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Variations of Macro- and Microelements in Yellow-Fleshed Cassava (*Manihot esculenta* Crantz) Genotypes as a Function of Storage Root Portion, Harvesting Time, and Sampling Method

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Featured Application: This study has provided information on the quantitative and qualitative information on the distribution of macro and trace elements and their concentrations within the cassava tuber (proximal, middle, and distal root portions). The data on the minerals of yellow-fleshed cassava roots could contribute to food composition databases. The knowledge generated would be of interest to researchers (cassava breeders and food scientists), food processors, dieticians, and policymakers in programming interventions. Yellow-fleshed cassava could be an alternative source of macro- and microelements for both humans and livestock.

Abstract: The correct estimation of the mineral content of cassava (*Manihot esculenta)* genotypes is vital from a nutritional point of view. This study evaluated the effects of the storage root section, maturity, and sampling method on the macro- and microelements in yellow-fleshed cassava root genotypes. In total, 44 genotypes were grown in replicated field trials of 2 sets (set 25 and set 19) and were harvested at 9 and 12 months after planting. Two sampling methods, sampling with a cork borer (A = proximal, B = middle, C = distal or method 1) and sampling without a cork borer (L = Longitudinal or method 2), were used. The minerals of the samples from the two methods were determined using inductively coupled optical emission spectrometry (ICP-OES). K and Mn were the most abundant minerals, and Na, Mo, and Co were the least abundant. Genotype, method, and maturity had a strong influence on mineral concentrations. Harvesting time affected the concentration level of some macro- and microelements in cassava roots. Additionally, Ca, Mg, K, P, Mn, Cu, Ni, and Zn contents were significantly ($p < 0.05$) higher in the proximal and middle portions for method 1. K and P and Mn and B were positively correlated, but K and Na and Fe and Ni were negatively associated.

Keywords: macroelements; microelements; yellow-fleshed cassava; genotypes; storage portions; sampling method; maturity

1. Introduction

Minerals are the constituents that remain as ash after the combustion of plant and animal tissues. Minerals can be classified as primary (macro) elements, trace elements, and ultra-trace elements, and the

main elements are essential for human beings in amounts >50 mg/day. Essential macroelements, such as Na, K, Mg, P, and S, are found in cassava and can play a vital role in the human body. Trace elements are naturally occurring inorganic substances required in humans in amounts <100 mg/day. They are essential components of biological structures and have an essential effect on and play a vital role in a variety of the processes necessary for life by mediating vital biochemical reactions [1].

Still, the potential of cassava as a significant source of these elements is yet to be fully exploited. Cassava (*Manihot esculenta* Crantz) is a tuberous root that belongs to the Euphorbiaceae family. It is also known as manioc, tapioca, or yucca. Cassava is adaptable to a variety of environmental conditions and is an essential source of nutrients and energy. It is the third-largest source of carbohydrates after rice and maize [2,3]. Although cassava leaves are consumed at times for food and medicinal purposes, its tuber (the swollen root of the plant) is the standard part of the plant that is consumed widely [4]. It is argued that more than two-thirds of the total production of cassava is used as food for humans, with lesser amounts being used for animal feed and industrial purposes [5]. Cassava can be consumed either in its natural form (i.e., boiled) or in a variety of industrially or traditionally processed forms, known under various names depending on the preferences and local customs. Cassava flour is one of these products, as well as chips and starch [6]. The root flour (high-quality cassava flour, HQCF) is gaining recognition as a suitable wheat flour substitute in biscuits and the fast-food industry. It is an essential raw material in the food industry preparation of a wide array of value-added products, such as bread, cookies, confectionery, pasta, and couscous-like products, and the production of adhesives. It is also used as a thickener in foods that are not subject to rigorous processing conditions. Indeed, although cassava flour has a low nutritional value, it remains an essential food in several parts of the world, as it is less expensive than wheat and can be used to produce a variety of food products [7–9].

Both macro and trace minerals are needed for the growth and maintenance of human body structures. The human body uses minerals for the proper composition of bone and blood, as well as the maintenance of normal cell function. Thus, diets rich in minerals are essential for proper growth and development. Further, as reported, essential macroelements, such as Ca, K, Mg, and P, which are found in cassava roots, play a vital role in the human body [10]. Ca, for example, is responsible for several metabolic functions, such as blood coagulation, muscle contraction regulation, hormone secretion, and neurotransmission. Mg is a macroelement that participates in energy metabolism and is involved in protein synthesis. Daily intake of sodium averages from 2.5 g (females) to 3.3 g (males); the adult average requirement ranges from 1.3 to 1.6 g/day (equal to 3.3–4.0 g/day NaCl). The intake of too little or too much sodium can result in severe disorders. From a nutritional standpoint, only the excessive consumption of sodium is of importance because it can lead to hypertension. A low intake of sodium can be achieved by a non-salty diet or by using diet salt [11].

Likewise, trace elements also have several important roles in human bodies. Some are essential for enzyme reactions, where they attract and facilitate the conversion of substrate molecules to specific end-products. Moreover, some of them donate or accept electrons in redox reactions that are of primary importance in the generation and utilization of metabolic energy. Some of them have structural roles and responsibilities for the stability of critical biological molecules. Furthermore, some trace elements have necessary actions throughout biological processes, for example, ıron (Fe), which can bind, transport, and release oxygen in the body. The established recommended daily amount (RDA) for Fe is 13.7–15.1 mg/day in children, 19.3–20.5 mg/day in men, and 17.0–18.9 mg/day in women, and for Zn, it is 8 mg/day for women and 11 mg/day for men. It is particularly vital for healthy skin and is essential for a healthy immune system and resistance to infection. Zn plays a crucial role in growth and cell division, where it is required for protein and DNA synthesis, in insulin activity, in the metabolism of the ovaries and testes, and liver function. Mn helps the body to form connective tissue, bones, blood-clotting factors, and sex hormones. It also plays a role in fat and carbohydrate metabolism, calcium absorption, and blood sugar regulation. Mn is also necessary for a healthy brain and nerve function. Co is an essential trace element for the human body, where it is a crucial constituent of

cobalamin (the scientific name of vitamin B12). It also has a substantial role in the formation of amino acids and neurotransmitters [1].

It has been reported in the literature that the mineral element contents of plants are affected by the plant cultivar, soil conditions, weather conditions during the growing season, use of fertilisers, and the stage of plant maturity at harvest [12]. However, the variability of values of macroelements reported in the literature for cassava roots has revealed discrepancies that surpass those expected from the effects of the factors above but could be due to analytic inaccuracy, especially from the sampling method used. The correct estimation of the macro- and microelement content of cassava genotypes is vital from a nutritional point of view, especially for controlling and improving mineral intake in sub-Saharan Africa. There is a scarcity of information on the spatial distribution of both macro- and microelement contents of yellow-fleshed cassava storage roots. Based on this background, the present study aimed to evaluate the spatial distribution of macro and microelements in yellow-fleshed cassava root genotypes and establish the effect of the sampling method and harvesting time on their content. The knowledge generated from this study can be used by researchers, processors, dieticians, and policymakers in programming interventions.

2. Materials and Methods

2.1. Collection of Genetic Materials

A total of 39 yellow cassava genotypes from unlimited yield trials (UYTs) with β carotene-rich storage roots (yellow-fleshed) and five white-fleshed varieties (as checks) were grown in replicated field trials at the research farm of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The 44 genotypes and varieties were planted in two sets. The set 1 trial comprised 22 genotypes with β-carotene-enriched roots and three check genotypes with white roots (30,572, TME 1, and 91/02324). The set 2 trial comprised 17 genotypes with β-carotene-enriched roots and two check varieties with white roots (30,572 and 91/02324). Through the crossbreeding of the wild-type varieties, the cassava breeders have been trying to improve the nutritional value, especially the β-carotene-enriched roots. The two sets were different from each other by the source (parent lines with different quality traits) used for the breeding crosses, which could dictate the mineral chemical properties of the genotypes. The experiments were planted during the rainy season in July and grown under rainfed conditions without the application of fertilisers or herbicides. The storage roots were harvested at 9 and 12 months after planting (MAP). Only the two middle rows were harvested per plot, and the cassava roots processed were collected from only one replication. Three plants per genotype were harvested, and six cassava roots of different sizes (large, medium, and big) were randomly selected per genotype and placed in a labelled polyethene bag and transferred to the laboratory for sample preparation for analysis.

2.2. Preparation of Samples

2.2.1. Sampling Method 1

The method reported by Maziya-Dixon et al. [13] was used for the first sampling method. In the laboratory, three storage roots of different sizes (large (900–2300 g), medium (500 to 899 g), and small (200 to 499 g)) were selected, washed thoroughly with potable water to remove dirt and sand particles, and air-dried on a clean concrete floor for about 5–10 min at atmospheric conditions. The storage roots were peeled manually using a stainless-steel knife and rinsed with deionized water. A cork borer (size 8) was used to bore through the storage roots, with the depth ranging from 4.6 to 9.7 cm, 3.8 to 7.1 cm, and 3.6 to 6.4 cm for the proximal, middle, and distal parts of the roots, respectively, and each portion was homogenized [13]. The rinsing of tubers and the sampling method guaranteed the elimination of mineral contaminants from the dirt and sand adhered to the tubers.

