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LEVELS OF MAJOR, MINOR AND TOXIC METALS IN TUBERS AND FLOUR OF *DIOSCOREA ABYSSINICA* GROWN IN ETHIOPIA

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ABSTRACT

Dioscorea abyssinica, commonly known as yam, is an indigenous plant in Ethiopia. Its root tuber is used as staple and co-staple food in South Nation Nationality People and Regional State of Ethiopia. This study was carried out to analyze the selected mineral nutrients in the tuber and flour of *D. abyssinica* grown in different parts of the country for human consumption. Samples collected from five different areas were analyzed for eleven metals (Ca, Mg, Fe, Zn, Cu, Mn, Co, Cr Ni, Cd and Pb) by flame atomic absorption spectrometry and two metals (K and Na) by flame emission spectrometry. Known weight of oven-dried sample was wet-digested using 3 mL of (69–72%) HNO_3 and 1 mL of (70%) $HClO_4$, for 2 h at variable temperature (120–270 ^oC). The validity of the optimized procedure was evaluated by the analysis of spiked samples whose recovery was in the range of 92–105%. The mean concentration range (in μg/g) of each metal in *D. abyssinica* samples were K (8,469–13,914), Na (133–405), Ca (172–448), Mg (180–354), Fe (28.3–144.5), Mn (12.0–14.5), Zn (12.3–44.5), Cu (7.26–17.6), Co (1.91–8.68), Cr (0.86–3.41) and Ni (2.43–5.31). *D. abyssinica* could be good sources of essential trace metals to the individuals, more particularly Fe and Zn were higher than the entire trace metals in the samples investigated while Cd and Pb were in minor quantities and hence the plant is free from toxic heavy metals. Consuming 100 g of this tuber per day contribute the following concentration range of Fe, Zn, Cu, Mn, Co, Ni and Cr in mg/100 g per day: 2.8–14.4, 1.2–4.5, 0.73–1.8, ND–1.5, ND–0.87, 0.24–0.53 and 0.09–0.34 mg/100 g, respectively. Statistical analysis revealed that significant variations in metal concentrations among the sampling sites were observed for some of the metals when pair wise test was made while insignificant variation were seen for the remaining metals. *D. abyssinica* could be a better source of K, Ca, Fe and Zn to human compared to the common cereal flours (barley, wheat and red teff flour) as well as tuber food products like potato, cassava, yam, and enset (*Ensete ventricosum*), while it could be an alternative source of the other essential mineral nutrients to the individual daily mineral intake.

Key words: Root tuber, *Dioscorea abyssinica*, metals, Ethiopia

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INTRODUCTION

The nutritional health and well-being of humans are majorly dependent on foods of plant origin. Plants are critical components of the dietary food chain in that they provide almost all essential mineral and organic nutrients to humans [1]. Tropical root and tuber crops including cassava, sweet potato, yam and aroids are raw materials for small-scale industries, and consumed as staple foods especially in the less developed countries [2]. They were critical components in the diet during the early evolution of humankind and were the most important food crops of very ancient origin in the tropics and subtropic [3]. Apart from providing basic food security and a source of income and diversity in diet, root and tuber crops also serve as proteins for the less affluent and as additional source of essential vitamins and minerals.

Root and tuber crops are found in a wide variety of production systems and do well under various levels of management from low to high input systems. This is a distinctive feature, which makes them important for improving the productivity and richness of agro-systems. Even though their agronomic properties have been well documented, their food and industrial quality characteristics have not been studied extensively. The full potential of these staples is being realized in developing countries and they would continue to contribute to energy and nutrient requirements for the increasing population.

Root and tuber crops are widely cultivated in southern Ethiopia, and support a considerable portion of the country's population as source of food. Prominent among these are: potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas* L.), enset (*Ensete ventricosum* (Welw), Cheesman), godere (*Colacasia esculanta* L.), yams (*Dioscorea spp.*), Ethiopian dinch (*Coleus parviflorus*), koteharrie (*Diaspora bulbiferous*), and anchote (*Coccinia abyssinica*). Among these, enset, anchote, and some yams are endemic to Ethiopia [4].

