Influence of Bio-Rock P Fertilizer on Nutritional Composition of Whole Maize Grains: the Case of Madaba and Morogoro, Tanzania

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Abstract

This study was designed to understand the influence of Bio-rock P fertilizer as the source of phosphorous on nutritional composition in maize grain. Bio-rock P fertilizer is a preparation made of rock phosphate and phosphate solubilizing bacteria (PSB). The experiment was laid out in randomized complete block design with three replications each receiving five rates of bio-rock phosphate fertilizer (Control, 20 kg P/ha with PSB, 40 kg P/ha with PSB, 60 kg P/ha with PSB and 80 kg P/ha with PSB). The study was carried out at two geographically different sites; Magadu in Morogoro and Madaba in Ruvuma for the duration of 90 days in the 2019 - 2021 cropping season. In both sites, the results showed that, bio-rock phosphate fertilizer rates had no significant influence on percentage protein, carbohydrate, fibre and moisture content. However, Bio-rock P rates had a significant effect on ash and fat contents of maize grains ($p<0.05$). Bio-rock phosphate fertilizer rates had no significant influence on percentage protein, carbohydrate, fibre and moisture content. For mineral content, there was significant difference in P, K, Mg, and Fe in Magadu and Madaba samples. Therefore, application of bio-rock phosphate increased macronutrients content (ash and fat) and some of micronutrients specifically phosphorous, potassium, magnesium and iron content and as the rates of bio-rock phosphate increased.

Keywords: Bio-rock phosphate, Maize, Nutritional, Quality.

Introduction

Maize grains contribute up to 60 % of human diet thus helping to lessen human nutrition problems as the results of nutrients composition in maize grains and its products (Bathla *et al.,* 2019). This is because the maize grain has a diversity of nutrients including macronutrients, minerals and vitamins that make healthy diets (Rouf Shah *et al.,* 2016). Furthermore, Tanzania National Nutrition Survey 2018 reported that, levels of malnutrition in mainland Tanzania is very high, especially in southern highlands regions, most of which having above 40 % prevalence of children stunting. Yet the same regions are reported to be major producers of staple crops in the country, including maize (Mtaki, 2019). In Tanzania, the use of phosphate solubilizing microorganisms (PSMs) to help avail otherwise unavailable phosphorus from insoluble sources to needy plants with the intention of increasing yield was first reported by Simfukwe and Tindwa, (2018). Deficiency of nutrients required by crops production increase demand of chemical fertilizer application for supply nutrients and causes high concentration in soils and water that can eventually contribute health problems (Sharma and Chetani, 2017). One way of mitigating the risk is by use bio fertilizers, which are eco-friendly and cheap compare to sole chemical inputs for maximizing productivity (Meena *et al.,* 2013).

With this respect, soil fertility of most agricultural soil in the Tanzania's Southern Highlands has been reported poor (Szilas *et al.,* 2007; Mohamed *et al.,* 2021), and that is among the factors for substandard plant and human nutrition in the regions (Njira and Nabwami, 2015). To address this, uses of fertilizer are needed for balanced of plant nutrients uptake, improved crop yield and subsequently better grains' nutritional quality for human consumption. Crops fertilization at various rates may lead to variations in chemical composition in plant based foods (Ogunyemi *et al.,* 2018).

Maize grains contain starch, ash, protein, fiber, oil, vitamins and minerals (Farhad *et al.,* 2009). However, there are nutritional problems associated with deficiency of nutrients like minerals, proteins and crude fibers. These problems lead to healthy complications such as cancer and compromised bones strength mainly due to lack of Ca, K, Mg and P (Gupta *et al.,* 2014). Nutritional quality of maize is under-deprived by minerals compositions and most of which are considered to be more important to the human body (Marta *et al.,* 2017). Apart from agricultural practices particularly application of fertilizer and inherent soil fertility factor above, maize processing including milling cause the variability of nutrients in maize (Prasanthi *et al.,* 2017).