2.2.2. Sampling Method 2

The second sampling method was also described by Maziya-Dixon et al. [13]. A new set of the 3 storage roots of different sizes (large, medium, and small) were selected, washed thoroughly with potable water to remove dirt and adhered sand particles, and air-dried on a clean concrete floor. The storage roots were peeled manually using a stainless-steel knife, rinsed with deionized water, and cut longitudinally (from the proximal end to the distal end) into four equal parts. Two opposite sections from each root of each genotype were taken, combined, manually chopped into small pieces, and mixed thoroughly.

2.3. Determination of Macro- and Microelement Content

The samples for the determination of macro- and microelements were taken from the batch samples from the above-described two sampling methods. The samples were rinsed with deionized water, and placed in a petri dish and dried in an uncorroded conventional oven at 40 °C for 3 days. After drying, the samples were packed in labelled mineral-free paper envelopes. The macro- and microelement contents were analysed using inductively coupled optical emission spectrometry (ICP-OES) according to the validated method described by Wheal et al. [14]. A radial view Spectro Ciros CCD ICP-OES (Spectro Analytical Instruments, Kleve, Germany) was used, and all samples were digested with the closed-tube nitric acid/hydrogen peroxide digestion method as described elsewhere by Wheal et al. [14]. About 0.30 g of the dried sample was weighed to 1 mg into 50-mL screw-cap polypropylene tubes, and 2.0 mL of HNO_3 and 0.5 mL of H_2O_2 were added to initiate the sample digestion. The digestion was done at 125 °C for 120 min using 72-position DigiPrep digestion blocks (SCP Scientific, Baie D'Urf e, Quebec, Canada). The samples were made to a final volume of 25 mL with 18 MΩ.cm water. The sample flow rate was 2.0 mL/min, and the total analysis time per sample was approximately 2.5 min. The calibration curves for all elements were created from mixtures of high-purity single-element standard solutions in a 4% (*v*/*v*) HNO_3 matrix. Background correction was applied to all wavelengths, and spectral interferences were applied where required using software algorithms [14]. A drift correction solution (a mixture of all elements prepared in 4% HNO_3) was analysed every 25 samples to account for within-run variation in the flows, etc. Additionally, the blank subtraction, the drift correction, and other data processing (mass and volume adjustments) were performed offline [14]. Six different reference materials (RMs) were obtained from the US National Institute of Standards and Technology (NIST, Gaithersburg, MD, USA) and used to establish the quality of the data [14].

Each sample was run in duplicate. The macroelements identified in all the genotypes and varieties investigated were calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), phosphorus (P), and sulphur (S). The microelements identified in all the genotypes and varieties investigated were iron (Fe), manganese (Mn), boron (B), copper (Cu), molybdenum (Mo), cobalt (Co), nickel (Ni), zinc (Zn), and aluminium (Al).

2.4. Statistical Analysis

Data were subjected to analysis of variance, descriptive statistics, and Pearson correlation analysis using the Statistical Analysis System software (SAS) [15]. Means were separated using Fisher's protected least significance difference test at $p < 0.05$.

3. Results and Discussion

3.1. Macro- and Micromineral Contents of Yellow-Fleshed Cassava Roots Across Genotypes, Locations, and Sets 1 and 2

The macro- and micromineral contents of yellow-fleshed cassava root across all the genotypes and locations are presented in Table 1. The most abundant mineral in cassava storage roots was potassium (K), with concentrations ranging from 4300 to 26,000 mg/kg with an overall mean of

12,116 ± 3543.58 mg/kg for trial 1, and ranged from 6300 to 38,000 mg/kg with a mean value of 17,883.60 ± 4898.77 mg/kg for trial 2. However, the least abundant mineral was sodium (Na), with concentrations ranging from 15.68 to 2100 mg/kg with an overall mean of 228.22 ± 316.74 mg/kg for trial 1, and from 11.47 to 186.73 mg/kg with a total mean value of 39.19 ± 23.41 mg/kg for trial 2. The results also showed that trial 2 had higher concentrations of calcium (Ca), magnesium (Mg), and potassium (K) than trial 1. Still, trial 1 sets had a higher content of Na, P (phosphorous), and S (sulphur). It could be deduced that the storage roots of cassava could be a good source of these macroelements, especially potassium. Diets rich in minerals are essential for proper growth and development [11]. This result agrees with Aro et al. [16], who reported that the highest mineral content of the cassava samples studied was K (269 mg/kg), but contradicts with Bamidele et al. [17]. Among the mineral compositions of the four cassava samples they studied, Mg was the highest mineral found in all four cassava samples investigated, with values ranging between 185.1 and 321.5 mg/kg. Manano et al. [18] studied some local and improved high-yielding and cassava mosaic disease (CMD)-resistant cassava varieties grown in Uganda. The findings of this study indicated that the levels of minerals differed with the cassava variety. The cassava yellow root genotypes for both trials and 1 and 2 had very low Na, and this indicates that these genotypes could form part of a low-sodium diet. However, K regulates the osmotic pressure within the cell, and is involved in cell membrane transport and the activation of several glycolytic and respiratory enzymes. Potassium intake in a regular diet is 2–5.9 g/day. The minimum daily requirement is estimated to be 782 mg. It implies that cassava, with a high level of K and low Na, might be an ideal crop to consume to reduce hypertension, although this needs further research evidence.

The most abundant mineral in cassava storage roots was manganese (Mn), with concentrations ranging from 7.390 to 39.990 mg/kg with an overall mean of 16.511 ± 6.200 mg/kg for trial 1, and ranging from 4.540 to 42.680 mg/kg with a mean value of 13.383 ± 4.698 mg/kg for trial 2. However, the least abundant minerals were molybdenum (Mo) and cobalt (Co), with concentrations ranging from 0.600 to 0.700 mg/kg with an overall mean of 0.694 ± 0.025 and 0.675 ± 0.043 mg/kg for trial 1, and ranging from 0.600 to 3.000 mg/kg with total mean values of 0.708 ± 0.237 and 0.696 ± 0.239 mg/kg for trial 2, respectively. The results also showed that all the minerals in trial 2 had higher concentrations than trial 1, as found for macrominerals. It could be deduced that the storage roots of cassava could be a good source of these microelements, especially Mn.

3.2. Mean Squares (MS) of Macro- and Microelements of Yellow-Fleshed Cassava Root

The effects of genotypes, maturity, and method of sampling on the macro- and microelements of yellow-fleshed cassava roots are presented in Tables 2 and 3. For trial 1, the ANOVA showed that genotype, method, and genotype × maturity interaction had a strong significant ($p < 0.001$) effect on all the macrominerals studied. However, maturity had no significant effect ($p > 0.05$) on Mg, Na, K, and S. Genotype × maturity interaction had a significant effect ($p < 0.001$) on all the minerals except for Ca. Only Mg, S, and Na showed a significant difference ($p < 0.001$) for genotype × method interaction. For maturity × method interaction, only Ca and Na showed a significant difference at ($p < 0.001$). For the data set 2 trial, there was a highly significant effect ($p < 0.001$) of genotype and genotype × maturity interaction on all the macroelements. Maturity and method had no significant effect ($p < 0.05$) on Mg and Ca, respectively. Though, genotype × method interaction had a significant effect (at $p < 0.001$) only on Na; maturity × method interaction showed no significant effect ($p < 0.05$) across all the minerals investigated. Thus, for both trials 1 and 2, the independent variables (genotype and maturity) explained the variations observed for all the dependent variables (Ca, Mg, Na, K, P, and S) rather than the basic mean.

Table 1. Summary of mineral (macro and micro) contents of yellow cassava root genotypes from trial sets 1 and 2.

Statistic	Ca	Mg	Na	K	P	Su	Fe	Mn	B	Cu	Mo	Co	Ni	Zn	Al
	Parameters (mg/kg)														
Trial Set 1															
Minimum	440.0	370.0	15.7	4300.0	600.0	123.7	3.69	7.39	2	0.85	0.6	0.6	0.9	4.23	4
Maximum	2700.0	3000.0	2100.0	26,000.0	3300.0	530.0	21.91	39.99	3.8	8.49	0.7	0.7	6.08	17.31	9.6
Mean	1149.7	1184.5	228.2	12,116.0	1233.0	290.9	8.46	16.51	2.16	3.49	0.69	0.68	2.3	8.69	5.04
Standard deviation (n − 1)	455.0	405.0	316.8	3543.6	471.3	67.3	3.35	6.2	0.33	1.39	0.03	0.04	0.79	2.23	0.68
Standard error of the mean	28.8	25.6	20.0	224.1	29.8	4.3	0.24	0.44	0.02	0.1	0	0	0.06	0.16	0.05
Lower bound on mean (95%)	1093.0	1134.0	188.8	11,674.6	1174.4	282.5	7.99	15.65	2.12	3.3	0.69	0.67	2.19	8.38	4.94
Upper bound on mean (95%)	1206.3	1234.9	267.7	12,557.4	1291.8	299.3	8.92	17.38	2.21	3.68	0.7	0.68	2.41	9	5.13
Trial Set 2															
Minimum	530.0	420.0	11.5	6300.0	540.0	146.5	4.1	4.54	2	1.78	0.6	0.6	0.9	4.52	4
Maximum	5200.0	2900.0	186.7	38,000.0	2600.0	440.0	41.42	42.68	9.82	26.52	3	3	6.48	20.52	24.57
Mean	1444.7	1129.7	39.2	17,883.6	1112.9	271.1	9.52	13.38	2.52	4.8	0.71	0.7	1.96	9.66	5.29
Standard deviation (n − 1)	622.5	371.6	23.4	4898.8	344.5	65.3	4.48	4.7	0.87	2.38	0.24	0.24	0.84	3.27	2.73
Standard error of the mean	45.3	27.0	1.7	356.3	25.1	4.7	0.36	0.38	0.07	0.19	0.02	0.02	0.07	0.27	0.22
Lower bound on mean (95%)	1355.4	1076.4	35.8	17,180.7	1063.4	261.8	8.8	12.63	2.38	4.41	0.67	0.66	1.82	9.13	4.85
Upper bound on mean (95%)	1534.0	1183.0	42.6	18,586.5	1162.3	280.5	10.24	14.14	2.66	5.18	0.75	0.73	2.09	10.19	5.73

Table 2. Mean squares (MS) of macroelements of yellow-fleshed cassava root.

