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Distribution of fluoride in beans and maize grown along the slope of Mount Meru, Tanzania

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Abstract

This study assessed the uptake and distribution of fluoride in maize and beans grown in fluoride contaminated soils, (Ngarenanyuki) around Mount Meru in Northern Tanzania during the rainy season. The study revealed that fluoride uptake increases with increasing fluoride concentration in soils except in a stem and root part of maize and beans respectively. It was observed that fluoride accumulation followed the order of soil >roots > leaves >stem >grain > cob for maize, while the order soil> root> grain> stem was observed for the beans. when the soil contained 116.93ppm of fluoride, the corresponding plants harvested had the mean fluoride accumulation (ppm dry weight) in root, leaves, stem, grain, and cob of maize of 38.560, 24.251, 10.629, 7.7756 and 2.100 respectively, while the soil with 129.2ppm mean fluoride concentration, the accumulation in root, grain, and stem of beans were 16.27, 11.328 and 8.459 respectively. It was reported that beans plant had a higher efficiency in fluoride uptake to bean grain than maize plant. Maize and bean grain collected from Ngarenanyuki contains higher fluoride levels than other fluoride endemic areas. It was also reported that fluoride in the soil samples has a strongly positive correlation with sodium (p-0.000). This suggests that there is a high possibility of fluoride to be present in the form of NaF. Significant accumulation of fluoride in both bean and maize were observed in this study at $p \leq 0.05$.

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Introduction

Soil pollution by the fluoride ion (F), caused by natural activities, is currently becoming a serious global environmental problem (Pratap and Singh, 2013). Fluoride is not a vital element to plants, although fluoride concentrations in plant part have been reported to be higher and in wide variation (Arnesen, 1997), (Chakrabarti, Patra, and Mondal, 2013). Fluoride contamination is a severe problem in most part of northern Tanzania, more prominently in Ngarenanyuki, Arusha (Ghiglieri *et al.*, 2010), (Gumbo and Mkongo, 1995). Ngarenanyuki is a semi-arid area located at the slope of Mount Meru. Studies conducted by (Ghiglieri *et al.*, 2010), (Ghiglieri *et al.*, 2012), (John Mkungu, Revocatus Lazaro Machunda, 2014) and reported high fluoride concentrations in agricultural soils associated with weathering of rocks and other natural environmental factors.

Reportedly, plants can absorb fluoride from soil, water, pesticide, and fertilizer through plant roots (Anbuvel *et al.*, 2015). Acceptance of fluoride by the plant relies on soil pH, plant species and fluoride activity (Domingos *et al.*, 2003). The reactive behavior of fluoride makes it appear in complex forms with other ions. This further enhances its uptake and translocation to the shoots and other parts of the plant (Stevens, McLaughlin and Alston, 1998). The commencement symptoms which may be observed in plants when exposed to fluoride depends on many factors such as concentration, time of exposure, type and age of plant, temperature, type of light and intensity, composition of the air, and its rate of circulation (Greenwood, 1956). To that effect, high fluoride accumulation in plant led to abnormal fruit development, chlorosis, leaf alteration and synthesis of poison enzyme (Garrec, Plebin, and Faivre-Pierret, 1984).

Intake of fluoride via food can have implication to human health (Chakrabarti, Patra, and Mondal, 2013). For instance, Fluoride is an essential element to human beings and animals. It strengthens the bones or enamel to prevent dental caries when taken in suitable amount (John Mkungu, Revocatus Lazaro Machunda, 2014). Excessive dietary intake of fluoride makes bones brittle or mottling the teeth and causes different types of fluorosis, such as primarily dental fluorosis, skeletal fluorosis and crippling fluorosis depending on the level and period of exposure (John Mkungu, Revocatus Lazaro Machunda, 2014). The World Health Organization (WHO, 1984) has set up the maximum acceptable limits of fluoride in drinking water at 1.5mg/l (Jha, Nayak and Sharma, 2009). Despite this, there are no strict threshold limits of fluoride in soil to plants which is reported to affect human upon consumption (Jha, Nayak and Sharma, 2009). Beans and maize are among the staple food consumed by the population as vegetable and crops respectively. Due to their frequency in use and cultivation by the communities along the Mount Meru area, we thought they are worth to be investigated to understand if they could accumulate fluoride from the soil into their various parts. In this study, beans and maize were used to investigate fluoride accumulation and uptake when grown on contaminated soil under the ambient environmental condition of Ngarenanyuki.

