5kg soil) and a constant dose (6 gm/5kg soil) of compound macronutrients for two consecutive growing seasons. Calcium content of the grains (Fig. 1a) before fertilization was 3.77, 11.01, 10.83 and 14.07 mg/100gm for the cultivars Tabat, Tetron, WadAhmed and Gadambalia, respectively during the first growing season while during the second growing season it was 4.50, 12.29, 12.63 and 14.12 mg/100gm for the cultivars, respectively. For all cultivars, Ca content of the grains harvested during the first growing season was increased with increase in fertilizer dose. However, the percent increase in Ca content was higher during the second growing season. During the first growing season, the maximum rate of increment in Ca content was 28, 92, 43 and 8% at a fertilizer dose of 8 gm/5kg soil for the cultivars Tabat, Tetron, WadAhmed and Gadambalia, respectively, while during the second growing season it was increased by 169, 66, 25 and 6% for the cultivars, respectively. Ca extractability (Fig. 1b) was also improved with micronutrients level and reached maximum value when the grains were fertilized by 8 gm/5kg soil. The grains of Tabat cultivar recorded higher value of extractable Ca (70.15%) followed by the cultivar Tetron (58.39%) during the second season.

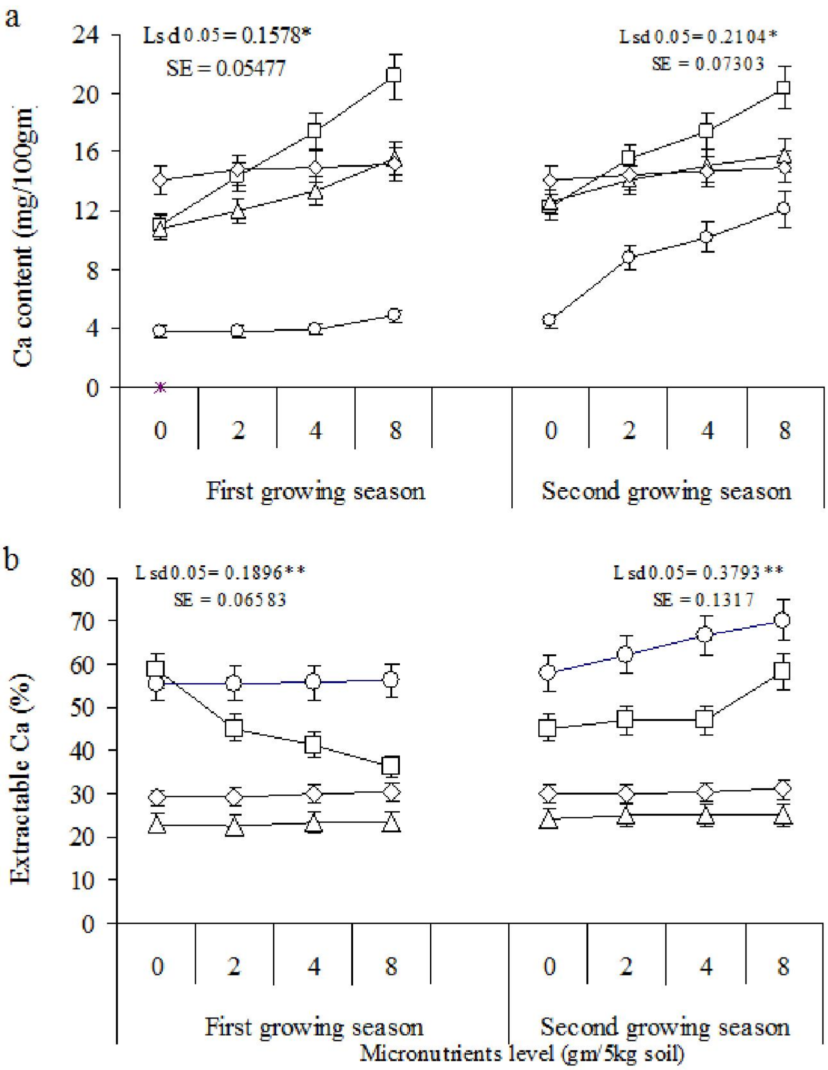

Fig. 1. ***Total (a) and extractable (%) Ca of grain sorghum cultivars (○, Tabat; □, Tetron; Δ, WadAhmed; ◊, Gadambalia) grown under different levels of micronutrients fertilization.***