Dioscorea abyssinica, belongs to the family Dioscoreaceae and the genus *Dioscorea*, is a climber plant twining to the right, with an herbaceous stem and a large tuber [5, 6]. It is cultivated during the raining season in the south, west and the south-west highlands of Ethiopia. Tubers of *D. abyssinica* have long been used for food, as they are rich in starch. Locally, *D. abyssinica* is commonly known by its vernacular name "Boyna" which is equivalent to the common English name "yam". The plant is still serving as a source of food within a restricted region of the country (Southern Nations Nationality Peoples Regional State) and few neighboring cities and rural areas to this region. This might be due to lack of awareness about its potential as a source of nutrition and bad cultural practices. It is also known that Ethiopia is one of sub-Saharan countries with various indigenous resources but poorest country in the Horn of Africa.

The literature survey showed that the main feature of *D. abyssinica* is its high energy values and the major constituent of it is starch accounting about 80% on dry weight

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basis. The proximate composition of *D. abyssinica* starch is about 0.1% ash, 0.5% protein, 1% fat and 98.4% starch [6, 7]. Though this species has promising importance and easily grown in areas where it is stapled and co-stapled food item, it has been an underutilized plant by Ethiopians and there is paucity of information about its mineral composition.

Furthermore, most plant nutrients are dependent on the type of the plant species, soil type, geographical location, and over all climatic conditions. Particularly mineral nutrients are more susceptible to these variables. Therefore, analyzing the mineral composition of *D. abyssinica* is important to evaluate the effect of variation of the above parameters in the selected mineral nutrients. Thus, the purpose of this study was to determine the major, minor and toxic metals in the tuber and flour of *D. abyssinica* grown in different parts of the country and to compare the result with similar food types. In addition, the findings of this study provide adequate information on the distribution of major, minor and toxic metals and ensures the dietary safety of the individuals in the region, in terms of essential and/or non-essential elements.

MATERIALS AND METHODS

Kjeldahl digestion block apparatus (Kjeldatherm, Germany) was used for digestion of the samples. Varian Spectra AA-20 Plus GTA-96 (Victoria, Australia) atomic absorption spectrometer equipped with a deuterium lamp background correction system using an air-acetylene flame was used for the analysis of metals (Ca, Mg, Fe, Zn, Cu, Mn, Cr, Co, Ni, Cd, and Pb) and flame photometer (EEL, Evans Electroselenium Ltd, Halstead. Essex, England) was used for the analysis of Na and K.

Sample site description, sample collection and preparation

In this study, both the tuber as well as the processed flour from the tuber, which is ready to be cooked, were collected from different zones of the region. The tubers were collected from the farm area while the processed flour was collected from open market. For the collection of *D. abyssinica* tubers, four zones (Gedio, Sidama, Welayta and Kembata) all in South Nation Nationality People and Regional State of Ethiopia and for the collection of dried flour samples of the tubers, eight shopping markets from Shashemene (administrative town of western Arsi zone in Oromiya region) were chosen. The reason for selection of these places was based on the availability of the plant and its popularity in consumption. The plant is widely grown in the South Nation Nationality People and Regional State of Ethiopia as wild and cultivated plant and thus fully recognized by the people around as a source of nutrition.

For each sampling site, about ten matured plants were randomly selected. Three tubers were taken from each plant and brought to the laboratory of Chemistry Department of Addis Ababa University, Ethiopia for further treatment but the final analysis was done at the Ethiopian Health and Nutrition Research Institute. In the laboratory, it was washed with distilled deionized water to remove adsorbed dust particulates and air-dried. The thin skin part of the tuber was removed with Teflon knife to separate the edible portion of the tuber from its cover. The separated portions of the tuber were air-dried and then it was oven dried at 70 °C for 48 hours. The dried samples were ground to finest in an agate mortar. To collect one bulk processed flour sample, eight market places (kiosks) were randomly selected. 500 g of dried flour of *D. abyssinica* tubers from each market area was collected. After mixing and homogenizing, 200 g was taken from the bulk and oven dried at 60 °C for 24 hours.

