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Micronutrient Composition of Soils and Supported *Solanum scabrum* in Bafut Sub-division (North-West Cameroon)

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil-plant metal interaction is vital in plant metabolism and on effects related to deficiency and toxicity, yet has received very little attention in terms of research in developing countries. The aim of the present study was to investigate the composition of Zn, Cu, Mn and Fe in soils and grown huckleberry (*Solanum scabrum)* in Bafut Sub-division (North-West Cameroon). Soils and huckleberry samples were collected in North and South Bafut in the rainy and dry seasons. The micronutrient levels in *Solanum scabrum* and soils were measured by Atomic Absorption Spectrometry. The results revealed that the metal levels of the soils were within the permissible range for agricultural soils. In the vegetables, only Fe and Mn, the most represented metals, were within the adequate and normal levels for optimum plant growth and human consumption, while Cu and Zn contents suggested a dietary intake deficiency for the inhabitants of the study area**.** The soil-metal transfer factors were globally less than 1 (0.03 to 0.95), lowest for Cu and highest for Fe. Between sites, Fe contents were fairly higher in South Bafut soils, while Zn, Mn and Cu were higher in North Bafut soils. These differences could be explained by the variation in the nature of parent

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rock in both localities and the slightly acidic soil pH which influences the solubility, mobility and bioavailability of soil nutrients. Between seasons, there was no significant difference (P<.05) between metal concentrations of soils and *Solanum scabrum,* except for Cu in the dry season vegetables. The present work suggests that *S. scabrum* could serve as a cheaper source of micronutrients especially Fe and Mn for the local inhabitants of Bafut and beyond.

Keywords: Solanum scabrum; soil; micronutrients; bioavailability; transfer factor; Bafut.

1. INTRODUCTION

Huckleberry (*Solanum scabrum*) is one of the most popular cash crops and most grown traditional vegetables in the western part of Cameroon [1]. It is an annual plant that is easy to cultivate, easy to cook and very palatable. *S. scabrum* serves as a traditional dish for most villages in the North West Region of Cameroon and it is mostly used in social gatherings and ceremonies. It is an indigenous vegetable that forms the basis of human nutrition: It is a source of vitamins and micronutrients required in minute quantities. These micronutrients have been given special attention worldwide due to the principal role that they play in numerous metabolic activities as well as harmful effects associated with deficiency and toxicity levels when their concentrations exceed certain limits [2-5]. The concentrations of micronutrients in vegetables depend on their intrinsic characteristics (varieties, maturity, genetics, age, etc) and environmental conditions (soils, geographical locations, season of the year, water quality, fertilizer use, etc) as well as on handling and processing techniques [6]. Vegetable contamination through metals is a serious threat because of the high toxicity, bioaccumulation and biomagnification of these metals once in the food chain [7]. The metals often accumulate in soils due to weathering, environmental pollution and irrigation with metal-contaminated water where they can then be absorbed by plants [8-10].

Much work has already been published on *S. Scabrum* mainly on its global distribution and consumption [1], its nutritional value [11-14] and its medicinal value [10,15,16]. However, some aspects like the micronutrient concentrations and soil-plant transfer factors are very rare in Cameroon. This can be due to some constraints like the long and fastidious methodology, high number of samples or the the high cost of their analyses that require very advanced technological approaches often out of reach of most developing countries. Some local studies, nevertheless, revealed a tendency for vegetables to accumulate variable levels of metals in their tissues: [17] in some edible upland plants in the Upper Noun valley (West Cameroon), [18] on vegetables grown along the Nkoup River (Foumbot), [19] in some vegetables in Ngaoundéré, [9] on metal levels in huckleberry grown along the Mezan River valley (Bamenda) and [20] on nutritional evaluation of indigenous vegetables (Yaoundé). The aim of the present work was, firstly, to quantify the metal levels of Fe, Mn, Cu and Zn in soils and vegetables grown in Bafut sub-division and, secondly, to investigate the effect of some environmental factors on the accumulation of micronutrients in soils and *S. scabrum*. The results obtained will supplement the available data on the bioavailability of metals in vegetables commonly consumed in Cameroon and beyond.

2. MATERIALS AND METHODS

2.1 Study Area

Bafut Sub-division is located in the north of Mezam division (North West region of Cameroon) between latitude 06º05´-06º11´ N and longitude 09º58´-10º11́ E (Fig. 1) [21]. It is situated at about 20 km northwest of Bamenda and covers an area of roughly 340 km^2. The mean annual precipitation is 2657.2 mm, with a long rainy season from March to November and a dry one from December to February. The mean annual temperature is 24ºC, but maximum temperature attains 26.7ºC in February while the minimum reaches 22.3ºC between August and November [22]. The natural vegetation of Bafut is the grassland savannah, marked by grasses mixed with deciduous shrubs and stunted trees here and there, meanwhile the swampy valleys are dominated by raffia bushes and palm trees [23]. This natural vegetation is strongly modified by human activities mainly farming and demographic pressure imposed by a rapidly increasing population [24]. On a hydrographic point of view, Bafut Sub-division is drained by River Mezam (main collector) and its tributaries. The main collector together with its tributaries form a sparse and more or less angular drainage pattern [25]. Geologically, Bafut sub-division is located on the Cameroon Volcanic Line and comprises three main geological formations: Volcanic rocks, metamorphic rocks and alluvial deposits. The metamorphic rocks, mainly gneiss and schist, outcrop mainly in the North especially on slopes of high plateaus and constitute the basement. The volcanic rocks, mostly basalts, outcrop in South Bafut [26]. The alluvial deposits cover the Mezam River valley. The distribution of soils in Bafut is conditioned chiefly by topography and climate. Thus, ferruginous and ferrallitic soils occur in the southern high plateaus. In the north, most of the hill slopes are covered by brunified soils; alluvial soils are abundant in the Mezam river valley. Hydromorphic soils are common in the swampy valleys [27]. The estimated population of 80.305 inhabitants (2005 census) is settled in three main zones [28]: The Mumala'a (heart of the country) at the Centre clustered around the Fon's palace, the Ntare (ridge area) to the South and the Mbunti (lower) to the North which descends abruptly to the Menchum valley.