However, Ca extractability of the cultivar Tetron was significantly ($P \geq 0.05$) decreased for the grains harvested during the first growing season. The results revealed that the cultivars Tabat highly respond to micronutrients fertilization with respect to total and extractable Ca. As shown in Figure 2, P content and extractability of the grains was increased significantly ($P \geq 0.05$) with micronutrients dose especially for the grains harvested during the second growing season. During the first growing season, phosphorus content (Fig. 2a) of the grains before fertilization was 128.11, 327.00, 329.81 and 330.00 mg/100gm for the cultivars Tabat, Tetron, WadAhmed and Gadambalia, respectively while during the second growing season it was 180.17, 330.05, 330.45 and 330.04 mg/100gm for the cultivars, respectively. The cultivar WadAhmed recorded higher percent increase in P (36%) followed by Tetron (13%) during the first growing season. However, during the second growing season Tabat recorded higher percent increase (92%) followed by WadAhmed (38%) when the plants grown under 8 gm/5kg soil. The rate of increment in P was significantly ($P \geq 0.05$) higher during the second growing season for all cultivars compared to the first growing season. P extractability (Fig. 2b) was fluctuated for grains harvested during the first season but for those harvested during the second season was significantly ($P \geq 0.05$) increased from 23.33 to 55.31% for the cultivar Tabat and from 35.55 to 43.25% for the cultivar Tetron.