Five bulk samples (four tuber samples from four sampling zones and one tuber flour from the markets) were prepared for the analysis. Three 0.5 g aliquots from each of the sampling sites were taken for the digestion and analysis. It should be noted that different bulk samples of the tuber and the flour from each of the five sampling areas were prepared and analyzed because of the fact that the geographical variation within the zones was assumed to be insignificant. Therefore, a total of five different composite samples were prepared for the analysis.

Chemical analysis of samples

A known weight (0.5 g) of a dried powdered sample was digested using 3:1 mixture of concentrated HNO_3 (69–70.5%) and concentrated $HClO_4$ (70%) under reflux at a temperature of 240 ^oC for 2:30 hours. The digests were filtered through Whatman No. 41 filter paper and the filtrate was used for the analysis of Ca, Mg, Fe, Mn, Cu, Zn, Co, Cr, Ni, Cd and Pb by atomic absorption flame emission spectrophotometer (AAS) and Na and K by flame photometer. Each *D. abyssinica* sample was digested in triplicate and three repeated measurements were performed by the AAS. Nine blank solutions were prepared following the same digestion procedure as the samples.

Instrument calibration and method detection limit

The instrument was calibrated with series of four working standards prepared from the stock solution of each metal. Method detection limit was determined from standard deviation of nine blank samples prepared under the same conditions as of the samples. The correlation coefficients of the calibration curve for each of the metals and method detection limits of each metal are given in Table 1. The detection limit of the method for each metal was calculated by multiplying the standard deviation of nine blank signals each determined in triplicate by three.

Precision and accuracy

The precision of the results of the present analysis is reported with corresponding pooled standard deviation of nine measurements for a bulk sample of triplicate reading per sample and relative standard deviation. Table 2 and 3 shows % RSD of each metal in each sample.

Recover test

In the absence of certified reference material for the *D. abyssinica* samples, the validity of the optimized procedure was checked by adding known concentration of

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each metal in 0.5 g sample from the stock solution as follow: 26.6 µg of Na, 67 µg of Ca, 53 µg Mg, 6.5 µg of Mn and 6 µg of Zn were spiked at once in to 0.5 g of *D. abyssinica* sample and the remaining metals: 696 µg of K, 7 µg of Cu, 3.5 µg of Co, 1 µg of Cr and 4 µg of Ni were spiked at once in to another round bottomed flask containing 0.5 g of *D. abyssinica*. Each sample was analyzed for their respective spiked metals by atomic absorption spectrophotometer and flame photometer. The recovery test for each sample was performed in triplicates.

Statistical analysis

In the present study, the significance of variation between the samples was studied using one-way ANOVA and calculations were made using SPSS software.

RESULTS

Analytical method detection limit

Table 1 shows the method detection limits and correlation coefficients of the calibration curves of the studied metals. As can be seen from the table, the method detection limits are generally low (≤ 6 µg/g), low enough to determine the metals in the samples at trace levels. The calibration curves were with good correlation coefficients.

Evaluation of analytical method

Results of the recovery experiments are given in Table 2. As shown in the table, the percentage recoveries for the studied metal nutrients are all between 92% and 103% which are within the acceptable range (100 ± 10%) verifying the validity of the proposed method for *D. abyssinica* analysis.

Composition of major, trace and toxic metals

Table 3 shows the results of the mean concentration ($n = 9$) of major, trace and toxic metals with the corresponding relative standard deviation (RSD) of the *D. abyssinica* samples. Even though it is not possible to tell how much of the RSD in the results (Tables 3) is from sample inhomogeneity and how much result from analytical error the overall error (resulting from sample inhomogeneity and from analytical error) is within the acceptable range (RSD ≤ 10%).

As can be seen from Table 3, there is a variation in mean concentration of macro- and microelements determined by atomic absorption spectrophotometer and flame photometer in *D. abyssinica* samples within the fresh tuber and processed *D. abyssinica* tuber (its flour) and there is slight variation in some metals along with geographical location.