In Bafut sub-division, vegetable cultivation is all year round to ensure a continuous supply, but cultivation is intensified in the dry season when it is more lucrative. In the rainy season, vegetables are grown both in uplands and lowlands. In the dry seasons, they are grown only in lowlands close to the banks of the Mezam River, main water course which runs through the Bafut municipality and whose water serves for irrigation. Hand watering using watering cans is common but flood irrigation is also practiced. Most of the farmers usually have a home garden for their own local consumption and a garden for commercial consumption usually some distance away from the home. The study sites were selected in North Bafut at Mbekong and in South Bafut at Mambu (Fig. 1). Bafut and Mbekong are two outstanding vegetable production zones in Bafut. The Mambu plot was located in a swampy valley at Atimuluh quarter flooded mainly in the rainy season while the Mbekong plot was located

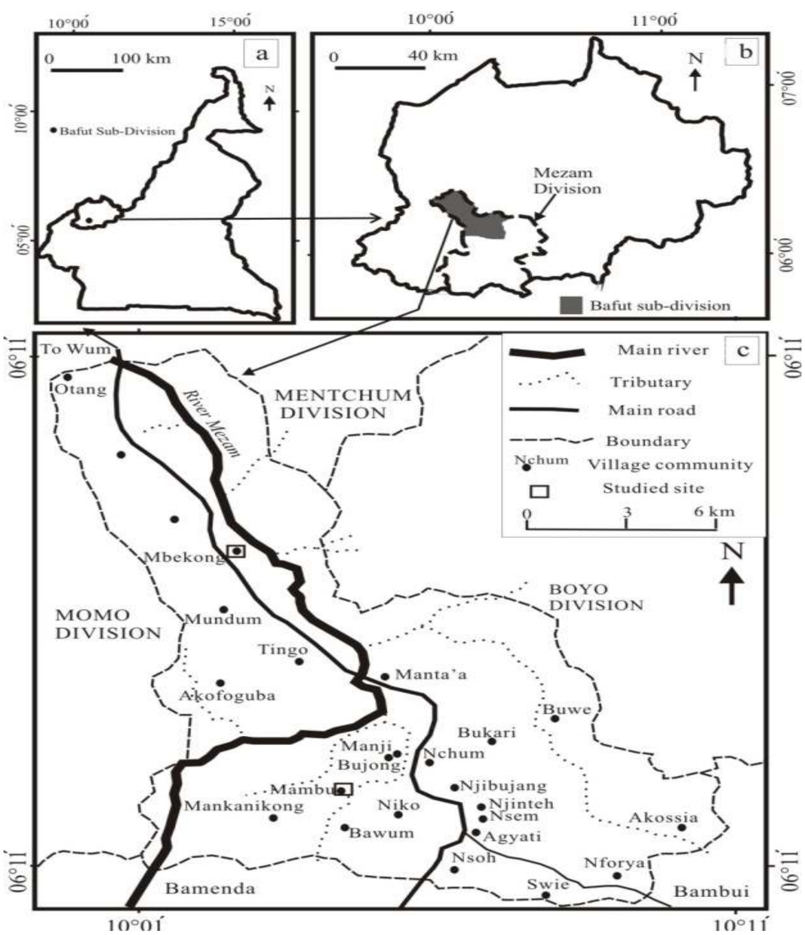

Fig. 1. Study area location (a) Cameroon map showing position of the Bafut sub-division; (b) Map of North West Region of Cameroon locating the Bafut Sub-division; (c) Map of Bafut Sub-division [21] showing the studied sites

along the Mezam main River Bank at the eastern side of the Bamenda-Wum road.