According to Marschner and Marschner (2012), application of fertilizer containing nutrient such as Nitrogen, Phosphorous and Potassium (NPK) can influence plant's uptake of micronutrients from soils, since the micronutrients content in grains are determined form the soils nutrients and fertilizer application (Mohammed *et al.,* 2021). Kakar *et al.,* (2020) reported that a combination of manure and inorganic fertilizer shows an effect on the chemical constituents in rice grains. Therefore, to add information on the implication of phosphorous fertilizer on nutritional parameters, the field study was conducted to evaluate the influence of Bio-rock phosphate. - a hard Minjingu rock phosphate-based biofertilizer on maize chemical compositions as a reflection of its nutritional quality.

Material and methods

This study was conducted in Madaba and Morogoro urban districts in Tanzania. The purpose of selecting these regions was based on a consideration for differences in agro ecological zones and on their high maize production capacity compared to many other regions of the country. Madaba district is geographically located in the south-west part of

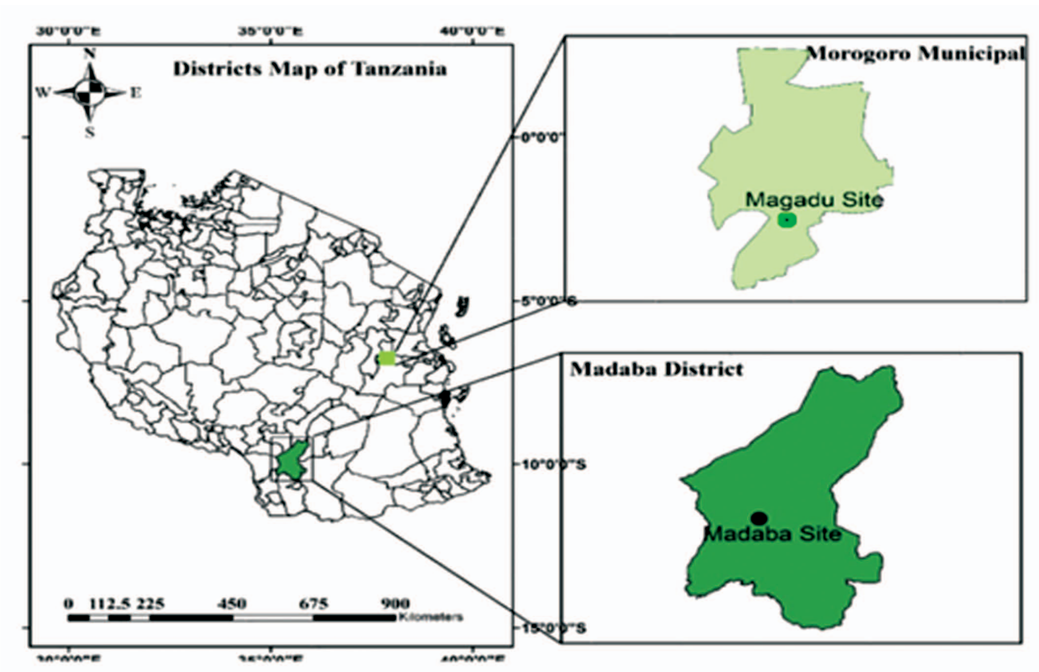

Figure 1: Map of Tanzania regions showing the locations of study area

Tanzania between the Latitudes 90°35′ to 11°45′ south of the Equator and longitudes 34°35′ to 38°1′ east of the Greenwich. The mean annual rainfall of Madaba ranges from 800 to 1800 mm and the mean daily temperature of 23 - 13°C (URT, 2019). Morogoro urban district is located in the Mid-south eastern part of Tanzania between latitude 5°58" and 10°0" south of the Equator and longitudes 35°25" and 35°30" east of Greenwich with a range of 600 - 1200 mm rainfall and temperature of 30-18°C and its agro ecological zones favor production of maize (URT, 1997).

Fertilizers and maize seeds

Bio-rock phosphate fertilizer was prepared by a combination of rock phosphate and phosphate solubilising bacteria (PSB) isolated and preserved from Soil science laboratory at Sokoine University of Agriculture. The mixed culture of isolates was composed of the Phosphate solubilizing microorganism and elemental composition was determined. Maize seeds variety DKC 90 – 89 with maturity of 90 days were obtained from Morogoro-Agro Vet Tanzania.