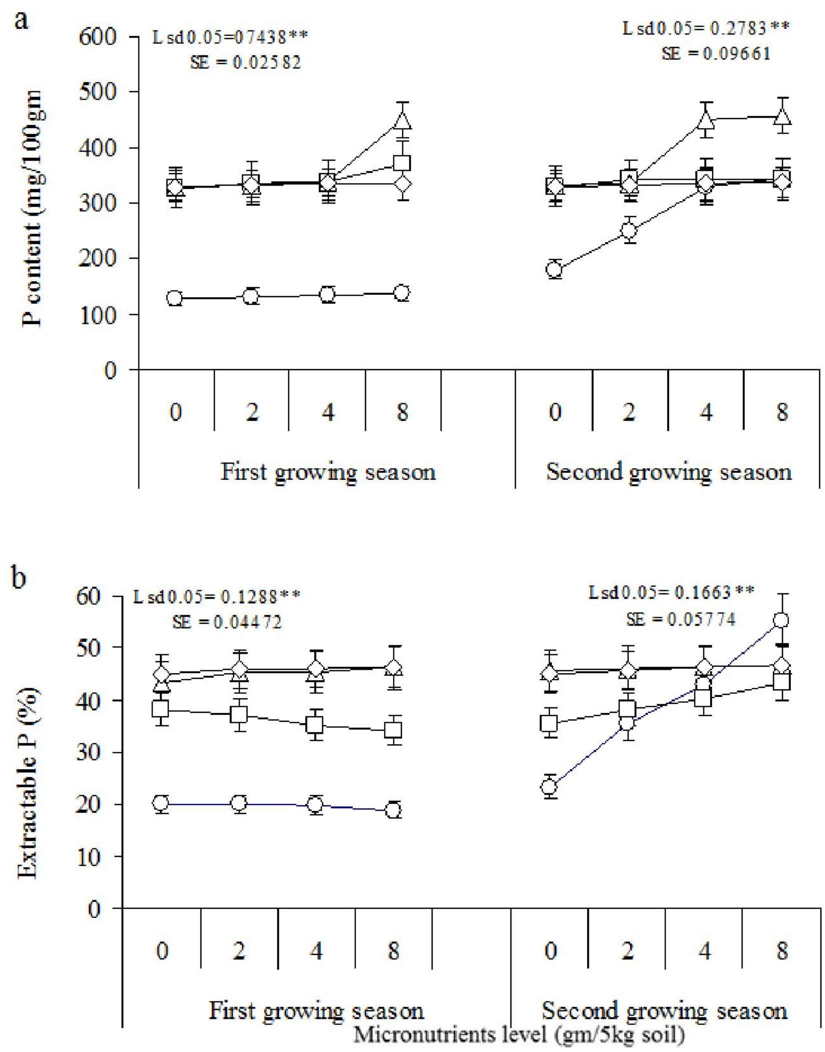

Fig. 2. Total (a) and extractable (%) P of grain sorghum cultivars (○, Tabat; □, Tetron; Δ, WadAhmed; ◊, Gadambalia) grown under different levels of micronutrients fertilization.

Magnesium content of the grains was increased significantly (P ≥ 0.05) with micronutrients dose especially for the grains harvested during the second growing season (Figure 3). Magnesium content (Fig. 3a) of the grains before fertilization was 65.17, 62.06, 52.53 and 50.00 mg/100g for the cultivars Tabat, Tetron, WadAhmed and Gadambalia, respectively during the first growing season while during the second growing season it was 67.6, 62.47, 54.87 and 50.05 mg/100gm for the cultivars, respectively. Fertilization of the plant with 8 gm/5kg soil during both growing season significantly (P ≥ 0.05) increased Mg content with a maximum rate of increment obtained for the grains harvested during the second season and the grains of Tabat cultivar recoded higher value (38%) followed by the grains of Gadambalia cultivar (16%). The rate of increment in Mg was significantly (P ≥ 0.05) higher in grains harvested during the second growing season for the cultivars Tabat and Gadambalia compared to the first growing season. Magnesium extractability (Fig. 3b) significantly (P ≥ 0.05) increased with fertilizer dose and reached maximum values when the grains were fertilized by 8 gm/5kg soil. For the grains harvested during the first season, Tetron (71.40%) and Gadambalia (62.81%) recorded higher values of extractability compared to other cultivars. However, during the second growing season the grains of the cultivars Tabat (92.88%) and Tetron (65.10%) recorded higher extractability values.