2.2 Methodology

2.2.1 Sample collection and pre-treatment

In the field**,** two plots (10 m x 10 m grid) were selected, one in Mambu and the other in Mbekong. Each was further divided into four equal sub-plots of 2.5 m by 2.5 m and planted with *S. scabrum* in March 2010 (rainy season) and in November 2010 (dry season). The *Solanum scabrum* shoots were harvested at six weeks after planting. The shoots of all vegetable plants from each plot were harvested by cutting stem at about 8 cm to the soil surface. The vegetables samples were randomly cut within each demarcated 2.5 m by 2.5 m sub-plot using a ceramic scissors to form a final composite sample of about 1 kg. All together four composite vegetable samples were obtained per 10 m x 10 m plot making a total number of 16 samples. In each sub-plot, after each vegetable sampling, five soil samples were also randomly collected at 0-20 cm depth (rooting zone) using a plastic shovel to avoid any metal contamination. These soil samples were mixed together to obtain a composite sample per sub-plot. All together, four composite soil samples were obtained per plot per season making a total numbers of 16 soil samples. Immediately after each collection, samples were stored in clean plastic bags and conveyed to the laboratory for further processing and analysis. In the laboratory, composite soil samples were air-dried at room temperature for one week and passed through a 2-mm polyethylene sieve to remove plant debris and pebbles. Afterwards, they were lightly crushed in an agate mortar into fine powder and passed through 0.149-mm nylon sieve. Vegetable samples were washed three times with distilled water to remove soil particles and were then oven-dried at 75ºC to a constant weight for 48 hours. The dried vegetable samples were ground into fine powder in an agate mortar and passed through a 0.149-mm nylon sieve. The soil and vegetable sample powders were then stored in glass containers and preserved under ambient conditions pending analysis.

2.2.2 Laboratory analyses

2.2.2.1 Soil analyses

The soil analyses were comprised of physico-chemical analyses and determination of soil micronutrient levels. The physico-chemical analyses were done in the Laboratory of Soil Science and the Laboratory of Physico-chemistry of Mineral Materials (University of Yaoundé I) as well as at the International Institute for Tropical Agriculture (IITA) Nkolbissong, Yaoundé. The determination of soil micronutrient contents was done at the International Institute for Tropical Agriculture (IITA) of Nkolbisson (Yaoundé, Cameroon).

A battery of physicochemical analyses was performed. Thus, the soil moisture content was determined by noting the weight-loss of an air-dried sample, after subjecting it to an oven temperature of 105ºC for 24 hours [29]. The bulk density (Db) was determined in reference to Archimedes' principle and particle density (Dp) was measured by pycnometer method [29]. Soil porosity was deduced from bulk density and particle density [29]. The particle size distribution was measured by Robinson´s pipette method [29]. The pH-H_2O was determined in a soil/water ratio of 1:2.5 using a glass pH-meter [30]. The organic carbon (OC) was measured by Walkley-Black method [31]. Organic matter (OM) was obtained from organic carbon (OC) using the Sprengel factor (OM= OC x 1.724) [32]. Total nitrogen (TN) was measured by the Kjeldahl method [33].

Determination of soil micronutrient levels was done by total digestion method [34]. Thus, aliquots of 0.5 g of dried soil samples were digested with HNO_3 acid, H_2O_2 and HCl acid mixture in the ratio 5:1:1 at 80ºC until a clear solution was obtained. The solution was filtered through Whatman no. 42 filter paper and diluted to 50 ml with deionized water. The filtrates were then directly analyzed for Fe, Mn, Cu and Zn using atomic absorption spectrophotometry PG-900 Model, equipped with an air-acetylene flame and a hollow cathode lamp, under standard conditions using wavelengths and slit-widths specified for each element [35].

2.2.2.2 Vegetable analyses

The dried vegetables were digested with HNO_3 acid, H_2O_2 and HCl acid mixture (5:1:1 ratio), filtered, diluted to 50 ml and then analyzed for Fe, Mn, Cu and Zn by atomic absorption spectrophotometry PG-900 Model [35].

All soil and vegetable samples were analyzed along with a blank solution. Calibration was performed with standard solutions while precision and accuracy were checked by repeated analyses of sub-samples of the standards. The micronutrient concentrations in soils and vegetables were expressed in mg kg^{-1}. The metal transfer factors were calculated as the concentration of the metal in the edible part of vegetable relative to the concentration in the soil [36].

2.2.3 Statistical analysis

Statistical analysis was performed using the SPSS software program (SPSS Inc., Version 12.0). The data were analyzed by one-way analysis of variance (ANOVA). To detect the statistical significance of differences ($P<.05$) between means, the Tukey's test was performed.

3. RESULTS

3.1 Soil Physico-chemical Characteristics

The studied soils (0-20 cm depth) were dark grey (10 YR4/1) in South Bafut to dark brown (10 YR3/3) in North Bafut. They showed a heavy clayey texture in north Bafut and a clayey texture in South Bafut (Table 1). The hygroscopic water content ranged between 7.65 and 14.23, with slightly higher values in the south. Bulk density was 1.5 g/cm^3 in both zones but particle density was slightly higher in the south (2.6 gcm^{-3}) compared to the north. Total porosity was mediocre. The pH.H_2O was slightly acidic (5.6 and 6.3). Also, the pH.H_2O values of the dry season soils were slightly higher than those of the corresponding rainy season soils. The organic matter content was medium (2.57-3.58 %). The total nitrogen content was low to medium (0.05-0.11 %). The C/N ratio was very high (17-32). The Bafut soils fall within the medium fertility range [37,38].

3.2 Micronutrient Levels in Bafut Soils

Fe was the most abundant micronutrient in the soils and ranged between 213.0 and 342.1 mg kg^{-1} (Fig. 2). Between sites, Fe contents were significantly ($P<.05$) higher for soils from South Bafut; meanwhile for the lower values observed in the north, those of the rainy season were slightly higher (241.0 mg kg^{-1}) than those of the dry season (213.0 mg kg^{-1}).