The results of total contents of the studied nutrient and toxic metals in the five samples showed the ability of *D. abyssinica* tuber to accumulate high amounts of both macro- and micronutrient elements. The most abundant metal among the macroelements analysed was K followed by Ca, Na and Mg. Whereas Fe content of

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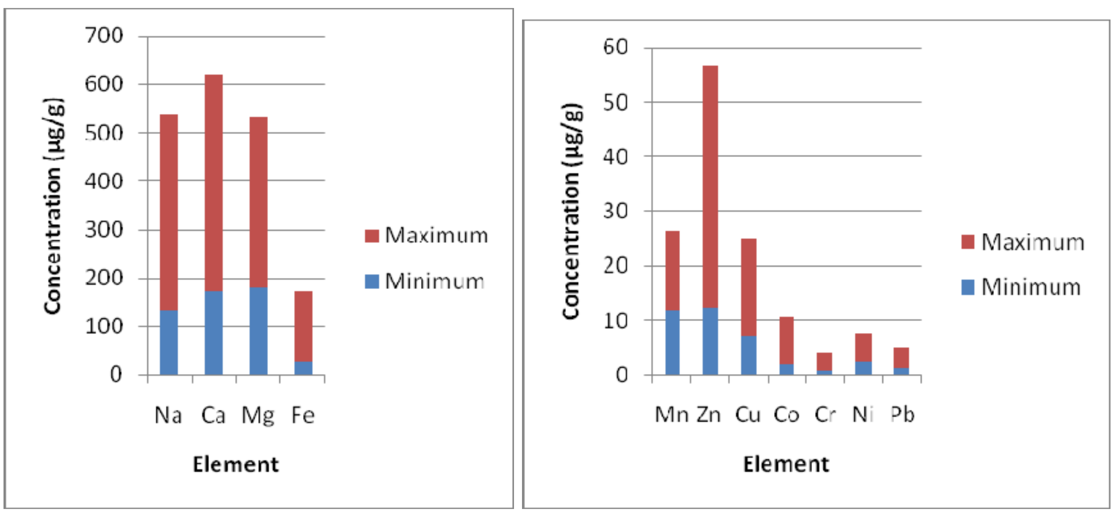
the *D. abyssinica* tubers was the predominant among the tested micronutrient heavy metals followed by Zn, Mn, Cu, Co, Ni and Cr. On the other hand, the content of the toxic non-essential heavy metal Pb was found at lower concentration while Cd was not detected in all the investigated samples. It can be deduced from the levels of all the metals in the studied *D. abyssinica* samples from all the sampling sites, that the concentrations of the macro- and the micronutrient metals followed non-uniform patter for all the samples. In general, ranges of concentrations of the studied macronutrient, micronutrient and toxic metals could be arranged according to their levels in the *D. abyssinica* samples of all the sampling sites in the following order in dry weight basis in µg/g : K (8,469–13,914) > Ca (172–448) > Na (133–405) > Mg (180–354) > Fe (28.3–144.5) > Zn (12.3–44.5) > Cu (7.26–17.6) > Mn (ND–14.5 > Co (ND–8.68) > Ni (2.43–5.31) > Cr (0.86–3.41) > Pb (ND–3.81). Figure 1 shows the comparative results of the concentration range (minimum and maximum) of the studied metals in the five samples. The concentration range of K is not included in the figure since its concentration range is far higher than the other metals so that its presence in the figure hides the value of the other metals.



(A) (B)

Figure 1: Concentration range of the studied metals (minimum and maximum concentration) in the five *D. abyssinica* samples

DISCUSSION

Major, trace and toxic metals in *D. abyssinica*

The mineral composition of *D. abyssinica* revealed an appreciable amount of Mg, K, Na, Ca, Zn, Cu, Fe, Co and Mn.

The higher levels of K, Ca and Mg in the tuber according to Marschner [8] was due to the fact that nutrient elements such as N, P, K, S, and Mg are highly mobile in the plant tissue and trans-located from old plant tissue to new plant tissue. Furthermore,

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broad range of Ca-bearing minerals in soil and water and usually abundant in ground water and surface water which can easily be absorbed by the plant.