Source	DF	Ca	Mg	Na	K	P	S
		Parameters (mg/kg)					
Trail Set 1							
Genotype	24	1,094,636.9 ***	870,988 ***	433,588.7 ***	67,299,657.4 ***	948,782.6 ***	31,643.2 ***
Maturity	1	6,634,645.5 ***	54,562.8	245.4	1,474,560	4,725,187.6 ***	1413.6
Method	4	645,224.4 ***	1,260,184.4 ***	627,252.2 ***	14,453,8100 ***	90,8662.4 ***	10,790.2 ***
Genotype × Maturity	24	223,944.8	275,492.7 ***	139,095.4 ***	14,043,235.9 ***	545,051.5 ***	4920 ***
Genotype × Method	96	58,200.3	52,372.4 **	52,509.3 **	3,109,278.3	53,274.7	1280.4 *
Maturity × Method	4	184,934.5 ***	8869.2	109,676.5 **	6,790,460	11,3824.6	521.2
Error	96	45,495.2	33,198.6	33,832.3	2,803,823.4	57,485.7	846.7
Trial Set 2							
Genotype	18	2,069,831.8 ***	766,222.2 ***	2390.6 ***	6,9316,383.5 ***	418,518.3 ***	22,729.8 ***
Maturity	1	8,586,896 ***	8351.6	1233.1 *	30,2441,860.2 ***	3,941,892.3 ***	86,920.9 ***
Method	4	2059,09.1	432,610.7 ***	1075.3 ***	223,459,232.4 ***	566,446.7 ***	18,305.5 ***
Genotype × Maturity	18	540,855.2 ***	223,119.8 ***	508.9 **	41,997,484.4 ***	230,692.9 ***	3301.1 ***
Genotype × Method	72	117,288.9	47,556.3	395.1 **	9,120,322.1	32,886.3	1144.7
Maturity × Method	4	108,416.7	8194.8	61.6	16,541,188.4	14,550.8	1102
Error	72	105,165.3	40982.7	230.6	8,178,619.1	27,741.9	1255.8

ns, not significant at $p > 0.05$; *, significant $p < 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

Table 3. Mean squares (MS) of microelements of yellow-fleshed cassava root.

Source	DF	Fe	Mn	B	Cu	Mo	Co	Ni	Zn	Al
		Parameters (mg/kg)								
Trial Set 1										
Clone_Name	24	22.869 ***	146.01 ***	0.216 ***	7.538 ***	0.001 ***	0.002	1.919 ***	13.665 ***	0.782
Maturity	1	483.888 ***	253.001 ***	2.859 ***	1.309	0	0	7.315 ***	0.334	0.141
Method	3	65.053 ***	64.268 *	0.127	18.985 ***	0	0.001	2.47 ***	51.981 ***	1.05
Clone_Name × Maturity	24	12.51 ***	51.154 ***	0.151 ***	2.062 ***	0.002 ***	0.003 **	1.399 ***	7.029 ***	0.419
Clone_Name × Method	72	4.075	13.67	0.048	0.596	0	0.002	0.221 *	1.543	0.336
Maturity * Method	3	12.469 *	28.784	0.131	3.044 ***	0.001	0.002	0.271	22.104 ***	0.41
Error	72	4.248	19.026	0.067	0.549	0	0.002	0.14	1.845	0.487
Trial Set 2										
Clone_Name	18	54.608 ***	89.043 ***	1.348 ***	13.281 ***	0.044	0.048	2.417 ***	41.364 ***	12.546 ***
Maturity	1	123.164 ***	78.197 ***	18.365 ***	0.869	0.036	0.026	2.717 ***	214.769 ***	33.793 **
Method	3	14.911	37.637 ***	0.208	28.696 ***	0.06	0.072	2.874 ***	65.65 ***	5.867
Clone_Name × Maturity	18	34.644 ***	35.097 ***	1.009 **	5.653	0.081	0.085	0.697 ***	7.536 ***	16.783 ***
Clone_Name × Method	54	12.511	8.671	0.504	4.184	0.053	0.051	0.361	2.703	4.786
Maturity × Method	3	8.457	9.294	0.495	4.014	0.145 *	0.134	0.98 *	9.108 *	8.092
Error	54	9.852	7.197	0.452	3.365	0.05	0.051	0.286	2.59	4.694

ns, not significant at $p > 0.05$; *, significant $p < 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

Table 4 showed the effects of genotype, maturity, and method of sampling on the microelements of yellow-fleshed cassava roots. For trial 1, the ANOVA showed that genotype, maturity, method, genotype × maturity interaction, genotype × method interaction, and maturity × method interaction had a strong significant effect ($p < 0.001$) on all the minerals investigated except Al. However, genotype × method interaction had no significant effect ($p > 0.05$) on all the minerals except for Ni. From the dataset 2 trial, the ANOVA showed that genotype, maturity, method, genotype × maturity interaction, genotype × method interaction, and maturity × method interaction had a strong significant effect ($p < 0.001$) on all the minerals investigated except Co. However, the genotype × method interaction had no significant effect ($p < 0.05$) on all the minerals investigated. The study also revealed that maturity × method interaction had a significant difference ($p < 0.001$) on Mo, Ni, and Zn. Both maturity and genotype × maturity interaction had a significant difference at ($p < 0.001$) on Fe, Mg, B, Ni, Zn, and Al. Thus, for both trials 1 and 2, the independent variables (genotype and maturity) explained the variations observed for all the dependent variables (Ca, Mg, Na, K, P, and S) than the basic mean.

3.3. Macromineral Concentrations of Yellow-Fleshed Cassava Roots by Genotype

The means of the macromineral concentrations of yellow cassava roots (trial set 1) by genotype are shown in Table 4. For trial 1, significant differences ($p < 0.05$) existed amongst the means of the macroelements for all the genotypes. However, genotypes 01/1224 (2033 mg/kg) and 01/1412 (1742.3 mg/kg) had the highest Ca concentrations among the samples investigated. The lowest Ca value (596.3 mg/kg) was found for TME1, the check variety. Genotypes 01/1368 (676.2 mg/kg) and 90/01554 (650.5 mg/kg) had the highest levels of Na in all the samples examined. However, the Na

concentrations were found to be the lowest in genotype 94/0330 (44 mg/kg). For K, considerably higher concentrations were recorded in genotype 01/1662 (20160 mg/kg). However, the lowest K values were recorded in genotype 94/3030 (8206.7 mg/kg). The highest concentrations for P were recorded in genotype 01/1335 (1993.7 mg/kg). However, the P concentration was considerably lower in the 01/1371 (813.3 mg/kg), 01/1412 (807.7 mg/kg), 01/1413 (847.7 mg/kg), and 01/1442 (801 mg/kg) genotypes.

Table 4. Means of the macromineral concentrations of yellow cassava roots (trial Set 1) by genotype.

Genotype	Ca	Mg	Na	K	P	S
	Parameters (mg/kg)					
01/1662	1369.3 cd	1081.7 defg	61.0 fg	20,160.0 a	1791.7 ab	308.7 cdef
01/1115	1090.0 defgh	1441.3 bc	316.9 cdefg	11,383.3 defg	1139.0 efgh	310.7 cdef
01/1224	2033.0 a	936.0 efgh	119.3 efg	11,050.0 efgh	989.7 gh	351.3 bc
01/1235	967.7 efghi	1551.7 b	66.9 fg	11,806.7 def	1275.7 cdefg	326.7 cde
01/1273	1423.3 bcd	1167.7 cdef	116.8 efg	16,590.0 b	1617.3 abc	275.8 fg
01/1277	1250.3 defg	1237.7 cde	658.4 ab	10,783.3 efghi	1410.0 bcdef	199.8 ij
01/1331	1128.0 defgh	1026.7 efg	200.0 cdefg	14,720.0 bc	1292.3 cdefg	270.0 fgh
01/1335	1309.0 cde	878.3 fgh	446.6 abcd	14,796.7 bc	1993.7 a	426.7 a
01/1368	830.0 hij	1410.7 bc	676.2 a	8693.3 ghi	996.3 gh	282.7 efg
01/1371	1424.3 bcd	1342.0 bcd	403.9 abcde	12,290.0 cdef	813.3 h	311.3 cdef
01/1412	1742.3 ab	1401.0 bc	131.9 efg	12,636.7 cde	807.7 h	289.9 ef
01/1413	1303.3 cdef	930.0 fgh	77.2 fg	12,303.3 cdef	847.7 h	300.3 def
01/1442	939.0 ghij	1047.0 defg	256.7 cdefg	10,556.7 efghi	801.0 h	272.7 fg
01/1610	1005.3 efghi	1941.0 a	356.8 bcdef	11,543.3 def	1252.7 cdefg	302.7 cdef
01/1646	1153.0 defgh	1347.7 bcd	61.3 fg	12,743.3 cde	1188.7 defgh	271.3 fgh
01/1649	870.0 hij	889.0 fgh	64.8 fg	13,930.0 bcd	1070.0 fgh	312.0 cdef
01/1663	947.3 fghij	1588.3 b	83.6 fg	12,966.7 cde	1152.0 efgh	377.3 b
90/01554	1629.3 bc	1418.7 bc	650.5 ab	9586.7 fghi	1317.7 cdefg	264.2 fgh
94/0006	708.7 ij	1028.0 efg	68.6 fg	12,736.7 cde	1563.7 bcd	351.7 bc
94/0330	1139.0 defgh	1419.0 bc	44.0 g	8206.7 i	1298.7 cdefg	222.8 hij
95/0379	827.0 hij	1137.7 cdef	72.5 fg	11,806.7 def	1125.3 efgh	238.3 ghi
98/2132	883.3 hij	1004.3 efgh	146.8 defg	11,513.3 defg	1503.3 bcde	273.7 fg
TME1(check)	596.3 j	776.7 gh	68.9 fg	8323.3 hi	1495.0 bcde	204.2 ij
91/02324(check)	1096.0 defgh	715.7 h	459.0 abc	11,146.7 defg	1082.0 fgh	342.3 bcd
30,572(check)	1076.3 defgh	893.7 fgh	97.1 efg	10,626.7 efghi	1002.0 gh	184.6 j