Materials and methods

Description of the study area

The study was conducted in Ngarenanyuki ward located in Arumeru District on the slopes of Mount Meru have approximately 54,000 acres (Kihampa, Ram Mato and Mohamed, 2010). This ward comprises of five villages Uwiro, Ngabobo, Olkung’wado, Kisimiri Chini and Kisimiri Juu located at 3°9'0'' South, 36°51'0'' East. The climatic condition of Mount Meru is oceanic rainfall with continental temperatures. Rainfall data indicate that the Southern slopes of mount Meru receive much higher rainfall of up to 1000 mm than the southeastern slope which receives 950 mm rainfall per year (John Mkungu, Revocatus Lazaro Machunda, 2014).

The mean annual temperature decreases linearly upslope with a lapse rate of 0.56°C per 100m starting at the foothills and the maximum and minimum temperature on the lower slopes (settlement areas) ranges are 15 - 30°C and 12 - l7°C, respectively (John Mkungu, Revocatus Lazaro Machunda, 2014). According to the 2012 census, the area has a total population of 20,379 and the main source of income is from small-scale farming whereby people cultivate food and cash crops (Kihampa, Ram Mato and Mohamed, 2010).

Establishment of the experimental plot

This study was based on the accumulation of fluoride in beans and maize. The trials were carried under ambient environmental condition (From February to May 2018) during the rainy season. Three experimental plots were selected (Momela, Uwiro and Olkung'wadu). Land preparation involved clearing, plowing and finally planting. The experimental design followed a randomized complete block design (RCBD) in a factorial arrangement with 3 replications per crop. The field plots measured 5m x 6m with 8 rows of maize spaced at (0.75m x 0.3m) apart and 8 rows of bean measured 5m x 2m spaced at (0.25m x 0.25m). The plots were interspaced by 1 m to allow management of crops.

Maize seeds variety (Situka) was obtained from SEEDCO Seed Company found in Arusha and local bean seeds variety (Lyamungo 90) were acquired from the local market. Two seeds were planted and later thinned to one plants after full-plant establishment. The soil was treated with urea (nitrogenous fertilizer) at the middle session of the cultivation. In all three experimental plots four plants in each replicate were monitored and then harvested for analysis.

Soil sample and analysis

The soil samples were collected from experimental plots (Momela, Olkung'wadu and Uwiro) from topsoil to subsoil (0-20cm) and (20-40cm) respectively. The soil was thoroughly mixed, dried, and grinded and sieved through 2.0 mm sieve. The basic characteristics of the soil such as pH, Electrical conductivity (EC), Cation Exchange Capacity (CEC), Sodium, Magnesium, Phosphorous, Nitrogen, Potassium, Calcium content and extractable fluoride were determined and are specified in Table 1. EC and pH of the initial soil were determined by using ORION ion Analyser (5-Star series). Textural analysis (Sand, Silt, and Clay) of the soil was carried out by International Pipette method, extractable F by the method adopted by (Larsen, S. Widdowson, 1971).

Total fluoride determination in beans and maize

The collected plants were taken and their parts separated (leaves, root, stem, grains cob), oven-dried for 72 hours at 60°C and grinded into powder, and sieved through a 40-mesh. The extracts were prepared and placed in Milestone Ethos Easy (MEE) with nitric acid at 65% and hydrogen peroxide at 30% followed by neutralization with aqueous KOH that used to digest fluoride in plant samples. Then extracted crop sample from MEE was mixed with TISAB and fluoride was measured by using Fluoride ion-selective electrode and indicated in tables 4 and 5 (Ahmad *et al.*, 2015).

