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Full Length Research Paper

Mineral content of cassava growing in four districts of Mozambique: Implications for consumer health

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Mozambique is the fifth highest producer of cassava in Africa. Cassava is mainly produced for human consumption and contributes to food security. Information on whether soil composition influences mineral concentrations in cassava roots is lacking. The aim of the study was to assess whether the concentration of aluminium, calcium, copper, iron, manganese, phosphorus, lead and zinc in cassava roots is influenced by soil concentrations of these minerals and indicate its implications for consumer health. Samples of cassava root and adjacent soil were collected from four districts in Mozambique. The concentrations of minerals were determined using inductively coupled plasma-optical emission spectrometry. The mineral concentration of soil from the four districts differed significantly ($p < 0.05$) as did the mineral concentration in the root samples. The concentration in the roots was lower than the adjacent soil. The low level of minerals is a concern to the health of mainly cassava consumers, since these levels would not provide sufficient nutrition, especially for the vulnerable population; young children and women of reproductive age. It is advised that fortification of cassava root products be investigated to determine whether the nutritional value could be improved for consumers who are almost exclusively dependent on cassava as a staple.

Key words: Cassava roots, health, iron, mineral concentration, Mozambique, soil type.

INTRODUCTION

Agriculture is paramount in contributing to social and economic growth in Mozambique (Ministry of Agriculture, 2009). Approximately 80% of the rural population in this country depends on this sector for their livelihood (INE, 2009). Small scale farmers cultivate 95% of the total land area, estimated at 5 632 781 ha (INE, 2011). The main agricultural product grown in Mozambique is cassava and Mozambique ranks as the 5th highest producer of cassava in Africa (FAO, 2011). Although, fertilizer is used for cassava in other parts of the world (Howeler, 2002; Kamaraj et al., 2008), this is not the case in Mozambique

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(INE, 2011).

Mozambique has a tropical climate which is characterized by high humidity and rainfall (1200 mm) as well as annual ambient temperatures that fluctuate between 23°C and 26˚C (Hoguane, 2007). Although cassava is cultivated along the country, only three areas are considered to be intermediate or high production (IIAM/PNRT, 2007) and include; Nampula (29.27%), Zambezia (26.76%) and Inhambane (8.80%) provinces (INE, 2011). Cassava is mainly produced (> 90%) for human consumption (Donovan et al., 2011; Haggblade et al., 2012) and contributes to food security, particularly in rural communities (MIC/FAO/EC, 2007). It is also considered a famine reserve crop in areas where drought occurs (INIA/IITA/SARRNET, 2003).

A balanced diet which contains sufficient levels of minerals ensures optimal functionality of the body which includes structural, physiological, catalytic and regulatory actions (McDowell, 2003). In African countries where people have inadequate food, micronutrient deficiencies are frequently found (Perlas and Gibson, 2002). The population groups most affected by micronutrient deficiency are women of reproductive age and children younger than five years of age (Black, 2001; Black 2008). Diets where mineral concentrations are imbalanced and/or inadequate may result in illnesses (FAO/WHO, 2004). For example, anaemia, which is reported to be a sign of poor diet and poor health and is associated with a deficiency in iron (Taljaard, 2011).

The uptake of minerals by plants is reported to be inversely proportional to the concentration in soil (Ross, 1994). Mineral concentrations in plants are influenced by soil texture, pH, electric field potential (Eh), cation exchange capacity, organic matter, clay mineral content, iron, manganese and lead oxides and hydroxides, as well as the presence of other metals and microbial transformations (Krˇíbek et al., 2014). Interactions and antagonism between minerals or other substances in the soil, humidity and temperature have also been found to influence mineral uptake from soil (Nubé and Voortman, 2006). Limited information is available on the effect that mineral concentration in soil has on the mineral concentrations in cassava roots from the same area, in Mozambique. The aim of the study was to assess whether the concentration of aluminium, calcium, copper, iron, manganese, phosphorus, lead and zinc in cassava roots is influenced by soil concentrations of these minerals and indicate its implications for consumer health.