Mean values in the same column with the different letters are significantly different at $p < 0.05$. Parameters were analyzed in duplicate and expressed in mg/kg.

From the results for trial 2 in Table 5, the study showed that genotype 01/1417 (2833.3 mg/kg) had the highest Ca content of all genotypes investigated. However, genotypes 01/1181 and 01/1206 showed a significantly higher Ca content than 30,572 (check) and 91/02324 (check). Although the highest Mg content was recorded in genotype 01/1417 (1679.7 mg/kg), its concentration was found to be the lowest in genotypes 01/1231 (753.7 mg/kg) and 01/1172 (721.7 mg/kg) from all the genotypes examined. The highest levels of Na content were recorded in genotype 01/1417 (73.9 mg/kg). The study revealed that the levels of K content in genotype 01/1206 (23,000 mg/kg) were higher than the rest of the genotypes. However, genotype 99/7558 (12,680 mg/kg) had the lowest levels of all the genotypes examined. For P, the study showed the highest concentration in the Z97/0474 (12,680 mg/kg) genotype of all the samples examined. However, genotypes 99/7558 (760 mg/kg) and 01/1296 (763.7 mg/kg) had the lowest levels of P content of all the genotypes. Genotype Z97/0474 (358 mg/kg) showed the highest levels of S content of all the samples studied. From the results above, all the genotypes with significantly higher mineral concentrations than the check genotypes could be recommended for breeding purposes. However, genotypes with no significant difference or significantly lower mineral concentrations than the check genotypes could not be recommended for such purposes as breeding.

Table 5. Macromineral contents of yellow-fleshed cassava roots (trial Set 2) by genotype.

Genotype	Ca	Mg	Na	K	P	S
	Parameters (mg/kg)					
00/0028	1296.0 cdefgh	1319.3 bcde	42.8 cdef	19,180.0 abcde	1166.7 bcde	320.0 abc
01/1181	1782.0 bc	1455.7 abc	54.8 abc	17,976.7 bcdef	1173.0 bcde	263.7 cdefg
01/1206	1922.3 b	1108.7 defg	18.4 f	23,000.0 a	1290.3 abc	206.4 gh
Z97/0474	1464.3 bcdef	1465.7 ab	35.5 cdef	20,046.7 abcd	1460.7 a	358.0 a
99/2987	1416.3 bcdefg	1460.7 ab	28.8 def	19,100.0 abcde	1219.3 abc	321.2 abc
01/1404	1550.5 bcdef	1147.0 bcdefg	32.9 cdef	17,461.7 bcdef	1204.6 abc	225.5 fgh
01/1417	2833.3 a	1679.7 a	73.9 a	21,630.0 ab	892.0 fg	338.3 ab
01/1380	1069.7 fgh	1039.7 efgh	23.7 ef	19,016.7 abcde	1143.7 cdef	250.4 defgh
01/1635	1603.0 bcde	1045.3 efgh	45.0 bcde	17,506.7 bcdef	1187.0 bcde	299.3 bcd
01/1659	863.3 h	1238.0 bcdef	19.6 f	20,850.0 abc	1303.7 abc	292.7 bcd
01/1423	1151.0 efgh	857.3 gh	29.2 def	18,356.7 abcdef	930.3 defg	275.8 cdef
01/1560	1393.0 cdefg	1126.7 cdefg	34.9 cdef	15,613.3 defg	884.3 fg	219.9 fgh
99/7558	810.0 h	895.7 gh	42.7 cdef	12,680.0 g	760.0 g	225.5 fgh
01/1296	1594.0 bcdef	1430.0 abcd	48.8 bcd	19,603.3 abcd	763.7 g	227.8 fgh
01/1231	1217.3 defgh	753.7 h	39.9 cdef	16,066.7 defg	1074.7 cdef	201.9 h
01/1551	1414.3 bcdefg	952.0 fgh	68.1 ab	14,263.3 fg	924.0 efg	286.7 bcde
01/1172	914.3 gh	721.7 h	28.6 def	16,513.3 cdefg	1126.7 cdef	288.7 bcd
91/02324 (check)	1708.0 bcd	835.0 gh	53.0 abcd	16,123.3 defg	1438.0 ab	319.3 abc
30,572 (check)	1446.7 bcdef	932.3 fgh	23.8 ef	14,800.0 efg	1202.0 abcd	230.4 efgh

Mean values in the same column with the different letters are significantly different at $p < 0.05$. Parameters were analysed in duplicate and expressed in mg/kg.

From these results, it could be inferred that most of the genotypes had higher levels of mineral density than the check genotypes, and they could be advanced to the next stage in the breeding program. Additionally, there were significant differences in the macroelement concentrations among the genotypes. Most of the values obtained for the macroelements for all the genotypes compared well with what most researchers reported. Chiwona-Karltun et al. [19] reported the macroelement content of the nine cassava varieties as follows: Potassium content ranged from 6810 to 12,200 mg/kg, and sodium ranged from 1720 (Nalumino variety) to 4590 mg/kg (Bangweulu variety). Otache et al. [20] reported that the macroelements of the peel of the three cassava cultivars studied was a calcium content of 137.4 to 198.1 mg/kg), sodium of 137.0 to 142.3 mg/kg, magnesium of 128.0 to 148.1 mg/kg, and potassium of 787.2 to 1239.8 mg/kg. Besides, the authors also corroborated the finding from this study that cassava roots are rich in macroelements, especially potassium. However, the values of macroelements reported by Afoakwa et al. [21] for six varieties obtained from the Crop Research Institute of Council for Scientific and Industrial Research (CSIR) in Ghana were lower than those obtained in this study and reported. The reported calcium content ranged from 0.06 to 1.60 mg 100 g^{-1}, sodium ranged from 0.25 to 0.37 mg 100 g^{-1}, magnesium content ranged from 1.35 to 2.52 mg 100 g^{-1}, and the potassium content ranged from 0.25 to 0.36 mg 100 g^{-1}. The difference in the values could be due to the genotypic differences and the environment. This study used yellow-fleshed genotypes, but most of the authors have used white-fleshed varieties. This implies that yellow-fleshed varieties are rich in macroelements compared with white-fleshed varieties. Additionally, it was observed in this study that most of the genotypes had the lowest sodium content among the macroelements, which was not in agreement with what some authors (Aro et al. [16]; Afoakwa et al. [21]; Otache et al. [20]) reported for white-fleshed varieties. This could also be due to genetic variation in terms of yellow-fleshed versus white-fleshed varieties. However, Chavez et al. [22] and Manano et al. [17] reported sodium as the lowest macroelement in cassava roots, as found in this study, which reported a sodium content of 3.6 to 3.9 mg 100 g^{-1}.

3.4. Micromineral Concentrations of Yellow Cassava Roots by Genotype

The means of the microminerals concentrations of yellow cassava roots (Trial 1) by genotype are shown in Table 6. There were significant differences (p 0.05) on the levels of minerals that existed amongst the cassava varieties. Genotype 01/1235 (13.033 mg/kg) had the highest Fe concentration compared to the rest of the samples of cassava genotypes investigated. However, the Fe contents

were the lowest in the check genotype 91/02324 (5.637 mg/kg). On the other hand, its concentrations were significantly higher in genotypes 01/1662, 01/1412, and 01/1610 compared to those found in the check genotypes (TME, 91/02324, and 30,572). Although genotypes 01/1662 (24.414 mg/kg), 01/1273 (24.800 mg/kg), and 01/1335 (24.823 mg/kg) had the highest Mn contents, its concentration was found to be the lowest in genotypes 95/03379 (9.544 mg/kg). On the other hand, genotypes 01/1224, 01/1663, 90/01554, 98/2135, 94/0330, 01/1413, 01/1331, 01/1277, and 01/1235 showed significantly higher contents of Mn than all the check genotypes. Genotype 01/1335 (2.698 mg/kg) showed the highest levels of B as compared to the rest of the samples examined. Its concentration was also found to be significantly higher in genotypes 01/1662, 01/1273, 01/1277, 01/1331, 01/1442, 01/1649, 90/01554, and 95/0379. However, the rest of the genotypes showed the least concentrations of B. Genotype 01/1662 (5.504 mg/kg) showed the highest levels of Cu as compared to the rest of the cassava genotypes investigated. However, its contents were the lowest in genotype 01/1235 (1.745 mg/kg). On the other hand, Cu contents were found to be significantly higher in genotype 98/2132. All the genotypes had significant amounts of Co and were significantly the same with the checks. For Ni, the highest levels were recorded in genotype 01/1273 (3.449 mg/kg). However, its levels were the lowest in genotype 01/1412 (1.449 mg/kg). On the other hand, genotype 01/1335 showed significantly higher levels of Ni than what was found in the checks. Zinc (Zn) had the highest levels in genotype 01/1115 (11.523 mg/kg). The results of the study also showed that genotypes 01/1273, 01/1442, 95/0379, 01/1662, and 01/1371 had significantly higher levels of Zn than those found in check genotypes.