Mn contents of the studied soils ranged between 113.0 and 264.0 mg kg^{-1} (Fig. 2; Table 2). However, no significant difference ($P<.05$) was observed between the different sites and seasons. The highest value was noted in the North (264.1 mg kg^{-1} in the dry season and 218.0 mg kg^{-1} in the rainy season). The lower contents in the South also showed a slightly lower value in the rainy season (113.0 mg kg^{-1}) relative to the dry season (141.0 mg kg^{-1}).

Zn contents in the two sites globally ranged from 82.0 to 118.0 mg kg^{-1} and no significant difference ($P<.05$) was noted between sites and seasons (Fig. 2; Table 2). However, the concentration of Zn in the soils was higher in the North than in South Bafut. In the north, zinc contents were slightly higher in the dry season (118.0 mg kg^{-1}) than in the rainy season (108.0 mg kg^{-1}). Zn contents of soils in the south were quite similar, though slightly higher in the dry season (94.0 mg kg^{-1}) than in the rainy season (82.0 mg kg^{-1}).

Cu contents in the Bafut soils ranged between 23.0 and 39.0 mg kg^{-1} (Fig. 2; Table 2). Generally, the Cu contents of the rainy season soils were slightly higher than those of the dry season for both sites. However, the Cu contents of soils sampled in North Bafut (28.0 mg kg^{-1} in the dry season and 39.0 mg kg^{-1} in the rainy season) were slightly higher than those of South Bafut (23.0 mg kg^{-1} in the dry season and 37.0 mg kg^{-1} in the rainy season). Nevertheless, there were no significant differences *($P<.05$)* in Cu contents between sites and seasons.

3.3 Levels of Micronutrients in *Solanum scabrum* grown in Bafut

Fe was the most concentrated metal in all the *S. scabrum* from the studied sites (Fig. 3; Table 3). In North Bafut, the highest Fe contents (202.3 mg kg^{-1}) appeared in the dry season *S. scabrum* as opposed to the rainy season ones (149.7 mg kg^{-1}). Globally, Fe contents in all other vegetable samples were significantly ($P <.05$) higher than VDS. In South Bafut, higher values were noted in the rainy season (192.3 mg kg^{-1}). Specifically in the South Bafut, Fe contents of VRS were significantly higher than those of VDS. In the north, there was no significant difference ($P<.05$) between Fe contents of rainy season and dry season vegetables.

The Mn levels in Bafut *S. scabrum* were slightly lower than those of Fe, varying between 58.3 and 81.3 mg kg^{-1} (Fig. 3; Table 3). Globally, only Mn contents of VDN were significantly ($P<.05$) higher relative to other sites and seasons. Thus, no significant difference was noted between VDS and VRS, meanwhile in the north VDN was significantly ($P<.05$) higher in Mn compared to VRN.

Table 1. Characteristics of the Bafut soils sampled at 0-20 cm depth (n =4)

Soil properties / Soil code	Moisture content (%)	Bulk density (gcm^{-3})	Particle density (gcm^{-3})	Porosity (%)	Particle size distribution (%)			Textural class	pH (H_2O)	OC (%)	OM (%)	TN (%)	C/N
					Sand	Silt	Clay						
SDS	14.23	1.5	2.5	40	25	14	61.00	Heavy clay	6.3	1.9	3.28	0.11	17
SRS	13.80	1.5	2.5	40	22	13	65.00	Heavy clay	6.1	1.6	2.76	0.06	27
SDN	8.23	1.5	2.6	42	40	14	46.00	Clayey	5.8	2.01	3.47	0.10	20
SRN	7.65	1.5	2.6	42	38	15	47.00	clayey	5.6	1.49	2.57	0.05	32

SDS: Dry season soil from South Bafut; SRS: Rainy season soil from South Bafut; SDN: Dry season soil from North Bafut; SRN: Rainy season soil from North Bafut

Table 2. Mean metal concentrations, standard deviation (in brackets) of soils in the Bafut Sub-division and permissible/critical levels for agricultural soils (n =4)

Soil micronutrient ($mg\ kg^{-1}$ dry weight) / Soil code	Fe	Cu	Mn	Zn
SDS	342.10^{b}	23.00^{a}	141.00^{a}	82.00^{a}
	(85.53)	(5.75)	(35.25)	(20.50)
SRS	296.80^{b}	37.00^{a}	113.00^{a}	94.00^{a}
	(74.20)	(9.25)	(28.25)	(23.50)
SDN	213.00^{a}	28.00^{a}	264.10^{a}	118.00^{a}
	(53.25)	(7.00)	(66.02)	(29.50)
SRN	241.00^{a}	39.00^{a}	218.00^{a}	108.00^{a}
	(60.25)	(9.75)	(54.50)	(27.00)
Permissible limits for agricultural soils [39]	50.00-250.00	50.00-140.00	15.00-500.00	150.00-300.00

SDS: Dry season soil from South Bafut; SRS: Rainy season soil from South Bafut; SDN: Dry season soil from North Bafut; SRN: Rainy season soil from North Bafut. Values in the same column followed by different letters are significantly different at P =.05

Zn contents of *S. scabrum* ranged from 28.4 to 43.6 mg kg^{-1} (Fig. 3; Table 3). There was no significant difference (P<.05) between Zn contents of *S. scabrum* from both sites and seasons, although *S. scabrum* VRS contents were fairly higher than VDS and VDN was slightly higher than VRN.