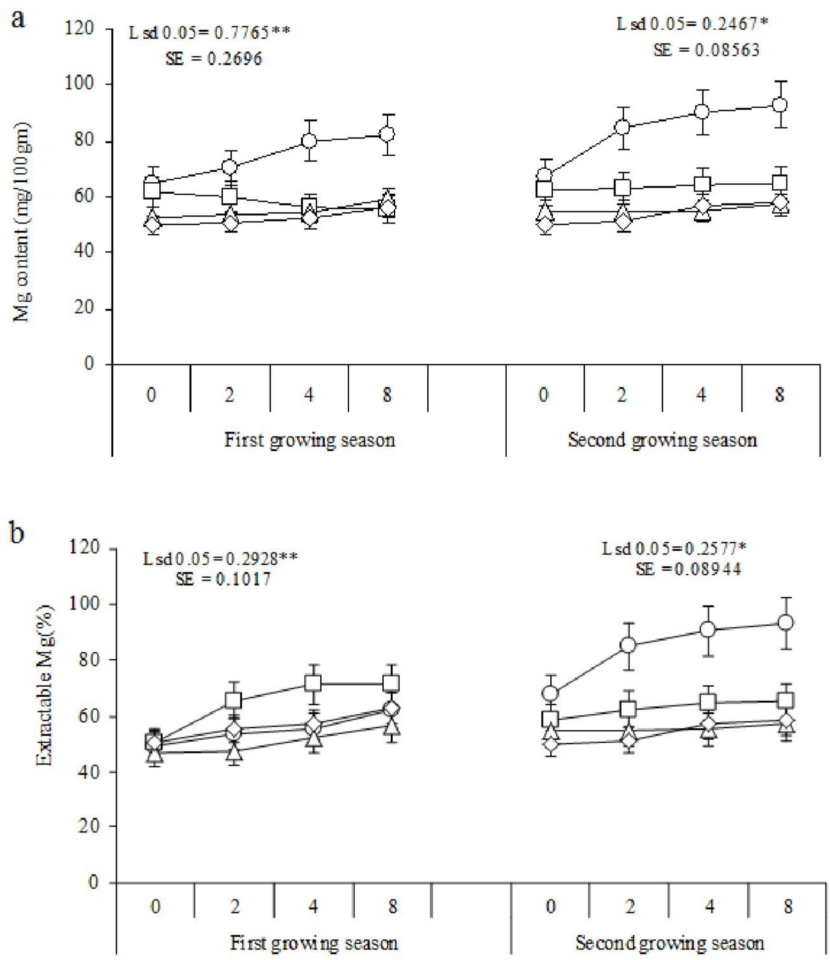

Fig. 3. Total (a) and extractable (%) Mg of grain sorghum cultivars (○, Tabat; □, Tetron; Δ, WadAhmed; ◊, Gadambalia) grown under different levels of micronutrients fertilization.

As shown in Figure 4, potassium content of the grains before fertilization was 440.18, 380.00, 380.00 and 419.53 mg/100gm for the cultivars Tabat, Tetron, WadAhmed and Gadambalia, respectively during the first growing season while during the second growing season it was 482.34, 391.14, 385.00 and 420.02 mg/100gm for the cultivars, respectively. Fertilization of the plant with 8 gm/5kg soil during the first growing season significantly ($P \geq 0.05$) increased K content with a maximum rate of increment observed for the cultivar Tetron (29%) followed by the cultivar WadAhmed (19%). The rate of increment in K content was significantly ($P \geq 0.05$) higher during the second growing season compared to the first growing season with a maximum rate of increase observed for the cultivar Tetron (36%) followed by the cultivar Tabat (34%). Potassium extractability (Fig. 4b) varied between cultivars and fertilizer dose with a maximum value of 57.16% obtained for the grains of the cultivar Gadambalia during the first growing season but for grains harvested during the second season Tabat recorded higher value (70.57%) followed by Gadambalia which recorded 61.12% of K extractability.