Table 6. Means of the micromineral concentrations of yellow cassava roots (trial set 1) by genotype.

Genotype	Fe	Mn	B	Cu	Mo	Co	Ni	Zn	Al
	Parameters (mg/kg)								
01/1662	10.799 ab	24.414 a	2.383 ab	5.504 a	0.700 a	0.700 a	2.044 efghij	9.789 abc	5.000 ab
01/1115	9.456 abcde	14.355 bcdef	2.106 b	3.519 cdefg	0.700 a	0.688 a	1.980 efghij	11.523 a	5.425 ab
01/1224	8.691 bcdef	19.011 abc	2.000 b	3.918 bcdef	0.700 a	0.663 a	2.164 defghi	7.939 bcdef	5.000 ab
01/1235	13.033 a	17.869 abcdef	2.032 b	1.745 h	0.700 a	0.688 a	1.784 ghij	7.806 bcdef	6.050 a
01/1273	9.749 abcde	24.800 a	2.449 ab	4.569 abc	0.675 ab	0.675 a	3.449 a	10.303 ab	4.750 ab
01/1277	7.016 bcdef	17.115 abcdef	2.210 ab	2.268 gh	0.700 a	0.688 a	2.994 abc	7.743 bcdef	5.000 ab
01/1331	6.654 def	17.208 abcdef	2.230 ab	3.553 cdefg	0.700 a	0.663 a	2.205 defghi	7.956 bcdef	5.363 ab
01/1335	7.140 bcdef	24.823 a	2.698 a	2.811 efgh	0.662 b	0.663 a	3.119 ab	9.230 abcd	4.625 b
01/1368	7.965 bcdef	10.376 def	2.000 b	3.069 defgh	0.675 ab	0.650 a	2.065 efghij	8.826 bcde	4.750 ab
01/1371	6.878 cdef	13.600 bcdef	2.103 b	3.873 bcdef	0.700 a	0.663 a	2.654 bcde	9.909 abc	5.000 ab
01/1412	10.256 abcd	15.101 bcdef	2.178 b	2.369 gh	0.700 a	0.688 a	1.425 j	10.010 abc	5.200 ab
01/1413	9.819 abcde	17.761 abcdef	2.089 b	3.350 cdefg	0.700 a	0.675 a	2.566 bcdef	9.228 abcd	5.000 ab
01/1442	8.898 abcdef	13.846 bcdef	2.380 ab	4.175 abcde	0.704 a	0.678 a	1.802 ghij	10.214 ab	5.012 ab
01/1610	10.706 abc	15.574 bcdef	2.115 b	3.360 cdefg	0.675 ab	0.650 a	2.409 bcdefgh	9.366 abcd	4.750 ab
01/1646	7.806 bcdef	15.798 bcdef	2.139 b	2.891 efgh	0.700 a	0.688 a	1.918 fghij	8.308 bcdef	5.000 ab
01/1649	8.543 bcdef	13.376 bcdef	2.228 ab	2.876 efgh	0.700 a	0.663 a	2.360 cdefgh	8.189 bcdef	5.000 ab
01/1663	9.433 abcde	21.625 ab	2.105 b	4.660 abc	0.700 a	0.688 a	2.138 efghij	7.140 def	5.575 ab
90/01554	8.465 bcdef	19.046 abc	2.259 ab	2.531 fgh	0.700 a	0.675 a	2.480 bcdefg	7.573 cdef	5.000 ab
94/0006	7.888 bcdef	9.726 ef	2.071 b	4.589 abc	0.663 b	0.638 a	2.576 bcdef	8.838 bcde	4.500 b
94/0330	7.353 bcdef	17.950 abcde	2.050 b	2.339 gh	0.700 a	0.700 a	2.653 bcde	9.411 abcd	5.000 ab
95/0379	7.800 bcdef	9.544 f	2.218 ab	4.443 abcd	0.700 a	0.675 a	2.296 cdefgh	10.238 ab	5.000 ab
98/2132	7.971 bcdef	18.186 abcd	2.088 b	5.053 ab	0.700 a	0.675 a	2.854 abcd	9.194 abcd	5.000 ab
TME1(check)	7.761 bcdef	14.791 bcdef	2.000 b	2.606 fgh	0.700 a	0.688 a	1.551 ij	5.933 f	5.025 ab
91/02324(check)	5.637 f	13.356 bcdef	2.007 b	4.158 abcde	0.700 a	0.676 a	1.708 hij	7.710 bcdef	4.999 ab
30572(check)	6.116 ef	12.750 cdef	2.000 b	3.005 efgh	0.688 ab	0.688 a	2.165 defghi	6.345 ef	4.875 ab

Mean values in the same column with different letters are significantly different at $p < 0.05$. Parameters were analysed in duplicate and expressed in mg/kg.

The means of the micromineral concentrations of yellow cassava roots (Trial 2) by genotype are shown in Table 7. There were significant differences in the microelement concentrations among the genotypes. Genotype 00/0028 (14.851 mg/kg) had the highest Fe concentration as compared to the rest of the cassava genotypes investigated. However, the Fe contents were found to be the lowest in the check genotype 91/02324 (5.539 mg/kg). Additionally, genotype 00/0028 (21.261 mg/kg) had the highest Mn content, while its concentration was found to be the lowest in genotypes 99/7558 (8.850 mg/kg) and 01/1172 (8.563 mg/kg). The study also revealed that genotypes 00/0028 (3.418 mg/kg) and 01/1181 (3.366 mg/kg) had the highest contents of B than the rest of the genotypes examined. However, its lowest concentrations were recorded in genotypes 01/1423 (2.105 mg/kg), 99/7558 (2.114 mg/kg),

01/1231 (2.106 mg/kg), 01/1551 (2.106 mg/kg), and check 91/0232 (2.107 mg/kg). For Cu, the highest concentrations were recorded in the check genotype 30,572 (8.131 mg/kg). However, its contents were the lowest in genotypes 01/1296 (3.061 mg/kg) and 01/1172 (3.326 mg/kg). All the genotypes recorded significant contents of both Mo and Co and were significantly the same with the checks. Nickel (Ni) had the highest concentration in genotype 00/0028 (3.325 mg/kg). All the genotypes showed significantly higher levels of the mineral concentration than the check genotypes, which are white-fleshed. Thus, the yellow-fleshed roots are richer in minerals than the white-fleshed roots. Besides, the genotypes that showed higher levels of mineral density than the check genotypes could be advanced to the next stage in the breeding program. Most of the values obtained for the microelements for all the genotypes compared well with what most researchers reported. Burns et al. [23] found that the concentrations of iron in tubers from all cultivars studied (range from 8–24 mg/kg) were at the low end of the published range for cassava (3−140 mg/kg). In contrast, the range of tuber zinc concentrations, 8−19 mg/kg, straddled the published standard for cassava of 14 mg/kg [23].

Table 7. Micromineral content of yellow cassava roots (trial set 2) by genotype.

Genotype	Fe	Mn	B	Cu	Mo	Co	Ni	Zn	Al
	Parameters (mg/kg)								
00/0028	14.851 a	21.261 a	3.418 a	5.040 abc	0.837 a	0.812 a	3.325 a	10.736 bcd	5.375 b
01/1181	14.465 ab	14.576 cde	3.366 a	4.666 bc	0.912 a	0.912 a	2.003 bcde	10.013 bcde	7.281 ab
01/1206	8.683 bcde	19.555 ab	2.979 ab	4.601 bc	0.775 a	0.775 a	1.436 de	16.036 a	5.852 ab
Z97/0474	10.116 abcde	15.940 bc	2.674 ab	6.732 ab	0.675 a	0.675 a	2.511 abc	11.971 b	4.750 b
99/2987	11.505 abcd	15.133 bcde	2.585 ab	5.636 abc	0.750 a	0.750 a	1.978 bcde	9.999 bcde	5.375 b
01/1404	7.343 de	15.118 bcde	2.831 ab	5.012 abc	0.751 a	0.750 a	1.674 cde	9.661 bcdefg	5.711 ab
01/1417	9.109 abcde	12.846 cdef	2.684 ab	3.929 bc	0.675 a	0.650 a	2.203 bcd	11.505 bc	4.750 b
01/1380	6.508 de	10.510 def	2.729 ab	6.186 abc	0.725 a	0.712 a	1.068 e	10.248 bcde	6.297 ab
01/1635	13.218 abc	12.000 cdef	2.265 ab	3.890 bc	0.662 a	0.662 a	2.101 bcd	7.745 efgh	4.625 b
01/1659	8.882 bcde	14.891 bcde	2.415 ab	5.274 abc	0.662 a	0.638 a	1.645 cde	9.104 bcdefgh	4.625 b
01/1423	11.038 abcde	13.353 cdef	2.105 b	4.159 bc	0.650 a	0.625 a	1.576 cde	12.009 b	4.500 b
01/1560	8.347 cde	15.453 bcd	2.230 ab	3.890 bc	0.650 a	0.650 a	2.309 bcd	7.711 efgh	4.500 b
99/7558	7.336 de	8.850 f	2.114 b	3.633 bc	0.687 a	0.675 a	2.079 bcd	7.010 fgh	4.875 b
01/1296	7.693 cde	11.360 cdef	2.363 ab	3.061 c	0.650 a	0.650 a	2.711 ab	8.170 defgh	4.500 b
01/1231	8.561 cde	11.210 cdef	2.106 b	4.373 bc	0.663 a	0.625 a	1.866 bcde	9.875 bcdef	4.500 b
01/1551	7.414 de	12.469 cdef	2.106 b	3.665 bc	0.662 a	0.650 a	1.578 cde	9.732 bcdef	4.500 b
01/1172	8.814 bcde	8.563 f	2.254 ab	3.326 c	0.625 a	0.600 a	1.370 de	6.495 h	4.250 b
91/02324 (check)	5.539 e	10.343 ef	2.107 b	5.891 abc	0.675 a	0.675 a	2.433 abc	6.744 gh	4.865 b
30572 (check)	11.376 abcd	10.841 def	2.479 ab	8.131 a	0.755 a	0.737 a	1.356 de	8.756 cdefgh	9.379 a