Cu contents of *S. scabrum* from Bafut were significantly low (0.78 and 1.99 mg kg^{-1}) compared to the other metals (Fig. 3; Table 3). Cu contents were significantly higher in the South (P <*.05*) than in the North. In the South, dry season *S. scabrum* showed no significant difference (P<*.05*) in Cu contents between seasons, although slightly higher (1.99 mg kg^{-1}) in the dry season than the rainy season ones (1.46 mg kg^{-1}). In the North, no significant difference (P<.05) was also observed between seasons, although higher Cu contents (0.78 mg kg^{-1}) were noted in the dry season compared to the rainy season (1.01 mg kg^{-1}).

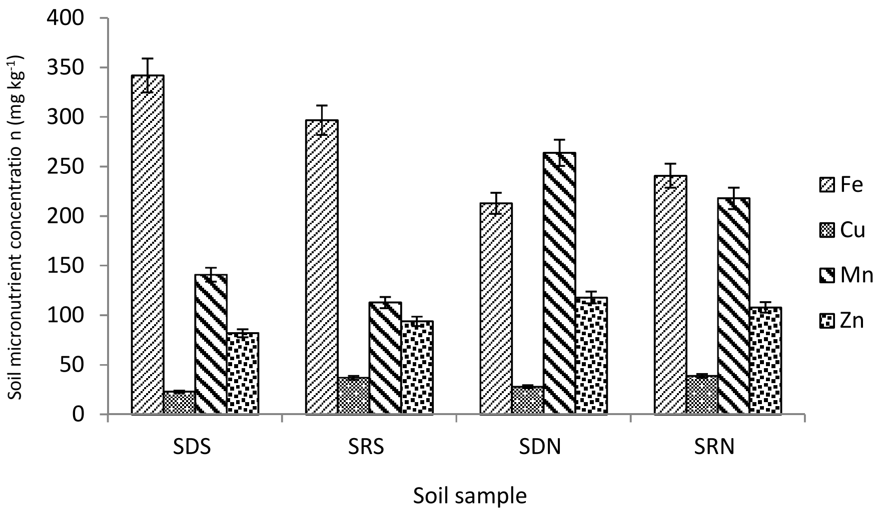

Fig. 2. Micronutrient concentrations (±standard error) in soils from Bafut Sub-Division
(SDS: Dry season soil sample from South Bafut; SRS: Rainy season soil sample from South Bafut; SDN: Dry season soil sample from North Bafut; SRN: Rainy season soil sample from North Bafut)

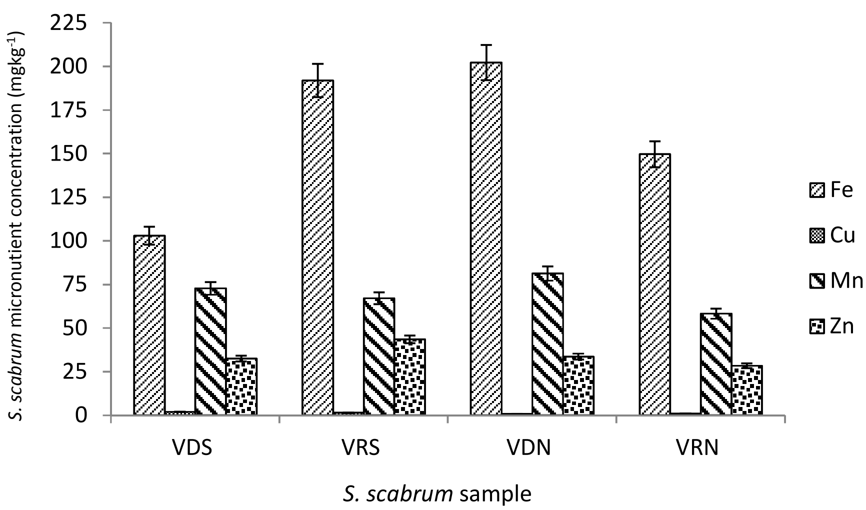

Fig. 3. Micronutrient concentrations (± standard error) in *S. scabrum* from Bafut Sub-Division
(VDS: Dry season S. scabrum samples from South Bafut; VRS: Rainy season S. scabrum sample from South Bafut; VDN: Dry season S. scabrum sample from North Bafut; VRN: Rainy season S. scabrum sample from North Bafut)

3.4 Linear Correlations and Metal Transfer Factors

The Pearson linear correlation test revealed positive (*P*<0.05) correlation coefficients between soil and vegetables micronutrient concentrations (Table 4). VRS versus SRS showed the highest correlation (r=0.99; p=.001) while the least was shown by VRN versus SRN (r=0.69; *P*=.002).