Data analysis

Data were analyzed using SPSS, STATISTICA and XLSTAT software. One way ANOVA was used to compare whether there was a difference in the mean levels of fluoride among plant samples. The univariate taste of significance for plant tissues in Momela, Olkung'wadu, and Uwiro was carried out by using STATISTICA software. Fluoride uptake and partition in plant were carried out by XLSTAT software. All the tests of statistical significance were decided at 95% confidence interval (α = 0.05 level).

Results and discussion

Characteristic of cultivated soils

The results indicated that available fluorides in the soil were significant ($P \leq 0.05$ and $P \leq 0.0001$) for maize and beans soils respectively, this indicated that there is a variation of fluoride levels in the soils in the study sites (Table 1). The pH values ranged from 8.3 to 9.4 with Momela being less alkaline (8.3), Uwiro being moderate alkaline (8.9) and Olkung'wadu being strong alkaline (9.4). With exceptional to beans soil in Olkung'wadu the soil pH increased with increased fluoride concentration. The pH results of the study sites were in line with the finding of (John Mkungu, Revocatus Lazaro Machunda, 2014) who reported that a pH is somehow alkaline in the same site (Ngarenanyuki area). Generally the soil in the study sites is alkaline in reaction with sodic in nature (Table 1).

The levels of water-soluble fluoride in the soil were higher in the more clay soil 8.3% than less clay soil (more sand soil) (Table 1 and 2). This result is in agreement with general trend reported by (Wang *et al.*, 2002) that soil with a high content of clay particle has intensive fluoride adsorption ability (Wang *et al.*, 2002). This physical adsorption at the surface of clay particle can enable fluoride ions to accumulate in soil (Wang *et al.*, 2002).

Electrical conductivity value was found to be higher 108.6μs/cm, 304μs/cm and 420μs/cm in Momela, Olkung'wadu and Uwiro respectively, indicating that the soils were saline in all study sites. Cation exchange capacity was higher in more clay soil than less clay soil (Table 1). This is in agreement with researches which postulated that there is a correlation between CEC and clay content, CEC is always related to percent of clay in the soil. As the per-cent of clay increase in the soil, the CEC also increases (Grisso, 2009).

Available phosphorous was constant except for Uwiro study site. The average content of calcium in soil was 13.8ppm, 27.5ppm, and 58.5ppm in Momela, Olkung'wadu and Uwiro respectively (Table 1). The magnesium content in the soil was low in all study sites; the potassium results were 50ppm, 151.33ppm and 208.8ppm in Momela, Olkung'wadu and Uwiro respectively which did not indicate consistent trend across the study sites.

The simple correlation coefficient was worked out between the water-soluble fluoride and other properties of the soils. The positive correlation coefficient between available fluoride and the essential nutrient (Na, Ca,mg and P) were also found which indicated their mutual geochemical origin. The correlations betweenmg, Ca, P and F in the soils were more consistent with p-value 0.750, 0.507 and 0.520 respectively whereas Na and F concentration was highly positively correlated at p=0.000, the correlation coefficient (r) was 0.269, 0.277, 0.135 and 0.961 for P, Ca,mg and Na respectively, suggesting that there is high possibility of fluoride to be present in form of NaF in the soil.

Table 1. Characteristics of cultivated soil in study sites.

Site	CEC (meq/100g)	N (g/kg)	P (mg/kg)	EC (μS/cm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	ESP %	pH	Soil texture
Momela	11.7	1.7	9.2	108.6	13.8	2	92.5	50	15	8.3	Sandy>50μm=85.3% Silt 2-50μm = 14.7% Clay<2μm = 0.1%
Olkung'wadu	11.4	1.3	9.2	304	27.5	2.5	250	151.3	72	9.4	Sandy>50μm=77.6% Silt 2-50μm = 16.7% Clay <2μm =5.7%
Uwiro	15.5	2.5	128.3	420	58.8	5	340	208.8	29	8.9	Sandy>50μm=75.7% Silt2-50μm =15.9% Clay<2μm =8.3%