From observed result, *D. abyssinica* is known to contain higher Na concentration next to K and Ca. As Grusak and Penna [1] reported, Na and Cr are required by humans, but not by plants. Fortunately for humans, however, plants can acquire these elements through non-specific influx processes using existing transporters localized to their roots. In fact, a wide range of plant's non-essential elements (both benign and detrimental) has been measured in plant tissues, with concentrations sometimes reaching dramatic levels if soil availability is high.

Consuming 100 g of the tuber per day may contribute (847–1391 mg/100 g K), (17.2–44.8 mg/100 g Ca), (13.3–40.5/100 g Na) and (18.0–35.4 mg/100 g Mg) (Table 4). The high concentration of K in the tuber makes it to be recommended for peoples with high blood pressure [9] but may not be suitable for people with renal failure. High Pb content in the diet leads to renal failure in most cases. The proper balance of K in the body depends on Na. Therefore, an excessive use of Na may deplete the body's stores of K. Daily intake of K up to 4700 mg is considered to be adequate for adults and safe, however, excess concentration of it can be harmful [10]. The high concentration of Ca is very significant because Ca is known to enhance the qualities of bones and teeth and also of neuromuscular systemic and cardiac functions. Thus including this tuber in the diet may contribute significant amount of Ca and Mg for the daily need. The required daily allowance (RDA) of Mg is set at 300 mg for women and 350 mg for men as per National Research Council [11].

It should be noted that the ratio of Na to K in the body is of great concern for prevention of high blood pressure [11]. Na/K ratio less than one is recommended. The ratio of Na/K are less than one in all the studied *D. abyssinica* samples*;* therefore, it would not promote high blood pressure.

Looking at Table 3, it is also clear that the concentration of Fe and Zn were higher than the entire trace metals in the samples followed by Cu, Mn, Co, Ni and Cr. Since the soil types of many plants growing areas of Ethiopia are moderately acidic to slightly basic with the pH ranges from 5.6 to 7.3, the plant is expected to have a better accumulation of micronutrients like iron and zinc Furthermore, these elements are main elements that plant could accumulate and be passed up the food chain. Therefore, the detection of Cu and the high concentration of Zn from trace metals next to iron in *D. abyssinica* may be because of the fact that these ions are readily transferred from the soil to plants, and accumulate in the tuber of the *D. abyssinic* [12, 13]. Thus, *D. abyssinica* could be good alternative source for Zn since Zn deficiency is apparent in developing countries like Ethiopia.

Consuming about 100 g of this tuber per day contribute the following concentration rang of Fe, Zn, Cu, Mn, Co, Ni and Cr in mg/100 g per day: 2.8–14.4, 1.2–4.5, 0.73–1.8, ND–1.5, ND–0.87, 0.24–0.53 and 0.09–0.34 mg/100 g, respectively (Table 4).

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The available instrument did not detect the toxic heavy metal Cd while Pb was detected at lower concentration. Comparing with currently available data on edible products from industrialized areas, the obtained concentrations of Pb in the samples are too low and it is possible to say that *D. abyssinica* is safer from heavy metal contamination. Thus continuous monitoring and evaluation of these toxic metals is important to evaluate the dietary safety of the individuals.

Comparing the distribution of metals in *D. abyssinica* within their respective site, it is impossible to have common trend in metals distribution across the sampling sites, the concentration of some of the metals were highest in some of the sampling sites while lower concentrations were noticed for the remaining metals. This diversified variation might be attributed due to various factors like difference in climatic conditions, variation in soil nature and fertility and variation in metals availability in the soil.

Analysis of variance (ANOVA) results revealed that no significant difference was observed ($p \leq 0.05$) at 95% confidence interval in mean concentration of Na between Welayta and Sidama sample sites. However, a significant difference ($p \leq 0.05$) in mean concentration of Na at 95% confidence level was observed between the other entire pair wise test. Similarly, except the mean concentration of Mn (between Gedio and Powder), Zn (between Sidama and Kembata) and Cu (between Kembata and Powder), there were a significant differences ($p \leq 0.05$) in mean concentrations of these metals at 95% confidence interval between all the other sample sites when pair wise comparison was made. On the other hand, the mean concentration of K, Ca, Mg, Fe, Co, Cr, Ni, and Pb were significantly different ($p \leq 0.05$) at 95% confidence interval between all the sampling sites when pair wise comparison was made.