MATERIALS AND METHODS

Study area

Mozambique is divided into ten agro-ecological zones based on altitude, climate (precipitation and temperature), and soil type (IIAM/PNRT, 2007). Each zone is annotated by the letter R which is followed by the number (Figure 1). The four districts from which soil and cassava root samples were collected are located in the agro-ecological zones R2, R5, R7 and R8 (Figure 1). The agro-ecological zones R2, R5 and R8 in combination produce 60% of the cultivated cassava, whereas R7 produces the rest. Agro-ecological characteristics for R2, R5 and R8 zones include an altitude between 0 and 200 m, annual precipitation ranging between 800 and 1400 mm and a temperature of 24°C to 26°C. In the R7 zone the altitude ranges between 200 and 500 m, the temperature from 20°C to 25°C and rainfall between 1000 to 1200 mm (IIAM/PNRT, 2007).

Sample collection

Samples of cassava root and adjacent soil (five per district) were collected using the non-probability judgement method (Motulsky, 2003). The perspective of judgement included the varieties (the most cultivated), type (bitter or sweet) and region/area of cultivation (high and intermediate). Five samples per variety of bitter cassava roots (*Tomo and Incirricano*) were collected from Rapale (R7) and Alto Molocue (R8) districts in the northern region. A further five samples per variety of sweet cassava roots (*Calamidade and Munhaca*) were collected from the Meconta (R5) central and Zavala (R2) southern regions. In each area where roots were sampled, three points were selected at random adjacent to the plants sampled and soil samples were taken at a depth of 20 cm. The samples were combined in equal ratios, resulting in a composite sample. All samples were kept in plastic bags and identified by number, location, variety and type. Cassava root samples were hand peeled using metal free instruments, washed and stored at 4°C until determination of mineral concentration.

Sample digestion

Soil sample (0.250 g) was weighed in a digestion vessel. Three milliliters ultrapure nitric acid (65%, Merck, Darmstadt, Germany) and 2 mL hydrofluoric acid (40%, Sigma Aldrich, Johannesburg, South Africa) were added to the sample. The vessels were capped and subjected to digestion using the Microwave Digestion Accelerated Reaction System – MARS (CEM Microwave Technology Ltd, Buckingham, England). The instrument was set to KA Soil-X Press method at 75% of 1200 W, control temperature of 180°C, ramping and holding time for 10 min and cooling down time of 15 min. After digestion, vessels were opened using the capping station and 2 mL boric acid (70%, Sigma Aldrich) was added. Vessels were re-capped and re-digested. The sample was transferred to a 50 mL volumetric flask and deionized water (<18.2 MΩ cm) was added to the full capacity level of the flask. Each sample was digested in triplicate.