Soil Sample and analysis

One composite soil sample was collected from top soils (30 cm depth) of 1 hector areas from each selected farm in Madaba and Magadu. The samples were shipped to the Soil Science Laboratory of the Sokoine University of Agriculture. The samples were air dried, ground, and sieved through 2 mm sieves. The analyzed parameters were soil pH, total nitrogen (TN), available phosphorus, organic carbon content, cation exchange capacity, and exchangeable calcium, potassium, and magnesium. Soil pH was determined potentiometrically in 1:2.5 (soil: water suspension) by using pH meter. Walkely and Black wet oxidation method (Nelson and Sommers, 1996) was used to determine soil organic carbon content. Total Nitrogen in the soil was determined by micro-Kjeldahl digestion-distillation method. Available phosphorous was done by Bray 1 extraction method (Okalebo, 1993). The hydrometer method was used to determine soil particle size distribution (Gee and Bauder, 1986) followed by soil textural classification through the United State Department of Agriculture (USDA) soil textural class triangle (United State Department of Agriculture, 1975). Exchangeable magnesium, potassium, calcium and selected micronutrients (Fe, Zn, Cu and Mn) contents were analyzed by using atomic absorption spectrophotometer (AAS) while the exchangeable K by the use of a flame photometer (Thomas, 1996). Organic carbon was determined by the Walkely and Black wet oxidation method (Nelson and Sommers, 1996).

Study design and field experiments

A field experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments in three replications, at two study sites- Magadu site in Morogoro and Madaba site in Ruvuma region. The treatments under this experiment were the different application rate of phosphorus from Bio-rock fertilizer. The rates were 0 kg p/ha (control), 20 kg p/ha, 40 kg p/ha, 60 kg p/ha, and 80 kg p/ha. Experimental farms were prepared by tilling with a tractor followed by the establishment of experimental plots sized 8 m x 5 m. Bio-rock fertilizer rates were applied to the planting holes and then covered with about 2 cm layer of soil before sowing and the seeds were planted at a spacing of 25 cm x 75 cm. Routine agronomic management of maize plants were carried out until the harvest maturity was reached.

Maize grains sampling and nutrients analysis

Sampling was done at maturity stage (90 days), maize grain samples were taken from maize ears harvested from within 4 m x 3 m central area of each experimental plot. For each farm 30 random samples of maize ears were collected. Maize ears were dehusked and then shipped to the laboratory for the analysis. Samples were prepared according to the procedures described by Stangoulis and Sison, (2008). For each sample 25 g of maize flour were collected and packed in new brown paper bags and stored in a clean and insect free environment until analyzed. Proximate analysis (moisture, ash, fat, protein and carbohydrate) and mineral contents (P, Ca, Mg, K, Fe and Zn) were done according to the AOAC (2005). All values for proximate parameters and minerals values were presented as Mean ± SD. The Analysis of Variance (ANOVA) was used to test the significance of treatment effects on proximately composition and mineral content as parameters for nutritional quality ($p<0.05$) and comparison of treatment means were done by Duncan New Multiple Range Test (DMRT).

Results and discussion

Physical and chemical properties of soils at Magadu and Madaba

Physicochemical properties of the soil in study areas are presented in Table 1. According to Landon, (2014); Msanya, (2012), The textural class of Magadu soil was clayey while that of Madaba soil was sandy clay. Soil of both sites were acidic in nature, whereby the Magadu soil were very strongly acidic for while the Madaba soil were strongly acidic. Soils of Madaba had medium range of soil organic carbon contents whereas the soils of Magadu had low OC contents. Organic carbon content has a direct implication on organic matter content of a given soil and therefore affecting both chemical and physical properties of the soil; generally, the higher organic matter content, the more fertile the soil might be. Soils in both study sites had low contents of total nitrogen, phosphorus, and potassium, and therefore deficiency of these nutrients is expected when crops are grown without fertilization

Influence of Bio-rock P fertilizer application on proximately composition in whole maize grains

Variation of treatments at Madaba - Ruvuma and Magadu - SUA Morogoro shows an effect on proximate composition in whole maize samples. Bio-rock phosphate rates had a significant influence on fat content and ash content of maize grains. However, variation of moisture content, crude protein, crude fiber and carbohydrates was not significant between the treatments (Table 3&4).