Fluoride uptake and partition in food crop

Significant accumulation of fluoride in both bean and maize were observed in this study. Table 3 evident that maize crop showed relatively higher accumulation than bean crop. In both plants (maize and bean), roots have a greater tendency for the accumulation of fluoride compared to the other parts. This may be due to the low mobility of fluoride within the plant. The accumulation of fluoride in maize and bean are given in table 4 and 5 respectively. In all cases except stem part in maize, fluoride uptake increase with increasing fluoride concentration in soils. Unlike in bean with exception to root parts the fluoride uptake increased with increasing fluoride concentration in the soils.

In maize the fluoride accumulation decreased in order soil> root>leaves> stem>grains>cob. Similarly in bean fluoride accumulation decreased in order soil>roots>grains>stem. These results do not contradict previous studies on fluoride concentration in plant parts. Based on those previous studies it shows that expect for tea plant where more fluoride is accumulated in the leaves (Fung *et al.*, 1999), fluoride accumulation in the roots is higher than other parts of the plant (Arnesen, 1997), (Gupta and Banerjeea, 2009), (Chakrabarti, Patra and Mondal, 2013). The results of this study site were also in line with the findings reported by (Ahmad *et al.*, 2015). Ahmad reported that mustard fluoride accumulation capacity depends on the concentration of fluoride in irrigation water which he suggested 3 to 24ppm. Ahmad further found that roots have high accumulation of fluoride about 18.754µg/g when it is irrigated with 24ppm than shoot and leaves (Ahmad *et al.*, 2015) which is consistent with the present findings.

Usually, water-soluble fluoride in the soil is taken up passively by roots and actually is easily conveyed in plants. Majority of the fluoride in the roots and their transport across the roots stay in the cell walls and intercellular spaces (apoplasts) than in the cell membranes and the endodermis (symplast) (Chakrabarti, Patra, and Mondal, 2013). The resistant Casparian strips in the wall of the endodermis act as barrier for fluoride to arrive in the conducting systems, which limit transport to the shoot and leaves. Though the Casparian strip is disjointed at the root tips and at sites of developing lateral roots, these allow molecules to be cross into the xylem and can be conducted within the system (Chakrabarti, Patra, and Mondal, 2013).

In all cases for bean and maize, there is no significant difference of the fluoride uptake among the study sites regardless of their variation of fluoride in the soils. This reflects that plants grown in this area will have the same accumulation irrespective of their location (Table 5 and 6). Comparison studies of the fluoride level in maize and bean grain of this study and those reported in the literature in endemic area showed that maize and bean grain of Ngarenanyuki contain higher fluoride levels than the other endemic areas. The previously reported value of maize grain was 5.1ppm, 5.9ppm and 4.53ppm for Burundi, India, and Ethiopia, respectively, whereas the value of bean grain was 1.1ppm and 0.015ppm for Burundi and India, respectively (Mustofa, Chandravanshi, and Zewge, 2014). Generally, the Ngarenanyuki grains contain high fluoride level compared to previous reported studies (Fig. 3 and 4). This will have an implication to human being when it is used as a source of food and finally becomes another source of exposure of fluoride to humans.

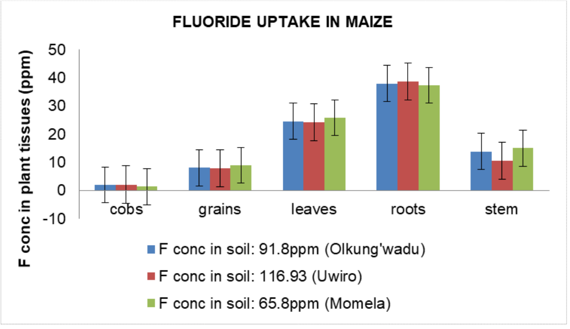

Fig. 1. Fluoride uptake and partition in maize.