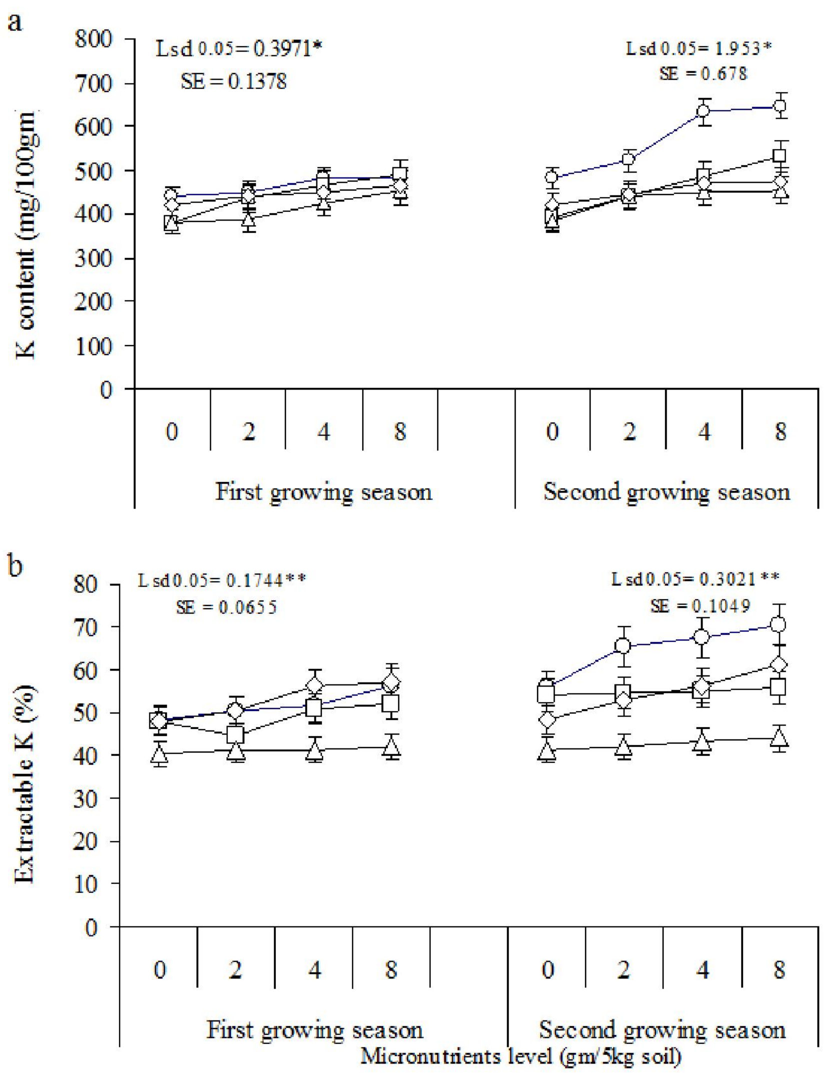

Fig. 4. Total (a) and extractable (%) K of grain sorghum cultivars (○, Tabat; □, Tetron; Δ, WadAhmed; ◊, Gadambalia) grown under different levels of micronutrients fertilization.

Sodium content of the grains before fertilization was 7.76, 8.80, 10.34 and 18.30 mg/100gm for the cultivars Tabat, Tetron, WadAhmed and Gadambalia, respectively during the first growing season while during the second growing season it was 7.93, 9.59, 10.29 and 22.60 mg/100gm for the cultivars, respectively (Fig. 5a). Fertilization of the plant with 8 gm/5kg soil during the first growing season significantly ($P \geq 0.05$) increased Na content with a maximum rate of increment observed for the cultivar Tetron (153%) followed by the cultivar WadAhmed (75%). The rate of increment in Na was significantly ($P \geq 0.05$) higher during the second growing season with a maximum rate of increase observed for the cultivar Tetron (163%) followed by WadAhmed (81%). Sodium extractability (Fig. 5b) was significantly ($P \geq 0.05$) affected by micronutrients fertilization and it increased during both seasons. The grains of the cultivar Tetron harvested during the first season recorded higher extractability (78.27%) compared to other cultivars while the grains of the cultivar Gadambalia harvested during the second season were observed to record higher value (81.14%) of Na extractability.