The processed sample (flour) was also compared with the unprocessed tubers. Except Cu, Cr, Ni and Fe, lower concentration of the remaining metals in the flour was noticed. Unexpectedly high concentration of Fe in the flour could be due to possible contamination during preparation stage and there might be contamination from the environment during drying of the tuber.

Generally, based on the current status, taking Ethiopian *D. abyssinica* as staple food appreciable amounts of macro and trace metals for the daily requirements of the individuals and is free from toxic heavy metals like Pb. Particularly, *D. abyssinica* could be good source of Fe and Zn for individuals who are taking this plant regularly as a staple and co-staple food.

Comparison of levels of minerals in *D. abyssinica* with other tuber plants and cereal flours

Results of the present study are compared with other varieties of dioscorea species grown in other parts of the world and other tuber staple foods (like enset (*Ensete ventricosum*) food products kocho and bulla) to the region in order to evaluate the potential of *D. abyssinica* to supplement mineral nutrients over the others to the users. Furthermore, in some areas, people prepare their meal with mixture of either of the following: *D. abyssinica* tuber flour with other cereal flour (maize, teff, and barley or wheat flour). Depending upon the individual interest, up to 20% of cereal flour can be mixed with the starchy *D. abyssinica* tuber flour. Therefore, comparison of the mineral contents of *D. abyssinica* food with other dioscorea species, other tuber plant and cereal flours is crucial so as to know the dietary habits of those individuals who rely on *D. abyssinica* as a staple and co-staple food. Many authors reported the concentration of selected metals in tuber plants and cereal grain and cereal flours, which are grown in different parts of the world including Ethiopia [14–21]. Table 5 summarizes the comparative results of selected metal concentrations for which the data are available in the literature.

As can be seen from the table, diversified concentration ranges of the studied metals were notice compared with other tubers like potato, cassava, yam, and enset food products (Table 5). For some of the metals comparable concentrations were noticed between *D. abyssinica* and other tubers while lower or higher concentrations with significant differences have been noticed for the remaining. This variation is not only due to species variability but also variations in agricultural practices and other parameters listed so far. The results obtained in this study indicated that Na, K, Ca, Mg, Fe, Zn and Mn are more in *D. abyssinica* than tubers like *D. alata*, *S. andigena*, *S. tuberosum* and *cassava* samples grown in other part of the world [14-16]. However, most of the studied metals are comparable if not higher in the *E. ventricosum* food products (kocho and bulla) samples analyzed from Ethiopia [17].

However, compared with cereal flours, like barley white flour, red teff, whole grain, maize, white four, whole wheat and white wheat flour, the studied tuber cultivars accumulated significantly higher concentration of Ca, Fe, Zn, Mn and Cu except Mn and Zn which were found to be lower in *D. abyssinica* samples compared with whole wheat and white wheat flour. Generally speaking, *D. abyssinica* accumulated significant amount of essential minerals and can be an alternative source of mineral supplement to the people who are using it as major dietary source or staple and co-staple food. Particularly it is rich in K, Ca and Zn compared with limited literatures survey (Table 5).

CONCLUSION

In general, metal concentrations in *D. abyssinica* are influenced by the production area and significant variations in metal concentrations among the sampling sites were observed for some of the metals. It has been found that *D. abyssinica* contain minerals that are higher if not comparable to other tubers and cereals food items. A daily consumption pattern of *D. abyssinica* contributes to the recommended dietary intakes of essential metals and trace elements, mostly K, Ca, Mg, Fe, Zn and Mn. Findings of this study have potential to promote the production and diversification of *D. abyssinica* consumption in Ethiopia and other African countries. Thus, the tuber should, therefore, be accorded its rightful position as a source of food in future and other feasibility studies should be conducted in other regions of the country to exploit its potential for nutrition and sustainable development.