Mean values in the same column with different letters are significantly different at $p < 0.05$. Parameters were analysed in duplicate and expressed in mg/kg.

3.5. Effect of Maturity on the Macroelement and Microelement Contents of Yellow-Fleshed Cassava Roots

Figure 1a,b shows the concentrations of macrominerals in yellow-fleshed cassava roots by maturity (harvesting time) for both trials 1 and 2. For trial set 1, the study showed that there was a significant difference ($p < 0.05$) in the mean values for the Ca and P contents in cassava roots harvested at 9 and 12 months, respectively. However, the concentrations of Ca and P were higher in the cassava roots that were harvested at the age of 9 months than those at 12 months. Thus, harvesting time had a strong influence on the Ca and P content of cassava roots. However, there was no significant difference ($p > 0.05$) in the concentrations of Mg, Na, K, and S of cassava genotypes harvested at 9 and 12 months. For trial 2, the study showed that there was a significant difference ($p < 0.05$) between the mean concentrations of Ca, Na, K, S, and P for cassava roots harvested at 9 and 12 months. However, the Mg concentration showed no difference in the mean value for cassava roots harvested at both maturity stages. The concentration of Ca, Na, K, and P were higher in the cassava roots that were sampled at 9 months than those at 12 months except for S, which was higher in the samples that matured at 12 months. It implies that harvesting time plays a major role in the concentration level of some macroelements in cassava roots while showing no effect on some. Additionally, it was established that harvesting time showed different effects on the two trials investigated. Thus, genotype plays a key role in the degree of the effects the harvesting time had on the macroelement concentrations of cassava roots. Richardson [23] evaluated the macroelements of cassava sample materials that were

harvested at nine months after planting and reported that the values of sodium ranged from 22.3 to 34.9 mg 100 g^{-1}. In contrast, the values for potassium ranged from 817.3 to 1301.2 mg 100 g^{-1} [24]. If compared with what was obtained in this study for cassava genotypes harvested at 9 months for both trials studied, the values of potassium in this study were higher and those of sodium lower. The difference could be due to the different genetic make-up of yellow-fleshed and white-fleshed cassava roots. This further confirmed that yellow-fleshed roots contain more macroelements than the white-fleshed roots, especially K. However, the values of the macroelements obtained at 12 months for trial 2 compared well with what Chavez et al. [22] reported for cassava roots harvested at 10 to 11 months. He reported that samples had an average magnesium content of 1153 mg/kg, sodium averaged at 66.4 mg/kg, potassium averaged at 8903 mg/kg, phosphorus averaged at 1284 mg/kg, and sulphur averaged at 273 mg/kg dry weight. However, the macroelement values for trial 1 at 12 months showed higher values than what was reported in the literature [22].

Figure 1c,d shows the levels of microelements in yellow-fleshed cassava roots by maturity (harvesting time) for both trial sets 1 and 2. For trial set 1, the study showed that there was a significant difference ($p < 0.05$) in the concentration of Fe, Mn, B, and Ni at different maturity levels. For Fe, Mn, and B, higher concentrations were found in cassava roots that were harvested at 9 months. However, higher contents of Ni were recorded in cassava roots that were harvested at 12 months. The results of the study also revealed that there was no significant difference ($p > 0.05$) in the contents of Cu, Mo, Co, Zn, and Al, regardless of the maturity stage. Thus, harvesting time had a strong influence on the contents of the minerals in cassava roots. For trial set 2, the study showed that there was a significant difference ($p < 0.05$) in the concentration of Fe, Mn, B, Ni, Zn, and Al at different maturity stages. The concentrations of Fe, B, Ni, and Al were found to be higher in the cassava roots that were harvested at 9 months. However, Mn and Zn contents were higher in cassava roots that were harvested at 12 months. The study further revealed that there was no significant difference ($p > 0.05$) in the contents of Cu, Mo, and Co regardless of the maturity stage. It implies that harvesting time plays a significant role in the concentration level of some microelements in the cassava roots while showing no effect on some. Additionally, it was established that harvesting time showed different effects on the two set trials investigated. Thus, genotype plays a vital role in the degree of effects the harvesting time showed on the microelement's concentrations of cassava roots.

3.6. Effect of the Method of Sampling on the Distribution of the Macro- and Microelement Contents of Yellow-Fleshed Cassava Roots

The mean values of the Ca, Mg, Na, K, P, and S content in yellow root cassava genotypes by sampling methods—method 1 (ABC) and method 2 (L) are presented in Figure 2a,b. The table also gives information on the distribution of the macroelements from the proximal, middle, and distal parts of cassava roots. There was no significant ($p > 0.05$) difference in the mean values of all macroelements studied in the proximal and middle parts of cassava roots except S, which showed a significant ($p < 0.05$) difference. Additionally, there were significant ($p < 0.05$) differences between the mean values of all the macroelements from the distal part and that of the proximal or middle part. It implies that macroelement concentrations are evenly distributed from the proximal to middle parts, but from the middle to the distal part, they are not evenly distributed. A similar pattern was observed for K, P, and S for set trial 2. However, a slightly different pattern was observed for the mean values of Ca, Mg, and Na, where there was no significant ($p < 0.05$) difference observed for the proximal, middle, and distal sections of cassava roots. The results showed that the distribution of macroelements within the cassava is mineral dependent. It was also observed that the macroelement concentrations were lower at the distal part than the proximal or middle section. This could be due to the dilution effect because it has been established that the water distribution of cassava increases from the proximal to distal parts. However, we could conclude that the best part to sample macroelements in cassava roots should be from the proximal or middle part. The two methods were compared by averaging the values of each of the macroelements from the proximal, middle, and distal parts (method 1) and

comparing them with the values of the macroelements from the longitudinal section of the cassava roots (method 2).

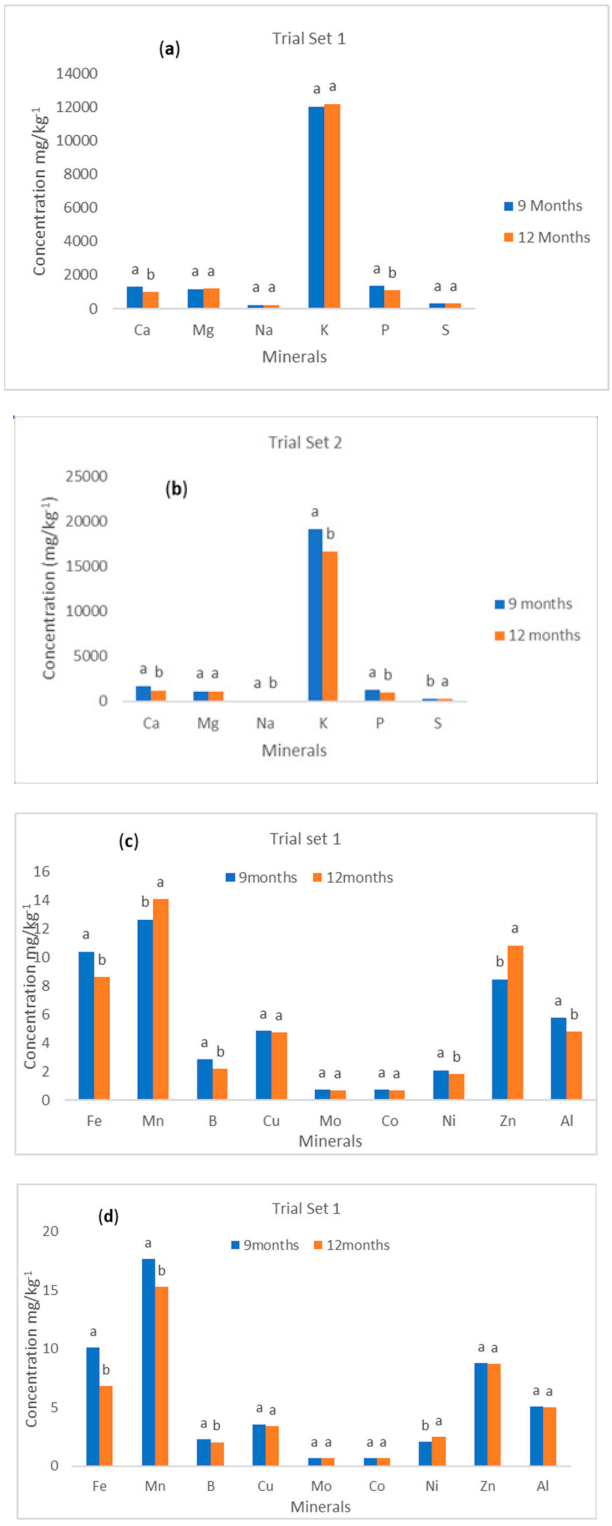

Figure 1. (**a**,**b**) Macromineral content of yellow-fleshed roots (trial sets 1 and 2) by maturity. Mean values with different letters are significantly different at $p < 0.05$. (**c**,**d**) Micromineral content of yellow-fleshed cassava roots (trial sets 1 and 2) by maturity. Mean values with different letters are significantly different at $p < 0.05$.