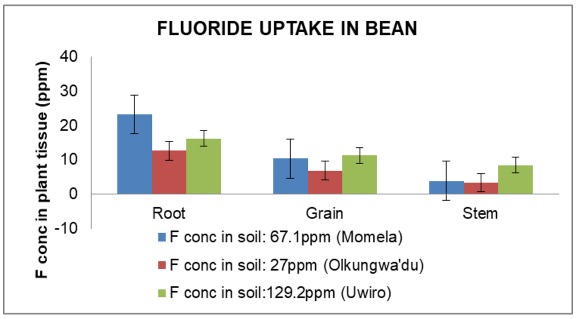

Fig. 2. Fluoride uptake and partition in bean.

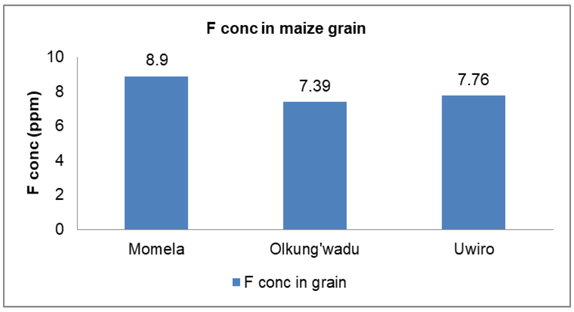

Fig. 3. Fluoride concentration in maize grain.

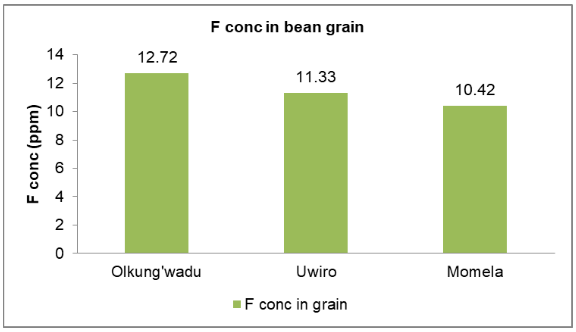

Fig. 4. Fluoride concentration in bean grain.

Effect of fluoride on plant yield

The levels of water-soluble fluoride in the soil were higher in the more clay soil (8.3%) than less clay soil (Table1 and 2). The dry matter yield of both bean and maize were higher in more clay soil than in the less clay soil (more sand soil). These results also agree with what was reported by (Arnesen, 1997), who reported that the sites which have more clay content in the soil have more yield than the sites with less clay content in the soil (Fig. 5 and 6). The Uwiro soil was enriched with considerable amount of nutrients which are considered essential for maintaining soil fertility and enhancing plant growth and yield as shown in Table 2. Momela and Olkung'wadu soils were phosphorous deficient containing only 9.2mg/kg (Table 2). According to (Mourice and Tryphone, 2012), soils are considered deficient in phosphorous contents if they have less than 40mg/kg. Being richer in phosphorus as compared to other sites could be one of the reasons as to why Uwiro soils produced more yield than other soils although it contains high fluoride levels. Therefore this result demonstrates that fluoride rates in the soil do not mimic the action of other essential nutrients for maize and beans growth and productivity.

Table 2. Water-soluble fluorides of the study sites.

Crop	Site	Water-soluble Fluoride in maize and bean soils
		Water-soluble F (ppm)
Maize	Momela	65.8±1.08584*
	Olkung'wadu	92.8±24.43991*
	Uwiro	116.9333±5.3419*
Bean	Momela	67.1±1.392726**
	Olkung'wadu	27±1.028591**
	Uwiro	129.2±4.398106**

Value presented are means ± SE, *, ** = significant at P≤ 0.05 and P ≤ 0.0001 respectively, SE= standard error.

Table 3. Fluoride uptakes in bean and maize.

Crop	N	Fluoride in Plant
Bean	23	11.06192±1.53961*
Maize	45	17.27719±1.975474*

The value presented is meant ±SE, *=significant at P≤ 0.05, SE=standard error.