The soil-plant metal transfer factors in both sites and seasons were all less than 1 (0.3 to 0.95 for Fe, 0.28 to 0.59 for Mn, 0.26 to 0.46 for Zn and 0.03 to 0.09 for Cu) (Fig. 4; Table 5). Globally, except for Fe, transfer factors were higher in the south that in the north. Thus, Fe, specifically in VDN/SDN displayed the highest transfer factor. Cu, on the other hand, showed the lowest transfer factors between sites and seasons. The transfer factors were in the following order: Mn>Zn>Fe>Cu for VDS/SDS, Fe > Mn >Zn >Cu for VRS/SRS, Fe>Mn>Zn> Cu for VDN/SDN and Fe>Zn> Mn> Cu for VRN/SRN.

Table 3. Mean micronutrient contents and standard deviation (in brackets) in *S. scabrum* from Bafut Sub-Division and predefined levels for growth and consumption (n =4)

Vegetable code \ Vegetable micronutrient (mg kg^{-1} in dry weight)	Fe	Cu	Mn	Zn
VDS	103.00^{a} (25.75)	1.99^{b} (0.50)	72.80^{a} (18.20)	32.50^{a} (8.13)
VRS	192.00^{b} (48.00)	1.46^{b} (0.37)	67.10^{a} (16.78)	43.60^{a} (10.90)
VDN	202.30^{b} (50.58)	0.78^{a} (0.20)	81.30^{b} (20.33)	33.70^{a} (8.43)
VRN	149.70^{b} (37.43)	1.01^{a} (0.25)	58.30^{a} (14.58)	28.40^{a} (7.10)
Normal levels in plant [48]	50- 500	5-20	20-1000	1-400
sufficiency levels in plants [48]	50-250	5-20	20-500	25-150
Critical levels for plant growth [48]	50-150	20-100	300-500	100-400
Toxicity levels in plants [46]	>500	20-30	>500	>400
Permissible levels in food [53]	-	<200	-	<500

VDS: Dry season S. scabrum from South Bafut; VRS: Rainy season S. scabrum from South Bafut; VDN: Dry season S. scabrum from North Bafut; VRN: Rainy season S. scabrum from North Bafut. Values in the same column followed by different letters are significantly different at P < .05; standard deviation in brackets

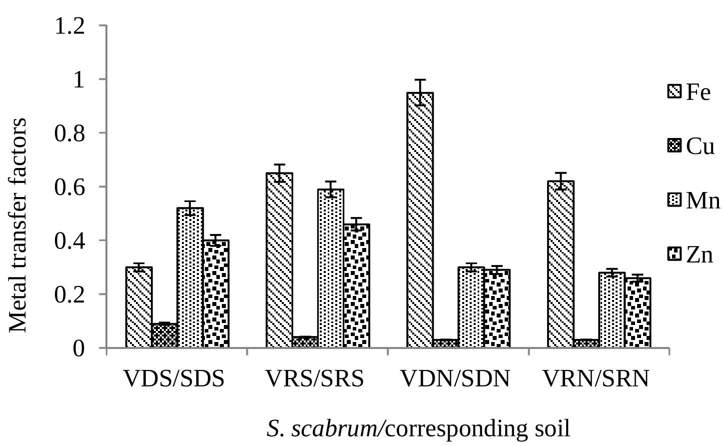

Fig. 4. Transfer factors (± standard error) of micronutrients

VDS: Dry season S. scabrum from South Bafut; SDS: Dry season soil sample from South Bafut; VRS: Rainy season S. scabrum from South Bafut; SRS: Rainy season soil from South Bafut; VDN: Dry season S. scabrum from North Bafut; SDN: Dry season soil from North Bafut; VRN: Rainy season S. scabrum from North Bafut; SRN: Rainy season soil from North Bafut

Table 4. Relationship between micronutrients in soils and vegetables from Bafut sub-Division (n=4)

Regression relationship	Correlation coefficient (r)	Probability level (p)
VRS versus SRS	0.99**	0.001
VDS versus SDS	0.94**	0.003
VDN versus SDN	0.87*	0.01
VRN versus SRN	0.69	0.02

***Significant at the 0.01 level; *Significant at the 0.05 level; VRS: Rainy season S. scabrum from South Bafut; SRS: Rainy season soil from South Bafut; VDS: Dry season S. scabrum from South Bafut; SDS: Dry season soil sample from South Bafut; VDN: Dry season S. scabrum from North Bafut; SDN: Dry season soil from North Bafut; VRN: Rainy season S. scabrum from North Bafut; SRN: Rainy season soil from North Bafut)*

Table 5. Mean soil-to-plant metal transfer factors and standard deviation (in brackets) of metals from the different sites and seasons (n=4)

Metal transfer factors / Vegetable/corresponding soil	Fe	Cu	Mn	Zn
VDS/SDS	0.30^{a}	0.09^{b}	0.52^{b}	0.40^{b}
	(0.075)	(0.023)	(0.13)	(0.1)
VRS/SRS	0.65^{a}	0.04^{a}	0.59^{b}	0.46^{b}
	(0.1625)	(0.01)	(0.1475)	(0.115)
VDN/SDN	0.95^{a}	0.03^{a}	0.30^{a}	0.29^{a}
	(0.2375)	(0.0075)	(0.075)	(0.073)
VRN/SRN	0.62^{a}	0.03^{a}	0.28^{a}	0.26^{a}
	(0.155)	(0.0075)	(0.07)	(0.065)