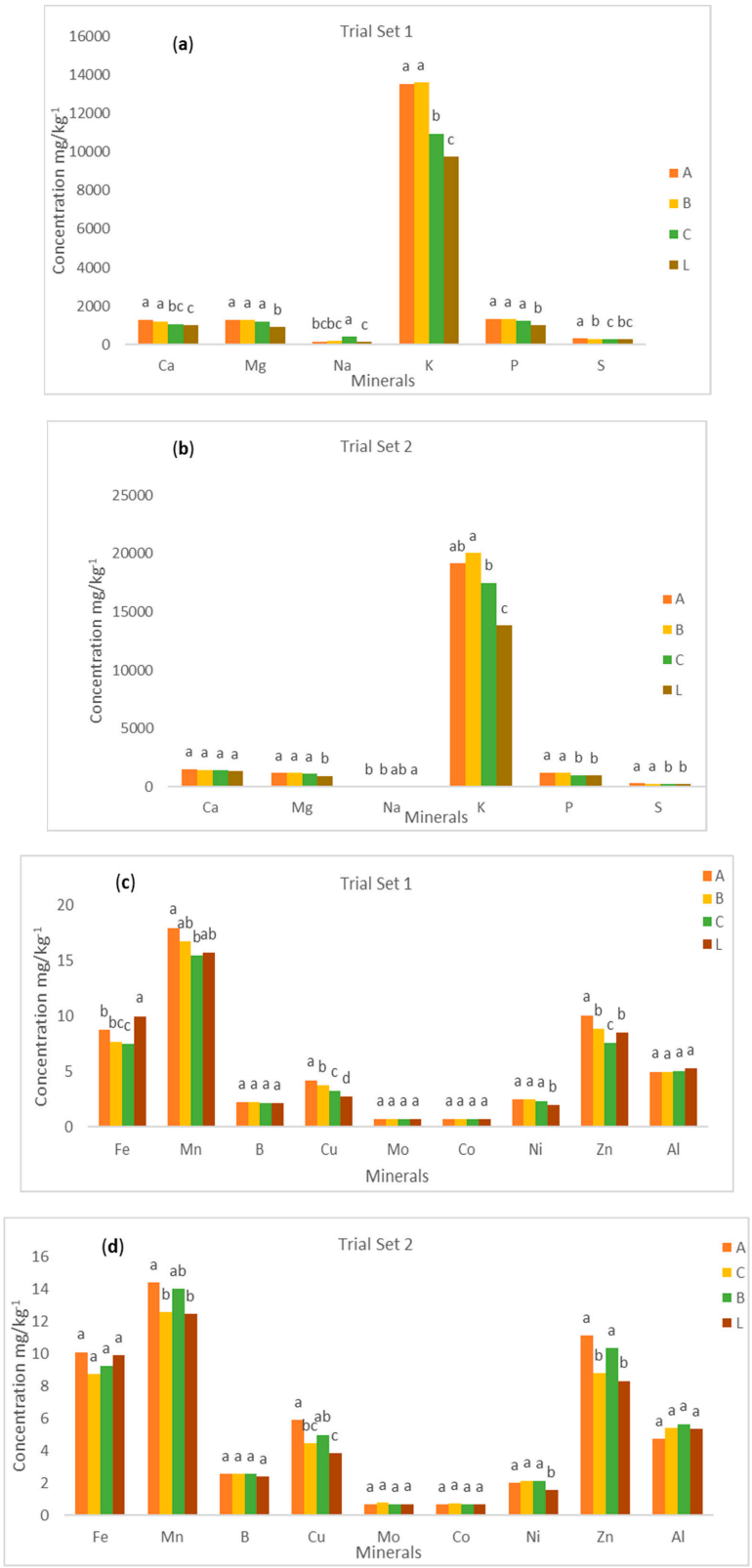

Figure 2. (**a**,**b**) Macromineral content of yellow-fleshed cassava roots (trial sets 1 and 2) by sampling methods. Mean values with different letters are significantly different at $p < 0.05$; A = Proximal; B = Middle; C = Distal; L = Longitudinal. (**c**,**d**) Micromineral content of yellow-fleshed cassava roots (trial sets 1 and 2) by sampling methods. Mean values with different letters are significantly different at $p < 0.05$; A = Proximal; B = Middle; C = Distal; L = Longitudinal.

For both trials 1 and 2, there was a significant ($p < 0.05$) difference in the mean values of all the macroelements except the Ca content of the set 2 trial. This shows that the concentration of the macroelements as a method is sampling dependent. It was observed that the mean value of all macroelements from method 1 was significantly ($p < 0.05$) higher than the mean values from method 2 for both trials 1 and 2. The levels of Ca, Mg, K, and P were significantly higher in the proximal and middle portions of the samples in method ABC (method 1) than method L (method 2). However, the levels of Na and S were far higher in the distal and proximal portions in method ABC than method L, respectively. From this result, method 1 (where samples were taken from all parts and averaged) was found to be the best, but it is not cost-effective. Method 2 could be the best alternative because it is cost-effective but not as accurate as method 1. It can be recommended that using sampling method 1 to determine Ca, Mg, Na, K, P, and S contents in yellow root cassava is better than using method 2 as it gives a far higher value of the mineral content. For set trial 1, the study showed that there was a significant ($p < 0.05$) difference in the mean values of macroelements. The levels of Ca, Mg, K, and P were significantly higher in the proximal and middle portions of the samples in method ABC than method L. However, the levels of Na and S were far higher in the distal and proximal portions in method ABC than method L, respectively. From this result, it can be recommended that using sampling method ABC to extract Ca, Mg, Na, K, P, and S contents in yellow root cassava is better than using method L as it gives a far higher value of the mineral content. This result was similar to Maziya-Dixon et al. [13]. They observed that the mean cis- and trans-beta-carotene contents were generally highest in the proximal end and lowest in the distal end of yellow-fleshed cassava storage roots. However, they reported that there was no significant difference ($p > 0.05$) between the two methods (the sectional and longitudinal) for the cis- and trans-beta-carotene content. The contrary results indicate that micronutrients are sampling dependent. The sampling method for minerals could be different for carotenes.

The mean values of Fe, Mn, B, Cu, Mo, Co, Ni, Zn, and Al contents in yellow root cassava genotypes by sampling methods—method 1 (ABC) and method 2 (L)—are presented in Figure 2c,d. The figure also gives information on the distribution of the microelements from the proximal, middle, and distal parts of cassava roots. From trial set 1, there was a significant difference ($p < 0.05$) in the mean values of Fe, Mn, Cu, and Zn elements in all the three sections (proximal, middle, and distal) of cassava root. A similar pattern was observed for Mn, and Cu in the trial set 2. The mean values for Zn showed a significant difference in the proximal and middle parts only. This result implies that the concentrations of these microelements are not evenly distributed from the proximal to the distal part of the cassava root. However, the study showed that there was no significant difference ($p > 0.05$) in the mean values of B, Mo, Co, Ni, and Al elements in the three sections of cassava root. Similarly, the mean values for Fe, B, Mo, Co, Ni, and Al did not show any significant difference ($p > 0.05$) in all three sections in the trial set 2. Further, the study revealed that there was no significant difference ($p > 0.05$) in the mean values of all microelements in the proximal part of the cassava root. It implies that the concentrations of Fe, B, Mo, Co, Ni, and Al are evenly distributed across the three cassava root sections that were studied.

The results showed that the distribution of microelements in the cassava root is mineral dependent. It was also observed that the microelement concentrations were lower in the distal part than the proximal or middle section. This could be due to the dilution effect because it has been established that the water distribution of cassava increases from the proximal to the distal part. However, we could conclude that the best part to sample microelements in cassava roots from is the proximal or middle part. The two sampling methods were compared by averaging the values of each of the microelements from the proximal, middle, and distal parts (method 1) and comparing them with the values of the microelements from the longitudinal section of the cassava roots (method 2). For both trial 1 and 2, there was a significant ($p < 0.05$) difference in the mean values of all the microelements except the B, Mo, Co, and Al content of trial set 1. Additionally, there was a significant difference ($p < 0.05$) in the mean values for all the microelements except for Fe, B, Mo, Co, and Al in the trial set 2. This shows

that the concentration of microelements in a method that is sampling dependent. It was observed that the mean value of all microelements from method 1 was significantly ($p < 0.05$) higher than the mean values from method 2 for both trial set 1 and 2. The levels of Mn, Cu, Ni, and Zn were found to be significantly higher in the proximal portions of the samples in method ABC (method 1) than method L (method 2). However, the study showed that Fe had far higher levels in method L (method 2) than method ABC (method 1) in the trial set 1.