The moisture content of all samples ranged from 7.79 - 8.68 % at Magadu - SUA Morogoro and 8.39-10.37% at Madaba-Ruvuma. According to East Africa Sandard (EAS), the allowable maximum moisture content in maize

Table 1: Physical and chemical properties of soils of Madaba and Magadu site

Site	Clay	Silt	Sand	Texture	pH	OC	TN	P	K	Ca	Mg	CEC	Fe	Zn	Cu	Mn
Units	%	%	%			%	%	$Mgkg^{-1}$	Cmol+/kg	Cmol+/kg	Cmol+/kg	Cmol+/kg	$Mgkg^{-1}$	$Mgkg^{-1}$	$Mgkg^{-1}$	$Mgkg^{-1}$
Magadu	56	9	35	Clayey	4.9	0.9	0.08	3.34	1.41	1.29	1.2	10.7	34.3	1.1	0.7	60.5
Madaba	43	11	46	Sandy Clay	5.2	1.4	0.09	3.91	2.75	1.8	1.8	17.4	21.5	12.8	9.4	41.5

Table 2: Elemental composition of Bio-rock phosphate inoculum

Parameter	Ca	Mg	K	Na	Fe	Zn	Cu	Mn
mg/kg	369.25	61.39	3247.71	250.55	53.24	5.14	20.89	7.55

grains is 13.5% (Mutungi *et al.,* 2020), which is highly comparable to the results of the current study.

Maize treated with 80 KgP/ha + PSB, 60 KgP/ha + PSB were significantly ($p<0.05$) higher in Ash content than the control and other treatments (Table 3 and 4). A study done in cereals reported that Ash content is an expression of minerals components in maize grains (Eleazu *et al.,* 2020). Hence from the results of this study an increased ash in in maize samples as the increased P rates implies an increment of mineral content in maize.

Protein content increased insignificantly with the rate of bio-rock phosphate fertilizer and values ranged from 8.55 - 10.2 % at Magadu SUA-Morogoro and Madaba-Ruvuma results was 7.55 - 8.25 %, This compares well with the study done by Ogunyemi, *et al.,* (2018) in maize due to the use of NPK and Biochar with results falling between (4.58 - 7.24%). The results differ with findings of the study done by Hussaini *et al.,* (2008) which reported that Phosphorous fertilizer increases the nitrogen uptake in maize grains. Also, Protein content in maize can be improved through agricultural practices by the application of nitrogen containing fertilizer (Enyisi *et al.,* 2014). Moreover, study conducted by Assefa *et al.,* (2021) report the observation aligns with this study that, application of phosphorous beyond 22 kg P were not significance different resulted by the effect of P and S in Nitrogen absorption due to nutrients interaction. There is significant ($p<0.05$) difference in fat content between treatments. The results indicate that as the rate of Bio-rock Phosphate fertilizer increased to 80 kg ha^{-1}, there was a corresponding and significant ($p<0.05$) increase fat content in the maize grains. The results show that fat content increased significantly ($p<0.05$) from 4.83 % in the control treatment to 6.52 % for the treatment receiving 80 kg ha^{-1}at Magadu SUA-Morogoro and from 4.66 % in the control to 5.89 % in treatment receiving 80 kg ha^{-1} in Madaba, respectively. The results aligned with the study done by Ibrahim and Kandil (2007), reported that high level of available phosphorous in the soils increased oils contents in maize grains. The results of current study are near equal

Table 3: Influence of Bio-rock P fertilizer application on nutritional composition in whole maize grains grown in Magadu ward