VDS: Dry season S. scabrum from South Bafut; SDS: Dry season soil sample from South Bafut; VRS: Rainy season S. scabrum from South Bafut; SRS: Rainy season soil from South Bafut; VDN: Dry season S. scabrum from North Bafut; SDN: Dry season soil from North Bafut; VRN: Rainy season S. scabrum from North Bafut; SRN: Rainy season soil from North Bafut

4. DISCUSSION

4.1 Particularities of Micronutrients in Bafut Soils and Vegetables

Fe was the most abundant micronutrient in all the soil samples and its contents varied between 213.0 and 342.1 mg kg^{-1}. These values fell between the permissible range for agricultural soils [39]. These soil iron levels were higher than the 21.4-58.9 mg kg^{-1} reported for some contaminated soils in Jos (Nigeria) by Pasquini [40] but lower than Fe contents documented for vegetable soils of the Cameroonian inland valleys of the Nkoup River in Foumbot [18] and Mezam River in Bamenda [20,11] (Table 6). In some environments, Fe availability under stress conditions is enhanced through the production of organic chelating agents by microorganisms [41]. The high Fe concentration of the soil might therefore be the result of the slightly acidic nature of the Bafut soils, conditions favorable to Fe accumulation. The main sources of Fe are probably the parent rocks, iron pipes, waste can containers and rusted iron rods commonly dumped into nature following rapid population growth in the Bafut sub-division as well as Fe present in irrigation water [42].

The Mn concentrations in Bafut soils, quite close to those of Fe and ranged from 113 to 264.1 mg kg^{-1}, were considered as moderate to high. These values fell within the permissible levels for crop cultivation [39]. Generally, the concentration of Mn in soil covers a particularly wide range, from as little as 0.20 mg kg^{-1} to over 300 mg kg^{-1} [43]. The lower values are typical of severely leached acid soils. In contrast, Mn toxicities are common in unleached acid soils and waterlogged conditions. Mn deficiency is most common in alkaline and calcareous soils. Soil pH is one of the main factors determining Mn availability in soils. A pH value close to or below 6.0 could favor Mn reduction and the formation of the more available divalent form (Mn^{2+}); higher pH favors Mn oxidation to Mn^{4+} ion, forming the insoluble oxides like MnO_2, Mn_2O_3 and Mn_3O_4 [43]. The moderate to high Mn contents recorded in the present study could be related to the slightly acidic pH of the studied soils [44].

Table 6. Comparison of micronutrient concentrations in soils and *S. scabrum* from Bafut with those of some areas in Africa

Micronutrient (mg kg^{-1})	Present study (Bafut)	Cameroon (Foumbot) (a)	Cameroon (Yaoundé) (b)	Cameroon (Bamenda) (c)	Tanzania (b)	Kenya (b)	Nigeria (d)
Soil							
Fe	213.0-342.1	NA	NA	297.0-507.0	NA	NA	NA
Cu	23.0-39.0	NA	NA	1.30-4.10	NA	NA	NA
Mn	113.0-264.0	NA	NA	49.60-84.10	NA	NA	NA
Zn	82.0-118.0	NA	NA	2.10-12.50	NA	NA	NA
S. scabrum							
Fe	103.0-202.3	115-882	182.00-387.93	297-619	184.45-266.52	147.37	280.5
Cu	0.78-1.99	0.013-0.097	NA	1.30-4.10	NA	NA	22.40
Mn	58.3-81.30	29.1-61.2	NA	49.6-84.10	NA	NA	359.40
Zn	28.40-43.60	14.7-47.2	39.70-38.33	2.10-12.50	38.90-39.21	41.80	52.99
Transfer factors							
Fe	0.30-0.95	NA	NA	0.92-1.20	NA	NA	NA
Cu	0.03-0.09	NA	NA	0.69-1.62	NA	NA	NA
Mn	0.28-0.59	NA	NA	0.56-0.72	NA	NA	NA
Zn	0.26-0.49	NA	NA	4.58-7.09	NA	NA	NA

(a) [9]; b) [20]; (c) [9]; (d) [14]; NA: not available

Zn contents in soils of the two studied sites globally ranged from 82.0 to 118.0 mg kg^{-1} and fell below the permissible limits for agricultural soils [39]. Zn is deficient in a wide range of soil types; soils with less than 0.30 mg kg^{-1} of zinc are likely to require zinc addition for optimum crop production. With highly alkaline soils, the critical level may attain 0.80 mg kg^{-1}. Certain soil conditions reduce Zn availability, notably high pH as the solubility of Zn decreases with pH [45].

The soil Cu contents of the studied Bafut soils fell between the permissible levels for optimum plant growth [39]. Most plants like *S. scabrum* (as well as cereals, oats, wheat, barley, maize, etc) are particularly sensitive to Cu deficiencies [45,46]. Soils derived from basic volcanic rocks and metamorphic rocks usually show low Cu contents whereas acidic conditions favor the availability of Cu [47]. Copper deficiency is most common on highly calcareous soils as well as in sandy soils with low organic matter contents [46]. High concentrations of other metals such as Fe, Mg and Al in soil can induce Cu deficiency due to “ionic balance effect” [48].