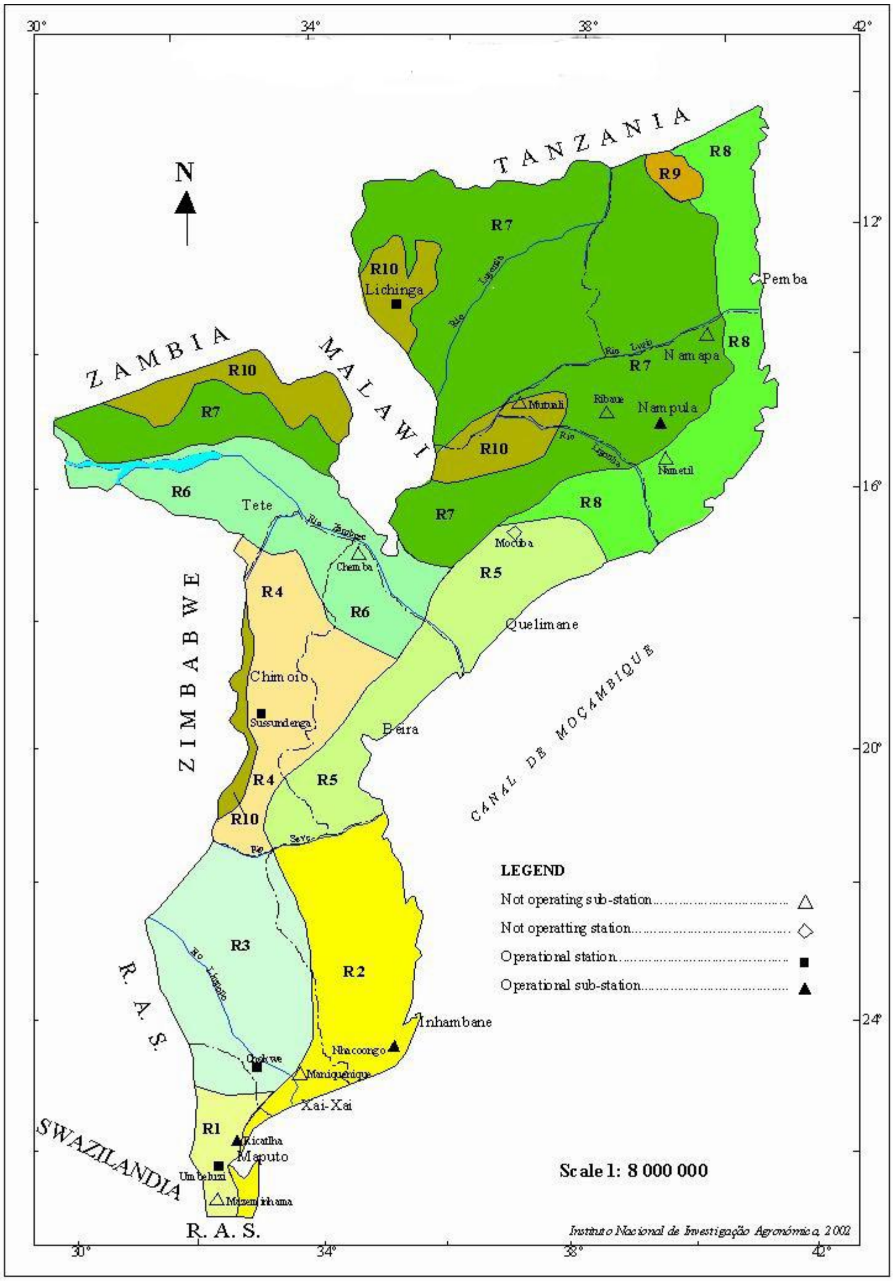

Figure 1. Map of Mozambique, indicating the ten agro-ecological zones. Samples were collected in zones R2, R5, R7 and R8 (INIA, 2002).

Grated fresh cassava root was dried in an oven at 210°C for 3 h. After drying, the grated cassava root was weighed (0.750 g) into a digestion vessel and 4 mL nitric acid (65%) and 2 mL hydrogen peroxide (30%, Merck) added. The vessels were capped and triplicate samples were subjected to digestion, as described for the soil samples. Each sample was analytically transferred to a 25 mL volumetric flask and deionized water (<18.2 MΩ cm) was added to the full capacity level of the flask. Samples were analyzed in triplicate.

Chemical analysis

Mineral content of the digested soil and root samples was carried out using inductively coupled plasma-optical emission spectrometry (ICP–OES; SPECTRO ARCOS

(Spectro Analytical Instruments, Kleve, Germany). Multi-element standard solutions were prepared by dilution of stock standard solutions (1000 mg/L, Merck) to the desired concentration. The ranges of the calibration standards were selected to match expected concentrations for the elements aluminium (Al), calcium (Ca), copper (Cu), iron (Fe), manganese (Mn), phosphorus (P), lead (Pb) and zinc (Zn) in the samples. Operating conditions for the ICP-OES are listed in Table 1.

Statistical analysis

Samples were analyzed in triplicate using STATA version 12. The normality of the data was assessed using the Shapiro-Wilk method. One-way ANOVA® was performed to test the variance and Bonferroni was used to compare means.

RESULTS

Concentration of minerals in the soil samples of four districts

The concentration of minerals in soil samples investigated is presented in Table 2. The mineral concentration of the samples in the four districts differed significantly ($p < 0.05$). The Ca concentrations of samples collected in the Alto Molocue district were lower than the detection limit of the instrument (0.004 µg/g). In the other three districts, Ca was found to be the mineral with the second highest concentration (Table 2). The concentration of Cu in the soil samples ranged between 0.005-0.026 mg/kg, with soil from Alto Molocue having more than twice the amount of Cu than the other districts (Table 2). Samples from the four districts tested, differed significantly ($p < 0.05$) in Fe and Mn concentration. The concentration of P in soil from Rapale and Zavala districts was below the detection limit of the instrument. The values for Pb in all samples were just above the limit of detection of the instrument and are considered negligible. The mean concentration of Zn (0.01mg/kg) in the samples was also found to be very low.

Concentration of minerals in the four cassava root varieties

The concentration of minerals in the roots of four varieties of cassava analyzed is presented in Table 3. The concentration of Al differed significantly ($p < 0.05$) between the *Tomo* and *Incirricano* varieties, even though concentrations were low. A significant difference ($p < 0.05$) in Ca, Cu, P and Zn concentration between the root samples of the four varieties of cassava was observed (Table 3). The concentration of Fe and Pb in all samples was lower than the detection limit of the instrument. Mn concentration was found to be significantly different ($p < 0.05$) between the varieties of cassava root sampled (Table 3).