Further, the results of the study revealed that the B, Mo, Co, and Al contents did not show any significant difference ($p > 0.05$) between the two sampling methods. For trial set 2, the contents of Mn, Cu, Ni, and Zn were found to be significantly higher in the proximal portions of the samples investigated in method ABC (method 1) than in method L (method 2). However, the study revealed that the levels of Fe, B, Mo, Co, and Al did not show any significant difference in the two sampling methods. As a result, any of the two methods could be used for the extraction of these microelements. It can also be recommended that using sampling method ABC (method 1) for extraction of Mn, Cu, Ni, and Zn contents in cassava roots is better than using method L (method 2).

3.7. Pearson Correlation Coefficients of Macro- and Micromineral Contents of Yellow-Fleshed Cassava Roots

The Pearson correlation coefficients of the macromineral content in yellow root cassava samples investigated are presented in Table 8. From the dataset of trial 1, there was a significant positive ($p < 0.001$) correlation between the K and P content (r = 0.513). This correlation shows the possibility of breeding yellow root cassava varieties with high K and P mineral contents. However, the results showed that there was a significant negative ($p < 0.05$) correlation between the Na and K content (r = −0.271). Further, a significant ($p < 0.05$) but weak correlation was observed between the P and Mg content (r = −0.062), P and Na content (r = −0.073), and S and Na content (r = −0.67). From the dataset of trial 2, the results showed a significant positive ($p < 0.001$) correlation between the Ca and Mg content (r = 0.605), Ca and K content (r = 0.502), Mg and K content (r = 0.606), and K and P content (r = 0.636). However, the study showed a significant negative ($p < 0.05$) correlation between the K and Na content (r = −0.126), and a significant ($p < 0.05$) but weak correlation between P and Na (r = −0.052).

Table 8. Pearson correlation coefficients of the macromineral contents of yellow cassava roots (dataset 1 and 2).

Variables	Ca	Mg	Na	K	P	S
Trial set 1						
Ca	1.00 ***					
Mg	0.291 ***	1.00 ***				
Na	0.099	0.193 ***	1.00 ***			
K	0.274 ***	0.074	–0.271 ***	1.00 ***		
P	0.14 *	–0.062	–0.073	0.513 ***	1.00 ***	
S	0.17 ***	0.024	–0.067	0.397 ***	0.276 ***	1.00 ***
Variables	**Na**	**Ca**	**Mg**	**K**	**P**	**S**
Trial set 2						
Na	1.00 ***					
Ca	0.341 ***	1.00 ***				
Mg	0.214 ***	0.605 ***	1.00 ***			
K	–0.126	0.502 ***	0.606 ***	1.00 ***		
P	–0.052	0.343 ***	0.306 ***	0.636 ***	1.00 ***	
S	0.054	0.097	0.382 ***	0.23 ***	0.216 ***	1.00 ***

ns, not significant at $p < 0.05$; *, significant $p < 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

The Pearson correlation coefficients of the micromineral contents in the yellow root cassava samples investigated are presented in Table 9. From the data set 1 trial, there was a significant positive ($p < 0.001$) correlation between the Mn and B contents (r = 0.539). This correlation shows the possibility of breeding yellow root cassava varieties with high Mn and B mineral contents. However, the results

of the study also showed that there was a significant negative ($p < 0.05$) correlation between the Fe and Ni contents (r = −0.22), and Al and Ni contents (r = −0.228). Further, a significant ($p < 0.05$) but a weak correlation was observed between the B and Mo contents (r = −0.161), Cu and Al contents (r = −0.186), as well as the Zn and Al contents (r = −0.141).

Table 9. Pearson correlation coefficients of the micromineral contents of yellow cassava roots (dataset 1 and 2).

Variables	Fe	Mn	B	Cu	Mo	Co	Ni	Zn	Al
Trial set 1									
Fe	1.00 ***	0.391 ***	0.345 ***	0.056	0.026	−0.029	−0.22 ***	0.178 **	0.425 ***
Mn	0.392 ***	1.00 ***	0.539 ***	0.184 ***	−0.053	0.05	0.16 *	0.322 ***	0.042
B	0.345 ***	0.539 ***	1.00 ***	0.22 ***	−0.161 ***	−0.112	0.001	0.297 ***	−0.084
Cu	0.056	0.184 ***	0.22 ***	1.00 ***	−0.071	−0.032	0.316 ***	0.377 ***	−0.186 ***
Mo	0.026	−0.052	−0.161 *	−0.071	1.00 ***	0.457 ***	−0.063	−0.084	0.401 ***
Co	−0.029	0.05	−0.112	−0.032	0.457 ***	1.00 ***	0.066	−0.036	0.183 **
Ni	−0.22 ***	0.16 *	0.001	0.316 ***	−0.063	0.066	1.00 ***	0.189 ***	−0.228 ***
Zn	0.178 **	0.322 ***	0.297 ***	0.377 ***	−0.084	−0.036	0.189 ***	1.00 ***	−0.141 *
Al	0.424 ***	0.042	−0.084	−0.186 ***	0.401 ***	0.183 **	−0.228 ***	−0.141 *	1.00 ***
Trial set 2									
Fe	1.00 ***	0.419 ***	0.663 ***	0.341 ***	0.64 ***	0.625 ***	0.389 ***	0.229 ***	0.536 ***
Mn	0.419 ***	1.00 ***	0.434 ***	0.246 ***	0.431 ***	0.446 ***	0.262 ***	0.618 ***	0.177 *
B	0.663 ***	0.434 ***	1.00 ***	0.32 ***	0.789 ***	0.783 ***	0.363 ***	0.249 ***	0.532 ***
Cu	0.341 ***	0.246 ***	0.32 ***	1.00 ***	0.256 ***	0.266 ***	0.142	0.26 ***	0.183 *
Mo	0.64 ***	0.431 ***	0.789 ***	0.256 ***	1.00 ***	0.991 ***	0.27 ***	0.27 ***	0.603 ***
Co	0.625 ***	0.446 ***	0.783 ***	0.266 ***	0.991 ***	1.00 ***	0.27 ***	0.283 ***	0.604 ***
Ni	0.389 ***	0.262 ***	0.363 ***	0.142	0.27 ***	0.27 ***	1.00 ***	0.052	0.089
Zn	0.229 ***	0.618 ***	0.249 ***	0.26 ***	0.27 ***	0.283 ***	0.052	1.00 ***	0.069
Al	0.536 ***	0.177 *	0.532 ***	0.183 *	0.603 ***	0.604 ***	0.089	0.069	1.00 ***

ns, not significant at $p < 0.05$; *, significant $p < 0.05$; **, significant at $p < 0.01$; ***, significant at $p < 0.001$.

From the data set 2 trial, the results of the study showed a significant positive ($p < 0.001$) correlation between the Mo and Co contents (r = 0.991), B and Mo contents (r = 0.789), B and Co contents (r = 0.783), Fe and B contents (r = 0.663), Mn and Zn contents (r = 0.618), Fe and Co contents (r = 0.625), Co and Al contents (r = 0.604), Mo and Al contents (r = 0.603), Fe and Al contents (r = 0.536), and B and Al contents (r = 0.532). However, the study also showed that there was no correlation between the Al and Ni (r = 0.089), Al and Zn (r = 0.069), and Ni and Cu (r = 0.142) contents.

The observed strong positive correlation shows that those minerals could be bred together to increase their concentrations in yellow cassava roots. However, those minerals with a negative and significant correlation could be difficult to improve together in the breeding program as one will increase, and the other will decrease. Curiously, both for macro- and microminerals, r values >0.5 and lower *p*-values were found for set 2 than set 1, and the levels of minerals were higher than set 1.

4. Conclusions

The most abundant macromineral in cassava storage roots was found to be potassium (K), and the lowest was sodium (Na). It implies that cassava, with a high level of K and low Na, might be an ideal crop to consume to reduce hypertension, although this needs further clinical evidence. The most abundant microelement was manganese (Mn), and the least abundant microelements were molybdenum (Mo) and cobalt (Co). The genotype and method had a strong influence on the concentrations of the macro- and microelements in yellow-fleshed cassava roots. Most of the genotypes had higher levels of mineral density than the check varieties, which are white-fleshed, and they could be advanced to the next stage in the breeding program. Genotype 00/0028 had a high level of most of the minerals, especially Fe, Zn, Mn, and B, and could be considered to be an outstanding genotype. It could be concluded that harvesting time plays a significant role in the concentration level of some macro- and microelements in cassava roots while showing no effect on some. However, it was confirmed that yellow-fleshed roots contained more macro- and microelements than the white-fleshed roots. Method 1 (where samples were taken from all the parts and averaged) was found to be the best, but it is not cost-effective.

Method 2 could be the best alternative because it is cost-effective but is not as accurate as method 1. The positively correlated elements could be bred together by breeders for improvements of the macro- and microelements in cassava roots. The quantitative and qualitative information on the distribution of macro- and microelements and their concentrations within the cassava tuber (proximal, middle, and distal root portions) would mostly benefit cassava breeders, food analysts, processors, and nutritionists. Yellow-fleshed cassava roots could be a good source of macro- and micro elements, and its potential as a functional food needs to be explored.

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