The concentrations of the various metals in the Bafut soils fell below the maximum permissible levels for agricultural soils [39] and consequently could not be expected to present any toxicity risks for the supported vegetables. There could instead be a potential risk of Zn and Cu deficiency.

Fe was the most represented element in all the vegetable samples from the studied sites. The vegetable Fe contents fell within the adequate levels and sufficiency levels for optimum plant growth, and were below the toxicity levels [49]. The high Fe contents of *S. scabrum* could be due to the naturally higher occurrence of Fe relative to the other metals in the soil environment and the slightly acidic pH which favors availability and uptake by plants [50]. These metal levels are similar to those already documented in Ngaoundéré (North Cameroon) [19] and Yaoundé [20], but far below those reported for vegetables grown along the Mezam River in Bamenda [9]. These metal values are also in the same order of magnitude as those reported in Kenya and Tanzania [20] and in Nigeria [14].

The Mn contents of the Bafut *S. scabrum* ranged between 58.3 and 81.3 mg kg^{-1}. These values were significantly (P<.05) higher than those (0.02 to 14.0 mg kg^{-1}) reported for some Russian vegetables [51] and the 0.18- 2.8 mg kg^{-1} range documented for some Indian leafy vegetables [52]. Globally, the dry season *S. scabrum* showed higher Mn contents than those grown in the rainy season. The vegetables metal contents in this study fell within the sufficiency levels and below the toxicity levels for optimum plant growth [48] as well as within the permissible values in food [53]. Mn and Fe are essential mineral elements for both plants and animals, and the recorded levels in this study indicate that the vegetables constitute very good sources of nutrients in the diet of the population.

The Zn contents of *S. scabrum* varied from 28.4 to 43.6 mg kg^{-1}. These values fell below the critical range for optimum plant growth [48] as well as the permissible level in food [53]. All the

S. scabrum samples contained inadequate Zn levels [48]. These observed values were in agreement with those published by Kamga et al. [20] and Idowu et al. [5], but higher than values reported for vegetables grown along the Mezam River valley in Bamenda [9]. These Zn levels were also analogous to the 25.2-50.0 mg kg^{-1} reported for *S. scabrum* in India [52], but higher than values recorded for vegetables in Nigeria [54], Egypt [12] and Latin America [55].

The Cu contents in *S. scabrum* were significantly low (0.78 to 1.99 mg kg^{-1}) compared to the other micronutrients in the vegetables. The Cu concentrations fell below the normal range and were inadequate for optimum plant growth [48] as well as below the permissible values in food [53]. These values were close to those already reported in Ngaoundéré (North Cameroon) [19], but higher than those for vegetables grown along the Nkoup inland River valley in Foumbot [18]. This range is within values reported for most vegetables irrigated with waste water [56-59].

The levels of Fe and Mn in *S. scabrum* from Bafut Sub-division fell within the sufficiency range. Cu and Zn contents suggested a dietary intake deficiency for the inhabitants of the study area, probably due to low soil concentrations and /or non-bioavailability of these metals. These deficient metals could be compensated through the consumption of other foodstuffs. Nevertheless, all the micronutrients were within the permissible range in food suggesting that *S. scabrum* could serve as cheaper source of micronutrients for the inhabitants of Bafut and beyond.

4.2 Soil-to-plant Metal Transfer Rates

The soil-to-plant metal transfer factors were globally low and less than 1. Although the highest correlation coefficients existed between VRS and SRS, and between VDN and SDN, one would have expected the highest metal transfer factors to correspond to soils with the highest metal concentration, which is not the case. This could imply that factors other than soil micronutrient concentrations are inducing metal uptake by plants [9,59]. The availability of metals to plants in the soils could be influenced by soil intrinsic factors (clayey to heavy clayey texture, humidity, mediocre porosity, acidic pH, high organic matter content, etc) and extrinsic factors (precipitation, temperature, gradient of slope, etc). These factors control solubility and mobility of soil metals and subsequent availability for plants absorption [36,60]. Similar findings [9] in Bamenda town revealed very high metal transfer factors for Zn (4.58-7.09 mg kg^{-1} dry weight) and Cu (0.69-1.62 mg kg^{-1} dry weight) compared to Bafut vegetables, while the Fe and Mn factors are comparable (Table 6). The differences results from vegetable irrigation with contaminated water from River Mezam in Bamenda which leads to the deposition of excess plant available metal in the soils.

5. CONCLUSION

The aim of the present study was to investigate the composition of Zn, Cu, Mn and Fe in soils and grown *Solanum scabrum* in the Bafut Sub-division (North-West Cameroon). The results showed that the soil metal contents were within the permissible level for agricultural soils. Also, Fe and Mn, most represented metals in vegetables, were within the adequate and normal levels for optimum plant growth and human consumption, while Cu and Zn were deficient suggesting compensation through the consumption of other food types. Metal transfer factors were not directly proportional to soil metal concentrations suggesting that factors other than soil metal concentrations could induce metal uptake by the plants.

Overall, the present study provides valuable information on the relationship between metal contents of soils and *S. scabrum* and suggests that *S. scabrum* could serve as cheaper source of micronutrients especially Fe and Mn for the population of Bafut and beyond.

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COMPETING INTERESTS

All authors have declared that no competing interests exist.

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