DISCUSSION

Concentration of minerals in the soil samples of four districts

The concentration of Al in the soil samples was much lower than those described in earlier studies (Burt el al., 2003; Maria and Yost, 2006). Cassava tolerates relatively high levels of Al in the soil, with levels <75% in soils being suitable for cultivation (Howeler, 2012). The concentration of Al found in soil would therefore not appear to impact negatively on cassava cultivation. This is important as excess Al may result in toxic levels.

A previous survey of soil fertility in Nampula Province, Mozambique, showed that the level of extractable calcium ranged between 2.33 and 4.34 $cmol_c$/kg (Maria and Yost, 2006). For optimal growth, cassava requires 0.25 to 1.0 me/100 g of Ca. Based on the latter, except for the Alto Molocue district, the soil was found to contain sufficient Ca for cassava cultivation. The mean concentration of Cu (0.012 mg/kg) in soils sampled (Table 2) was found to be much lower than the 1.25 mg/kg, described previously in unpolluted Nigerian soil where cassava was cultivated (Kolawole, 2012).

The concentration of Fe in the soils was found to be the highest of all minerals determined (Table 2). These results are supported by Nubé and Voortman (2006), who also noted Fe as the most abundant mineral in the soil. The iron concentration range of 2.6 to 24.8 mg/kg (± 10.8 mg/kg) was however lower than the range of 38.4 to 279 mg/kg (± 50 mg/kg) reported by Maria and Yost (2006) for soil in Mozambique but higher than that detected in Zambian soil (median 0.8 mg/kg) (Krˇíbek et al., 2014). The Mn concentration was lower than the 3 mg/kg considered normal for soil (Davies, 1986). The P concentration in soil from Rapale and Zavala districts was below the detection limit of the instrument (Table 2). This may indicate a P deficiency in those districts, as has previously been described by Maria and Yost (2006). The concentration of P was significantly different ($p < 0.05$) between the Alto Molocue and Menconta districts. The mean concentration of Pb (0.03 mg/kg) was considerably lower than that found in Zambian soils (11 mg/kg) where cassava was cultivated (Krˇíbek et al., 2014). The mean concentration of Zn in the soil samples was low (0.01mg/kg), which is in agreement with Cakmak (2002)

Table 1. ICP-OES operating conditions.

Method parameters	
RF power (W)	1400
Coolant flow rate (L/min)	12.00
Nebulizer flow rate (L/min)	1.00
Auxiliary flow rate (L/min)	1.00
Pump speed (rpm)	30
Rinse time (s)	30
Replicate read time (s)	15
Element	**Emission line (nm)**
Al	394.401
Ca	317.933
Cu	219.958
Fe	238.204
Pb	283.305
Mn	257.611
P	214.914

but lower than that documented for Zambian soil (median = 15 mg/kg) (Krˇíbek et al., 2014).

Concentration of minerals in the four cassava root varieties

The mean concentration of Al in the cassava roots was low (Table 3). This may implicate that the roots do not absorb Al from the soil. The Al concentration in the root samples did not differ significantly between the types of cassava, bitter or sweet. The Ca concentration ($9.29x10^{-3}$ mg/100 g) was lower than that found by previous investigators (Okigbo,1980; Ayodeji, 2005; Charles et al., 2005; Oluyemi et al., 2005; Adeniji et al., 2007). There was also variability between different varieties, which was not related to whether the variety was bitter or sweet, but is rather postulated to be related to the bioavailability of this mineral. The Cu concentration ranged between 0.10 to 0.20 mg/100 g x 10^{-3} which is lower than those found in previous studies; 0.1 mg/100 g (USDA, 2011) and 5.8 mg/100 g (Charles et al., 2005).

Similar to Al, the Fe concentration was also low (Table 3). Different authors have reported a wide variability in Fe concentration in cassava roots; 0.53 mg/100 g (Oluyemi at al., 2005), 10 mg/100 g (Ayodeji, 2005), 17.1 mg/kg (Charles et al., 2005), 11.73 mg/100 g (Adeniji et al., 2007), 0.27 mg/100g and 40.51 ppm (Kolawole, 2012). In Nampula Province the iron concentration was below the limit of detection. Burns et al. (2012) found Fe levels in roots collected from the same area to vary between 8 and 24 mg/kg. The low Fe concentration in roots has been ascribed to its unavailability to crops (Meng et al., 2005).