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Table 1: Method detection limits (μg/g) and correlation coefficient (r) for *D. abyssinica* samples

Metal	r	MDL[1] (μg/g)	Metal	r	MDL[1] (μg/g)
Na	0.9999	1.3	Cu	0.9998	0.40
K	0.9997	5.2	Co	0.9996	0.41
Ca	0.9998	4.4	Cr	0.9998	0.70
Mg	0.9997	1.1	Ni	0.9999	0.35
Fe	0.9999	1.9	Cd	0.9999	0.46
Mn	0.9999	0.46	Pb	0.9999	0.60
Zn	0.9999	0.50			

[1] Method detection limit

Table 2: Recovery test values for *D. abyssinica* sample

Metal	Conc. in sample[1] (μg/g)	Amount added (μg/g)	Conc. in spiked sample[2] (μg/g)	Recovery (%)[3]
Na	133	53.2	189 ± 6.4	105 ± 3.5
K	13,914	1,391	15,208 ± 19.1	93 ± 2
Ca	448	134	574 ± 7.5	94 ± 1.4
Mg	354	106	458 ± 5.5	98 ± 2.5
Fe	28.3	23	50.6 ± 3.2	97 ± 7
Mn	14.5	13	26.5 ± 1.8	92 ± 8
Zn	13.2	12	24.6 ± 2.6	95 ± 4.3
Cu	17.4	14	30.8 ± 4.3	96 ± 0.25
Co	8.68	7	15.5 ± 3.1	98 ± 5.1
Cr	2.31	2	4.37 ± 1.2	103 ± 6.2
Ni	4.11	4	7.79 ± 2.3	92 ± 2.6

[1] Mean concentration of samples analyzed in triplicate

[2] Mean concentration ± SD of samples spiked in triplicate

[3] Mean recovery ± SD of percentage recoveries of triplicate analyses

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Table 3: Mean concentration (X ± SD, n = 9, µg/g dry weight) of metals in *D. abyssinica* samples

Metal	Welayta	Gedio	Sidama	Kembata	Powder	Range (µg/g)
			Concentration of metal (µg/g)			
Na	167 ± 7	405 ± 11	167 ± 6	133 ± 3	150 ± 2	133–405
K	11,189 ± 168	9,954 ± 219	9,872 ± 178	13,914 ± 227	8,469 ± 288	8,469–13,914
Ca	229 ± 5	172 ± 1	151 ± 7	448 ± 2	233 ± 2	172–448
Mg	180 ± 2.3	248 ± 2.0	221 ± 5.1	354 ± 6.4	195 ± 5	180–354
Fe	68.9 ± 0.7	62.6 ± 1.5	44.1 ± 1.5	28.3 ± 1.9	144.7 ± 2.0	28.3–144.5
Mn	ND[1]	12.0 ± 0.3	ND	14.5 ±0.9	12.3 ± 0.6	12.0–14.5
Zn	44.5 ± 2.8	12.3 ± 0.6	13.4 ± 0.5	13.2 ± 1.5	34.2 ± 0.8	12.3–44.5
Cu	15.2 ± 0.6	11.4 ± 0.1	7.26 ± 0.2	17.4 ± 1.0	17.6 ± 0.4	7.26–17.6
Co	1.91 ± 0.08	ND	4.67 ± 0.2	8.68 ± 0.2	3.46 ± 0.8	1.91–8.68
Cr	0.860 ± 0.02	1.53 ± 0.03	2.14 ± 0.03	2.31 ± 0.09	3.41 ± 0.2	0.860–3.41
Ni	2.43 ± 0.08	2.53 ± 0.3	4.73 ± 0.3	4.11 ± 0.3	5.31 ± 0.3	2.43–5.31
Cd	ND	ND	ND	ND	ND	–
Pb	ND	2.81 ± 0.08	3.82 ± 0.1	3.46 ± 0.1	1.23 ± 0.03	1.23–3.81

ND[1] = not detected

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Table 4: Contribution of 100 g of *D. abyssinica* samples to the individuals daily need of minerals