Bio-rock P rate	%Moisture	%Ash	%Crude protein	%Crude fiber	%Fat	%Carbohydrate
Control	8.68a ± 0.88	0.87a ± 0.31	8.75a ± 0.31	2.24a ± 0.24	4.83a ± 0.79	73.79a ± 1.96
20kg P/ha + PSB	8.53a ± 0.82	1.62ab ± 1.2	8.71a ± 1.21	2.79a ± 0.19	6.05b ± 0.63	71.31a ± 1.3
40kg P/ha + PSB	8.32a ± 0.03	1.18ab ± 0.32	9.14a ± 0.32	2.44a ± 0.35	5.68ab ± 0.22	73.25a ± 0.76
60kg P/ha + PSB	7.9a ± 0.63	1.69b ± 0.8	8.55a ± 0.8	2.85a ± 0.34	6.18b ± 0.47	72.96a ± 1.94
80kg P/ha + PSB	7.79a ± 0.1	2.75c ± 0.59	10.02a ± 0.59	2.6a ± 0.59	6.52c ± 0.51	71.78a ± 0.93
p-value	0.2	0.001	0.26	0.6	0.01	0.06
CV	7.4	29.4	10.9	17.5	10	1.9
STD	0.65	0.79	1.08	0.45	0.74	1.4

Mean values bearing different superscripts in each column are significantly different ($p<0.05$) Duncan Multiple Range Test.
Key: p-Value: Probability value, CV: Coefficients of Variation, STD: Standard Deviation

Table 4: Influence of Bio-rock Phosphate fertilizer application on nutritional composition in whole maize grains grown in Madaba District

Bio-rock P rate	%Moisture	%Ash	%Crude protein	%Crude fiber	%Fat	%Carbohydrate
Control	9.32a ± 0.58	0.69b ±0.62	7.55a±1.04	3.83a±1.87	4.66a±0.98	75.35a±1.77
20kg P/ha+PSB	8.39a ± 0.29	1.32ab±0.56	7.59a±1.91	2.95a±0.53	6.2a±0.38	75.14a±1.94
40kg P/ha+PSB	9.32a ± 1.02	1.32ab±0.09	7.09a±0.32	3.23a±1.51	5.4a±0.48	74.16a±2.4
60kg P/ha+PSB	10.38a ± 1.98	1.55ab±0.44	8.26a±0.54	1.95a±0.49	5.83a±0.92	72.06a±1.94
80kg P/ha+PSB	9.45a ± 1.77	1.67a±0.45	8.1a±0.50	2.36a±1.19	5.89c±0.5	72.53a±1.02
p-Value	0.25	0.1	0.6	0.03	0.34	0.18
CV	14.7	28.6	13.5	25.6	17.8	2.5
STD	1.42	0.53	0.98	1.26	0.98	2.1

Mean values bearing different superscripts in each column are significantly different ($p<0.05$) Duncan Multiple Range Test.
Key: p-Value: Probability value, CV: Coefficients of Variation, STD: Standard Deviation

with the findings on influence of mulching on proximately composition in maize grains done Saeed *et al.,* (2013). The results show no relation in the level of bio-rock phosphate and carbohydrate contents in maize grains. The study done in Nigeria by Awopegba *et al.,* 2017 reported relate value of carbohydrate due to the effect of different types of mulch. The results differ with the study done by Ongunyemi *et al.,* (2018) on the effect of NPK and biochar.

Selected minerals content in whole maize grains fertilized with different rates of Bio-rock Phosphate fertilizer

Phosphorous

The phosphorous content in Magadu samples ranges between 284.3 mg/100g - 600.13 mg/100g and 228.5 mg/100g - 299.6 mg/100g for Madaba samples (Fig. 2). The highest phosphorous content was recorded in plots treated 80Kg P/ha + PSB in comparisons with other rates. Maize planted with no application of Bio-Rock Phosphate fertilizer were significantly low in phosphorous content in comparisons with other rates, with exception for the 20 kg P + PSB treatments in all study areas Magadu (p=0.007) and Madaba (p=0.001). Results resemble with the study done by Pereira *et al.,* (2020) on the increase of uptake of phosphorous in corn due to application of inoculants with phosphate source (P_2O_3). Solubilization of the less soluble rock phosphate occurs after release of organic acids (Wu *et al.,* 2019). General as the rate of bio-rock phosphate rates increase the uptake of phosphorous increase as presented in Figure 2.