The mean concentration of Mn ($0.80x10^{-3}$ mg/100 g) was low compared to that of other studies: 1.4 mg/kg (Charles et al., 2005), 00.05 mg/kg (Oluyemi et al., 2005), 2.45 to 2.82 mg/100 g (Adeniji et al., 2007) and 0.384 mg/100 g (USDA, 2011). Ayodeji (2005) did not detect Mn in cassava roots. The mean P concentration appeared to be different in bitter and sweet types, although the range was similar (Table 3), but lower than that observed in previous studies (Ayodeji, 2005: 50 to 70 mg/100 g, Charles et al., 2005: 0.165%; Adeniji et al., 2007: 60 to 120 mg/100 g, USDA, 2005: 27 mg/100g). Although Pb was not detected in the root samples analyzed, a concentration of 159.3 mg/kg (Kolawole, 2012), 113.6 mg/kg (Kolowole, 2012) and 0.7 mg/kg (Krˇíbek et al., 2014) has been noted previously.

The Zn concentration ranged between $0.20x10^{-3}$ and $0.70x10^{-3}$ mg/100 g compared to 0.082 mg/100 g (Oluyemi et al., 2005), 7.5 mg/kg (Charles et al., 2005), 4.80 mg/kg (Krˇíbek et al., 2014), 210 to 260 mg/100 g (Ayodeji, 2005) and 9 to 19 mg/kg (Burns et al., 2012). A significant difference ($p < 0.05$), in Zn concentrations between different types of cassava (bitter or sweet) was noted. The differences in mineral content between studies may be due to geographic locality and cultivar (Burns et al., 2012).

A summary of the mineral concentrations obtained for the

Table 2. Mineral concentration of soil samples collected from four districts in Mozambique where cassava root samples were collected.

Mineral content (mg/kg)								
District	Al	Ca	Cu	Fe	Mn	P	Pb	Zn
Rapale	1.83 ± 0.09^{a}	2.76 ± 0.10^{a}	0.005 ± 0.000^{a}	2.6 5 ± 0.1^{a}	0.11 ± 0.00^{a}	<LDL (0.05)^{*a}	0.02 ± 0.00^{a}	0.01 ± 0.00^{a}
Alto Molocue	1.21 ± 0.03^{b}	<LDL (0.004)^{*b}	0.026± 0.003^{b}	24.8 ± 0.7^{b}	0.49 ± 0.02^{b}	0.30 ± 0.02^{b}	0.04 ± 0.00^{b}	0.01 ± 0.00^{b}
Meconta	2.60 ±0.09^{bc}	2.70 ± 0.08^{acd}	0.010 ± 0.001^{ac}	6.45 ± 0.10^{bcd}	0.24 ± 0.01^{bcd}	0.05 ± 0.00^{bc}	0.03 ± 0.00^{bc}	0.01 ± 0.00^{b}
Zavala	2.54 ± 0.13^{bc}	2.54 ± 0.05^{bc}	0.006 ± 0.000^{ac}	9.22 ± 0.16^{bc}	0.16 ± 0.01^{bc}	<LDL (0.05)^{*acd}	0.04 ± 0.00^{bcd}	0.02 ± 0.00^{bc}
Range	1.21 - 2.60	<LDL - 2.76	0.005 – 0.026	2.65 – 24.8	0.11 - 0.49	<LDL - 0.30	0.02 – 0.04	0.01 – 0.02
Mean	1.60	2.67	0.012	10.8	0.25	0.17	0.03	0.01
SD	0.66	0.12	0.010	9.72	0.17	0.18	0.00	0.00

^{abcd}value in the same column with different superscripts are significantly different ($p < 0.05$)
LDL- Limit of detection of instrument (mg/kg)
*Value of limit of detection of instrument
n = 15

Table 3. Mineral concentration of cassava root varieties cultivated in four districts of Mozambique.