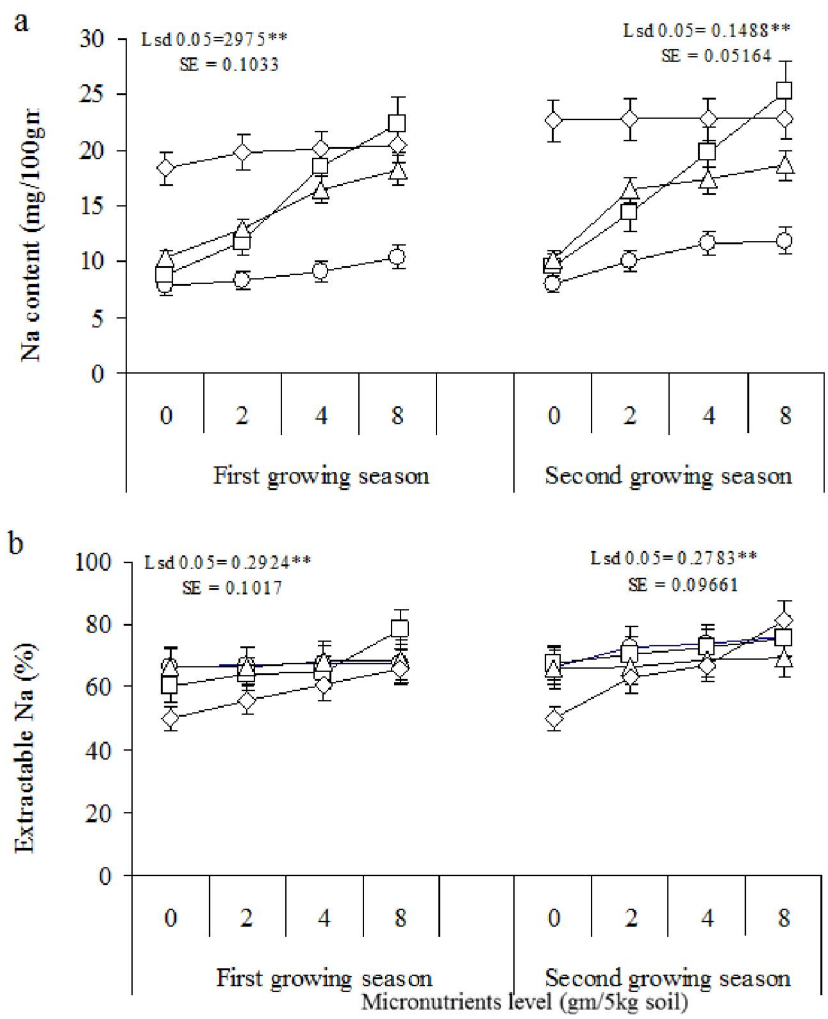

Fig. 5. Total (a) and extractable (%) Na of grain sorghum cultivars (○, Tabat; □, Tetron; Δ, WadAhmed; ◊, Gadambalia) grown under different levels of micronutrients fertilization.

The results obtained for macroelements content and extractability of sorghum grains indicated that micronutrients fertilization is an effective method in improving macroelements of sorghum grain. Moreover, the increment in macroelements content was accompanied by a significant ($P \geq 0.05$) increase in macroelements extractability. The results obtained showed that all cultivars highly respond to micronutrients application especially during the second growing season. However, the degree of response varied between the cultivars. The differences among plant cultivars have been attributed to genetics, physiological/biochemical mechanisms, responses to climate variables, tolerance to pest and diseases, and responses to agronomic management practices. Genetic variations in plant acquisition of micronutrients have been reviewed [18]. The development of cultivars effective in the acquisition and use of micronutrients and with the desired agronomic characteristics is vital for improving yields and achieving genotypic adaptation to diversified environmental conditions and increased resistance to pests [19]. It has been reported that the application of micronutrient-enriched NPK fertilizers provides a double benefit: increasing grain yield and improving the nutritional quality of the harvested grains, since micronutrient-enriched NPK fertilizers also increase the concentration of micronutrients in grain [20]. There are significant differences between crop cultivars in the efficiency with which they absorb and utilize micronutrients, and these differences may be one valuable tool for increasing food quality on some tropical soils. The absorption and utilization of most elements by plants are strongly influenced by factors other than elemental concentration in the soil solution such as soil pH, organic matter, CEC and interactions with other nutrients. Although it has been reported that macro- and micro-nutrients interact with each other forming complexes and reduced the acquisition of such minerals [6]. In the present study we optimize the conditions that reduced the accessibility of the minerals as indicated by increase in both total and extractable macroelements.

4 CONCLUSIONS

The observations about macroelements content and extractability in the studied samples tend to suggest that the application of micronutrient-enriched NPK fertilizers improved the nutritional quality by improving the content and extractability of macroelements of sorghum grains since micronutrient-enriched NPK fertilizers also increase the concentration of micronutrients in grain. Moreover, micronutrients fertilization when compared with chemicals or heat treatment as means to improve the nutritional quality emerges as an attractive and healthy alternative.

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