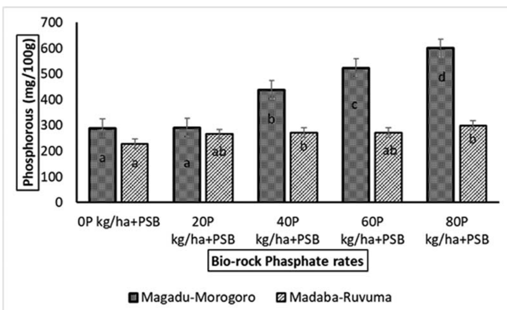

Figure 2: Phosphorous content in maize grains fertilized with Bio-rock Phosphate fertilizer

Calcium

The differences in calcium content of maize grains fertilized with different rate of bio-rock phosphate fertilizer show no significant for Magadu (p =0.073) and Madaba (p=0.125) maize samples as presented in Figure 3. The results related with the study done by Gaj *et al.,* (2018), where by application of phosphorous fertilizer has no effect on maize plant and in addition the study highlights the reasons could be nutrients shortage in the soils, acidic soil reactions and malfunction of nutrients uptake. All values of calcium content in maize grains fertilized with different rate of bio-rock phosphate fertilizer recorded approximately equal value (Fig. 3).

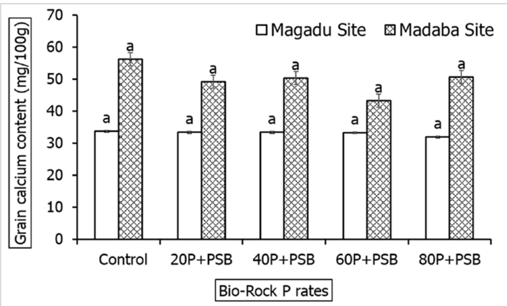

Figure 3: Influence of Bio-rock P fertilizer on Calcium (Ca) contents of maize grains grown in Madaba district

Potassium

Maize samples from Magadu and Madaba planted with no application of bio-rock phosphate fertilizer were significantly low in potassium content compared to those that receive different rates of bio-rock phosphate, Magadu (p=0.007) and Mdaba (p<0.001). The highest potassium content was recorded in plots treated with 80 Kg P/ha+ PSB (Fig. 4). As the rate of bio-rock phosphate fertilizer increased

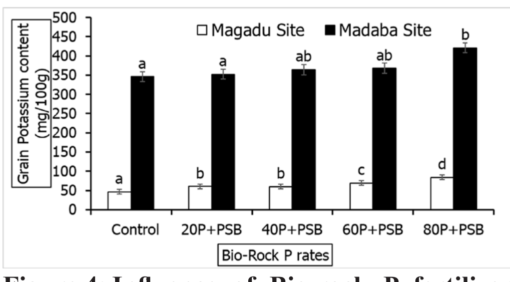

Figure 4: Influence of Bio-rock P fertilizer on Potassium (K) contents of maize grains grown in Madaba district

it resulted in significant (p<0.05) increase in potassium content in maize grains. According to the study done by Njira and Nabwami (2015), the increase in uptake of potassium in maize by increase the phosphorous content in the soil is due to synergistic uptake between phosphorous and potassium uptake.

Magnesium

Maize samples planted with no application of bio-rock phosphate fertilizer were significantly low for Magadu (p=0.003) and Madaba (p<0.001) in magnesium content compared to those that receive different rates of bio-rock phosphate as presented in figure 5. The highest magnesium content was recorded in plots treated with 80 Kg P/ha+ PSB. As the rate of bio-rock phosphate fertilizer increased it resulted in significant increase in magnesium content in maize grains. Results resemble with the study done by Rodrigues *et al.,* (2017) which reported that there was an increase of uptake of magnesium in corn due to application of fertilizer from phosphate source.

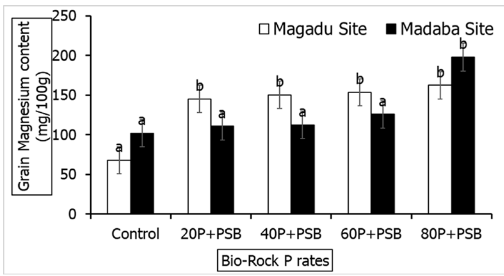

Figure 5: Influence of Bio-rock P fertilizer on Magnesium (Mg) contents of maize grains grown in Madaba district