Mineral content (mg/100 g) x10^{-3}								
Cassava variety	Al	Ca	Cu	Fe	Mn	P	Pb	Zn
Tomo BT (Rapale)	0.08 ± 0.00^{a}	139 ± 2^{a}	0.20 ± 0.00^{a}	<LDL (0.052)^{*a}	1.10 ± 0.10^{a}	135 ± 2^{a}	<LDL (0.084)^{*a}	0.70 ± 0.00^{a}
Incirricano BT (Molocue)	0.03 ± 0.00^{ab}	23.9 ± 1.3^{b}	0.10 ± 0.00^{b}	<LDL (0.052)^{*a}	0.30 ± 0.00^{b}	42.3 ± 1.9^{b}	<LDL (0.084)^{*a}	0.20 ± 0.00^{b}
Calamidade SW (Meconta)	0.04 ± 0.00^{ab}	189 ± 3^{bc}	0.20 ± 0.00^{ac}	<LDL (0.052)^{*a}	1.40± 0.00^{bc}	127 ± 3^{bc}	<LDL (0.084)^{*a}	0.60 ± 0.00^{bc}
Munhaca SW (Zavala)	0.02 ±0.00^{ab}	19.5 ± 0.7^{bcd}	0.10 ± 0.00^{bc}	<LDL (0.052)^{*a}	0.30 ± 0.00b^{cd}	49.3 ± 2.2^{bcd}	<LDL (0.084)^{*a}	0.20 ± 0.00^{bcd}
Range	0.02 – 0.08	19.5 – 189	0.10 - 0.20	<LDL (0.052)^{*a}	0.30 – 1.14	42.3 -135.	<LDL (0.084)*	0.20 – 0.70
Mean	0.04	9.29	0.15	<LDL (0.052)*	0.80	88.5	<LDL (0.084)*	0.40
SD	0.03	8.49	0.10	<LDL (0.052)*	0.60	49.5	<LDL(0.084)*	0.20

* ^{abcd}value in the same column with different superscripts are significantly different ($p < 0.05$),
BT-Bitter,
SW-Sweet,
LDL- Limit of detection of instrument,
*Value of limit of detection of instrument in µg/g,
n = 15.

cassava root samples in the preset study and that from literature is provided in Table 4.

Implications for consumer health

The Al concentration was lower in the roots than in the soil, which implies that consuming cassava roots in Mozambique is unlikely to result in toxicity by this mineral. According to the World Health Organization, approximately 1 mg/kg of body weight per week is considered the amount that can be safely consumed (Scientific opinion of the panel on food additives, 2008). The bioavailability of Al consumed with food staples is reported as 0.1 to 0.3% (EFSA, 2008). Neurodegenerative disorders, metabolic bone disease, dyslipemia and even genotoxic activity have been associated with aluminium toxicity (Krewski et al., 2007). However, with the concentrations detected there is no threat in developing any of these diseases.

Calcium, an essential microelement in human nutrition, is only available to the body via diet. It is particularly important for bone composition (Wang et al., 2006). Although the requirement for Ca varies according to age, the range is between 1000 and 1500 mg/day (Bailey et al., 2010). As cassava roots are the main staple of the population of Mozambique, the very low levels found in the roots are a cause for concern. Copper forms part of several enzymes in diverse biochemical processes including respiratory, anti-oxidative defense and iron metabolism (Scheiber and Dringen, 2013). The low levels of Cu detected in the roots would not alleviate Cu deficiency in the consumer.

Iron is an essential trace element in human nutrition. Iron deficiency in human populations is mainly caused by a low concentration of Fe in food consumed (Pedersen et al., 2010). In Mozambique, Fe deficiency and related anaemia are considered to be a serious public health concern, affecting almost 40% of the population (WHO, 2008). The population groups most at risk of diet related Fe deficiency are preschool children and woman of reproductive age (MISAU/INE/ICFI, 2011). A woman of reproductive age needs to consume 18 mg/day of iron (Nordic Council of Ministers, 2004). This amount will not be obtained through the consumption of cassava which had low iron concentrations. Children born to mothers suffering from Fe deficiency are known to have poor cognitive development and lower intelligence (Milman, 2011). A pregnant woman with Fe deficiency may have a difficult parturition and are at risk of giving birth to children with low birth mass (Cogswell et al., 2003).

The concentration of Mn found in cassava roots was low ard ranged between 0.30 x 10^{-3} to 1.14 x 10^{-3} mg/100 g. This implies that people consuming cassava as basic staple may be deficient in Mn. Consumption of food deficient in Mn has led to the manifestation of Mseleni's disease (Fincham et al., 1981), skin diseases and bone abnormalities (Norose and Arai, 1987). A well-nourished person contains between 200 to 400 µmol of Mn (WHO, 2011). Manganese acts as an enzyme activator and forms part of the pyruvate decarboxylase and manganese-superoxidase enzymes (Hurley and Keen, 1987) and it also regulates the body pH (Kuhn et al., 1995).