Metal	Range of metal concentrations (mg/100 g)	Metal	Range of metal concentrations (mg/100 g)
K	847–1391	Zn	1.2–4.5
Na	13.3–40.5	Cu	0.73–1.8
Ca	17.2–44.8	Mn	ND–1.5
Mg	18.0–35.4	Co	ND–0.87
Fe	2.8–14.4	Ni	0.24–0.53
Zn	1.2–4.5	Cr	0.09–0.34
Cu	0.73–1.8	Pb	0.12–0.38

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Table 5: Comparison of metal concentration (µg/g) in *D. abyssinica* with other tuber plants and cereals

a) Tuber plants

Tuber type	Concentration (µg/g dry weight) of metals in different tubers							
	Na	K	Ca	Mg	Fe	Mn	Zn	Ref.
D. alata	84–131	10,550–15,447	260–535	390–595	24.9–60.6	5–25	10.1–17.6	[14]
S. andigena	22.3–36.7	5,969–6,938	47.6–81.0	188–250	8.25–11.2	1.81–2.14	2.91–5.12	[15]
S. tuberosum	17.1–377	4,890–5,989	50.6–87.3	221–2,450	7.19–10.4	1.43–1.77	2.18–4.58	[15]
S. tuberosum	21.2–176	4,523–6,198	21.6–147	188–298	5.14–17.3	0.75–2.26	1.89–7.21	[15]
M. esculenta	46.9–63.7	2,600–3,900	700–900	700–1,300	117.3–184.2	24.5–32.3	5.6–8.5	[16]
Kocho from *Ensete ventricosum*	462–688	2,753–4,380	498–584	180–290	92.5–135	8.58–10.13	31–32.1	[17]
Bulla from *Ensete ventricosum*	402–442	708–875	385–446	58.4–89.5	36.5–59.8	1.0–4.98	22–44.3	[17]
D. abyssinica	133–405	8,469–13,914	172–448	180–354	28.3–144.7	12.0–14.5	12.3–44.5	This study

Tuber type	Concentration (µg/g dry weight) of metals in different tubers						
	Cu	Co	Cr	Ni	Cd	Pb	Ref.
D. alata	10.10–15.67	–	–	–	–	–	[14]
S. andigena	0.92–2.12	–	–	–	–	–	[15]
S. tuberosum	0.54–1.72	–	–	–	–	–	[15]
S.xchaucha	0.47–1.68	–	–	–	–	–	[15]
M. esculenta	4.6–10.9	–	–	–	–	–	[16]
Kocho from *Ensete ventricosum*	3.4–4.3	5.5–6.1	5.96–6.42	≤ 5.61	ND[1]	ND[1]	[17]
Bulla from *Ensete ventricosum*	2.01–3.53	5.0–5.01	≤ 5.38	ND[1]	ND[1]	ND[1]	[17]
D. abyssinica	7.26–17.6	1.91–8.68	0.86–3.41	2.43–5.31	ND	1.23–3.81	This study

[1]Not detected. *S. tuberosum* (potato), *D. alata* (purple yam), *S. Andigena* (Andigena potatoes), *S. xchaucha* (chaucha potatoes), *M. esculenta* (cassava), *Ensete ventricosum* (false banana), *D. abyssinica* (yam family)

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b) Cereal plant

Cereal types	Concentration (µg/g dry weight) of metals in different cereals					Ref.
	Ca	Fe	Mn	Zn	Cu	
Barley, white flour	45.0	8.4	–	3.57	0.28–0.50	[18]
	39.5–42.1	3.1–3.8	0.9–1.5	1.47–2.17	–	[20]
Red teff, whole grain	155.0	>150.0	–	4.0	–	[18]
Maize, white four	120.0	4.9	–	21.5	–	[18]
	13–76	14.7–27	3.6–7.0	12.5–14.1	0.6–2.6	[20]
Whole wheat	–	43	46	35	5	[21]
	414–444	19–41	24.1–46	18.1–34	3.2–6.2	[20]
White wheat flour	–	11	7	8	2	[21]
D. abyssinica	172–448	283–145	12.0–14.5	12.3–44.5	7.26–17.6	This study

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