Iron

Maize samples planted without application of bio-rock phosphate fertilizer were significantly low in iron content compared to those that receive different rates of bio-rock phosphate for both in Magadu (p=0.006) and Madaba (p=0.012) samples (Fig. 6). The highest iron content was recorded in plots treated with 80 Kg P/ha+ PSB. As the rate of bio-rock phosphate fertilizer increases it resulted in significant (Magadu, p=0.006) and Madaba p=0.012) increase in iron content in maize grains. In Magadu samples, highest content was recorded in plots treated 60 KgP/ha + PSB and fell at 80 kgP/ha + PSB contrary to observation in Madaba samples, in which the content was insignificantly different ($p<0.05$) (Fig. 6). According to Xie *et al.,* (2019) high levels of phosphorous facilitates the translocation of Iron from the roots to shoots to be reduced hence leading a negative increase Iron content maize. Likewise, phosphorous application has less effect on iron (Fe) concentration but its bioavailability may be reduced as the Phytic acid, (PA)/Fe moral ration rise (Bindraban *et al.,* 2020).

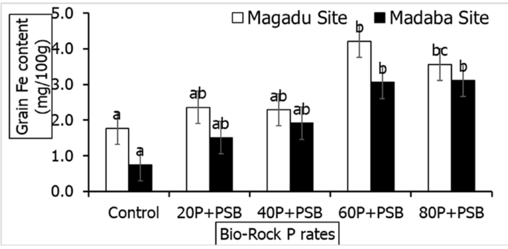

Figure 6: Influence of Bio-rock P fertilizer on iron (Fe) contents of maize grains grown in Madaba district

Zinc

There was no significant difference in zinc content of maize grains fertilized with different rates of bio-rock phosphate for Magadu ($p=0.073$) and Madaba ($p=0.580$). The observed results agreed with the study done by Taliman *et al.,* (2019), which reported that phosphorous fertilizer has little effects on concentration of zinc and iron in soybean. Moreover, high rate of phosphorous fertilization lowers zinc in plant tissues or not necessarily through repress absorption or dilution of zinc in plant tissue by phosphorous (Mohammed *et al.,* 2021). Similar finding reported by Zhang *et al.,* (2017), that application of Phosphorous may limit zinc uptake by roots. Maize planted without application of bio-rock phosphate fertilizer were low in zinc content in comparisons with other applications. The highest Zinc content was recorded in plots treated 80 KgP/ha + PSB, with the value of 2.8 - 3.03 mg/100g in Magadu samples and 1.65-2.032 mg/100g in Madaba samples as presented in Figure 7. The results of selected micronutrients in the currently study, differ very slightly with the data from Tanzania food composition table with the value of 3.5 and 1.8 mg/100g for iron and zinc respectively (Lukmanji *et al.,* 2008).

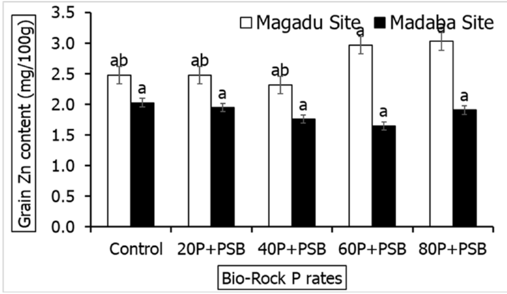

Figure 7: Influence of Bio-rock P fertilizer on Zinc (Zn) contents of maize grains grown in Madaba district

Conclusion and recommendation

Bio-rock phosphate fertilizer contributed to the proximate composition of whole maize grains. It increases macronutrients (ash and fat) and some of micronutrients specifically phosphorous, potassium, magnesium and iron contents as the rates of fertilizer increased. However, bio-rock phosphate did not affect moisture, proteins and fibers and carbohydrate in all samples from Magadu and Madaba sites. The positive response was also observed in mineral contents (P, K, Mg and Fe); hence the fertilizer could enhance the nutritional quality as the rate of fertilizer application increase. Application up to 80 kgP/ha + PSB are recommended for boost the nutritional quality of maize grains without impair the uptake of other nutrients. Applications of 60 KgP/ha + PSB and 80 kgP/ha + PSB rates are recommended to be used by farmers to improve mineral contents in maize grains. The observation is may not only contributed by the effect of bio-rock phosphate fertilizer, although physical chemical characteristics of the soils, hence more studies is needed.

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