Phosphorus is an essential macronutrient for bone and teeth composition. The recommended daily allowance of P depends on age and sex (Institute of Medicine, 2013). The concentration of P detected in the roots sampled in this study, was lower than the norm of 21 mg/100 g (USDA, 2011). This is a concern, especially in a country where there is limited access to foods of animal origin which are rich in P, and are required for good health (Calvo and Park, 1996).

Lead was not detected in the root samples and therefore health concerns related to bioaccumulation of this metal, including mental impairment in children (Rogan et al., 2001), colic, anaemia and renal disorders (WHO, 2010) would not pose a threat. Nutritional deficiency of Zn has been found to result in skin disease, diarrhea and sore throats (Passad, 2012), as well as poor growth, mental disorders and epileptic convulsions (Takeda, 2000). The deficient levels of Zn in the roots would not be beneficial to health and fortification of cassava root products should be considered.

Both Fe and Zn were much lower in the cassava root samples than in the soil. Iron deficiency and resultant anaemia is known to be associated zinc deficiency (Hotz and Brown, 2004). The simultaneous deficiency of Fe and Zn is ascribed to both minerals being involved in the synthesis of hemoglobin (Garnica, 1981). Also, a deficiency in these minerals has also been related to the consumption of plant foods which contain inhibitors of non-heme Fe and Zn absorption (Gibson and Huddle, 1998; Huddle at al., 1999).

CONCLUSIONS

The concentration of minerals in the soil, between the four districts, as well as between the roots of the four varieties of cassava, was significantly different. In all cases, the mineral concentration in roots was lower than that found in the adjacent soil. The large difference in mineral concentration between the soil and roots indicates that uptake of minerals from soil may be a problem.

The low level of minerals is a concern to the health of mainly cassava consumers, since these levels would not provide sufficient nutrition, especially for the vulnerable population;

Table 4. Summary of the mineral concentration in root samples found for the present study (in two units) and the concentrations reported in literature.

	Mean concentration in roots		Mineral content in cassava roots from previous studies	
Mineral	mg/kg	(mg/100 g) x 10^{-3}	Content	Reference
Al	0.004	0.04	NA	NA
Ca	0.093	9.29	116 mg/100g	Okigbo ,1980; Charles et al.,2005
			0.076%*	Charles at al., 2005
			5 -35 mg/100g	USDA, 2011
Cu	0.010	0.10	0.1 mg/100g	USDA, 2011
			5.8 mg/kg	Charles at al., 2005
Fe	<LDL	<LDL	0.27 mg/100g	USDA, 2011
			17.1 mg/kg	Charles at al., 2005
			0.53 mg/100 g	Oluyemi at al., 2005
			10 mg/100 g	Ayodeji, 2005
			11.73 mg/100 g	Adeniji et al., 2007
			40.51 ppm	Kolawole, 2012
			8 - 24 mg/kg	Burns at al., 201
Mn	0.008	0.80	0.05 mg/kg	Oluyemi et al., 2005
			1.4 mg/kg	Charles at al. 2005
			2.45 to 2.82 mg/100 g	Adeniji et al., 2007
			0.384 mg/100g	USDA, 2011
P	0.089	88.5	50 to 70 mg/100 g	Ayodeji, 2005
			0.165%*	Charles at al., 2005
			60 to 120 mg/100 g	Adeniji et al., 2007
			27 mg/100g	USDA, 2011
Pb	<LDL	<LDL	159.3 mg/kg	Kolawole, 2012
			113.6 mg/kg	Kolowole, 2012
			0.7 mg/kg	Krˇíbek et al., 2014
Zn	0.00	0.40	0.082 mg/100 g	Oluyemi et al., 2005
			7.5 mg/kg	Charles at al. 2005
			210 to 260 mg/100 g	Ayodeji, 2005
			0.34 mg/100g	USDA, 2011
			8 - 19 mg/kg	Burns at al., 2012
			4.80 mg/kg	Krˇíbek et al., 2014

LDL- Limit of detection of instrument, NA-not available, *percentage in dry matter.

young children and women of reproductive age. It is advised that fortification of cassava root products be further investigated to determine whether the nutritional value could be improved for consumers who are almost exclusively dependent on cassava as a staple.

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