Table 4. Fluoride uptake and partition in Maize plant.

F in soil (ppm)	F in root (ppm)	F in grain (ppm)	F in stem (ppm)	F in leave (ppm)	F in cob (ppm)
65.8±1.08584	37.260 a	8.901 d	14.967 c	25.775 b	1.312 g
92.8±24.43991	38.132a	7.389def	15.959c	23.759b	2.408efg
116.9333±5.3419	38.560 a	7.756 de	10.629 cd	24.251 b	2.100 fg

The value presented is meant ±SE, means followed by dissimilar letter in a row are significantly different from each other at P=0.0000

Table 5. Fluoride uptake and partition in bean plant.

Site	F in soil (ppm)	F in root (ppm)	F in grain (ppm)	F in stem (ppm)
Momela	67.1±1.392726	23.259 a	10.416 bc	3.982 c
Olkung'wadu	27±1.028591	13.417 c	12.716 bc	6.926 bc
Uwiro	129.2±4.398106	16.270 ab	11.328 bc	8.459 bc

The value presented are meant ±SE, means followed by a dissimilar letter in a row are significantly different from each other at P=0.029.

Table 6. Fluoride uptake and partition in bean in study sites.

Parts	Fluoride in plant tissues
Grains	11.33268± 0.49064 ns
Roots	15.67795± 3.78751 ns
Stem	6.39699± 0.85166 ns

Value presented are means ± SE, N=24, ns= not significant, SE= standard error.

Table 7. Fluoride uptake and partition in maize in study sites.

Parts	F in plant tissues
Cobs	1.93993±0.22546 ns
Grains	8.015±0.57599 ns
Leaves	24.59511±0.91824 ns
Roots	37.98425±1.46529 ns
Stem	13.85166±1.43521 ns

Value presented are means ± SE, N=45, ns= not significant, SE= standard error.

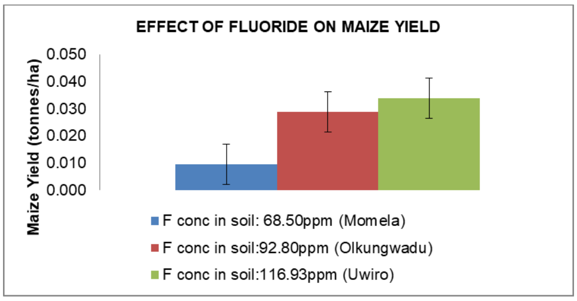

Fig. 5. Effect of fluoride on maize yield.

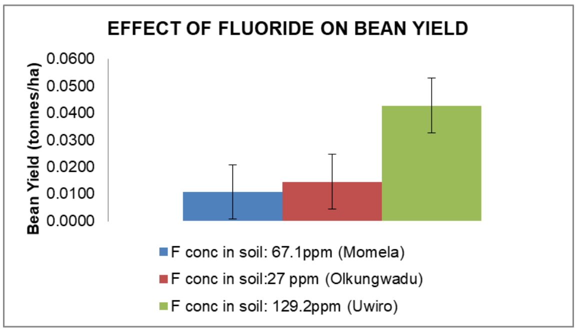

Fig. 6. Effect of fluoride on bean yield.

Conclusion

Fluoride in plants around the slope of Mount Meru is attributed by the soil from weathering of volcanic rock. This study has shown that the distribution of fluoride concentration in Mount Meru does differ among plants. It can be concluded that beans plant has high efficiency in a conveyance of fluoride to bean grain than maize plants. The fluoride accumulation in the maize plant follows the order root> leaves> stem> grain> cob and in bean root>grain>stem. Among the bean and maize, maize plant exhibited greater uptake of fluoride than bean plant. In general soil analysis indicated that sodium has been shown positive correlation with fluoride which indicates that there is high possibility of fluoride to be present in form of NaF. Therefore this study address fluoride uptake during the rainy season, it would be a remarkable experience if further research effort is recommended for fluoride uptake during the dry season and under various environmental conditions.

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