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MINERAL MICRONUTRIENT DENSITY IN LOCAL CEREALS SAMPLED FROM BUNGOMA, MASENO AND KIBWEZI AREAS

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ABSTRACT

Cereals constitute a food staple in the African bread (*Ugali*) form. Overdependence on maize as a predominant staple is partly blamed on the constricting indigenous cereal phyto-diversity. Strategies rekindling interest in their restoration remain few and disconnected. Thus, the objectives were to: (1) search for micronutrient density information among accessions of sorghum, finger millet, pearl millet and maize on the basis of 'where-they-were-as they-were' (free-call diversity); (2) determine micronutrient densities linked to eco-nutrametric variation for distinguishing differences among accessions. The accessions were collected in 2003/04 from the Bungoma-Maseno-Kibwezi (BMK) phyto-regions and subjected to Energy Dispersive X-ray Fluorescence (XRF) analysis. A nested design was used for sampling in which the cereal species were nested within sites and sites nested within phyto-regions. For each accession with its soil, a gamut of element concentrations was XRF-generated. The data were subjected to a Clustered Bar Graphing (CBG) test for identifying variation-picking element(s). By CBG test, a given element's concentration data range was placed along the X-axis upon which species/accessions' density categories along the Y-axis were graphed as series in rows giving way to density variation comparisons. Where no such density variations were visible, the element was disregarded as non-variation-picking. The CBG test revealed that all accessions were 'imperfect' in that none of them had the gamut elements (density as subject score) in-all-top or in-all-low density, i.e. none of the accessions scored high 'As' or low 'Cs' in every elemental density case. This implied that a phenotypic characterization as a whole would have required describing an accession in as different (number of) ways as the number of the variation-picking elements included. A soil-to-plant mineral flow (elemental uptake-ability or EU) was further calculated as a single value [plant ppm]/[soil] x 100. In sorghum the EUs were as follows: 2.4% for Fe (in accession tC74), 211% for Zn (in tC65), 332% for Cu (in tC36) and 408% for K in (tC70). The CBG test among the cereal accessions is invaluable for distinguishing within and between accessions in respect of their single element uptake-ability. A single nutrametric value (NMV) or grade, on the other hand, appears useful in describing a nutrametric phenotypic variant as it bypasses the genotype-environment interaction dilemma. Its robustness is its ability to distinguish various phenotypic mineral micronutrient diversity grading and offers opportunities for mineral micronutrient mapping across phyto-regions.

Key words: Micronutrients, Coarse Cereals, Nutrametric Grading

INTRODUCTION

In eastern, central and southern Africa sub-region, the maize cereal generally constitutes a predominant food staple prepared in a form generally, known as ugali. In fact, maize production in Kenya relies on the small-scale farmers who contribute about 75% of the overall production, with the remaining 25% being contributed by the large-scale farmers. A monocultural crop, therefore, has potential to displace the coarse grain agrobiodiversity as the cropping areas seem to expand in nonmaize ecologies.

The coarse grains include millets and sorghum. They are principally grown in Eastern, Nyanza and Coast Provinces, and their consumption is localized to these areas. Millets (generally nutritious high-calcium content food) occupy a wider inter-genus range as they belong to 5 genera; namely: Penissetum, Eleusine, Setaria, Panicum and Paspalum with 50% of the total millet grain production being pearl millet, 30% proso/golden and foxtail millet and 10% finger millet. There are 8 other species with little economic importance which account for only 10% of world millet production [1]. The minor millets are the most vulnerable in dropping out of agrobiodiversity as maize acreages expand to their ecologies. The challenge, therefore, is to enhance the consumption of the 'lost crops' not only at the grassroots but also nationally to a level where they can compete with maize.

Methods which rekindle interest in restoring the conservation and use of the 'lost' cereals are urgently needed. In part, taking the laboratory 'world about them' down to the grassroots is one of the methods that could effectively restore their lost traditional dietary grandeur. This can be done through forging laboratory-evidenced links across their agrobiodiversity, soil health, plant and human nutrition by way of: benefits-evidenced relationship of: (a) a cereal crop mix rather than monocrop emphasis; (b) a 3-way soil-plant-nutrients nexus potential for improving food security and nutrition [2, 3]. In terms of the foregoing, mineral content of a soil surrounding a plant has a direct influence on a plant's mineral micronutrient density as influenced by the following four natural factors: (i) the soil's physico-chemical conditions; (ii) the mineral flow dynamics across a soil-plant interface; (iii) a plant's eco-physio-genetic uptake-ability (EU) and phloem loading/offloading processes [4, 5, 6, 7, 8]; and ultimately (iv) the extent of the prevailing biodiversity spectrum [9, 10, 11]. Additionally, human land use-based interventions in the active and/or inactive areas of use on the far-house or near-house farms profoundly affect nutrient fluxes across the natural factors. In effect, as human land use changes occur, so do the nutrient fluxes and so are the magnitudes of plant mineral micronutrient inter- and intra-diversity among and within crop species. Looping all the mentioned factors (both the natural and human) into a holistic food model, could rescue local cereal genetic resources from disappearing [12, 13].

With the above in mind, a study using the Energy Dispersive X-Ray Fluorescence technique was used to: (1) search for micronutrient density information among accessions of sorghum, finger millet, pearl millet and maize on the basis of 'where-

they-were-as they-were' (free-call diversity); (2) determine micronutrient densities linked to eco-nutrametric variation for distinguishing differences among accessions.

MATERIALS AND METHODS

A nested design was used for sampling in which the cereal species were nested within sites and sites nested within phyto-regions (Figure 1). The primary level covered three phyto-regions of Kenya: the Lower Mt. Elgon in Bungoma area, the Lake region around Maseno area and the Eastern region around Kibwezi area (the BMK phyto-regional setting) from which accessions encountered were collected in 2003/04 on the basis of 'where-they-were-as they-were' for example free-call diversity. Bungoma sites (1,370 masl altitude) in the Mt. Elgon area visited lie on 0^{o} 32′ N and 34^{o} 33′ East. The collection sites have a well-distributed mean annual rainfall of 1200-1800 mm, with 500-100 mm during the long rains and 430-800 mm as short rain seasons. The area soils are deep, moderate-to-deep red, reddish-brown Ferralsols [14]. Lake Victoria Basin sites (1,463 masl) lie on 0° 38′ S and 34° 35′ E with a bimodal rainfall averaging 1,100-1,500 mm annually [14]. The Eastern region (914 masl), located on 2° 35′ S and on 32° 28′, has mostly chromic well-drained, moderately deep-to-deep red, reddish brown friable firm sandy clay-to-clay Luvisols. Annual rainfall is bimodal with 500-1300 mm average range [15].

Sampling

From each site, respective samples of the encountered germplasm (tC-Sorghum; tC-Finger millet; tC-Pearl millet and sC-Maize) and their adjoining soils were collected and replicated three times. Mature grains from plants directly growing from the fields in the various sites were picked, cleaned, and packed ready for transport. While collecting plant material, soil material was also collected from various points in the same fields, bulked and then packaged into polyethylene bags. An auger was used to collect soils at a depth of 0-30 cm.

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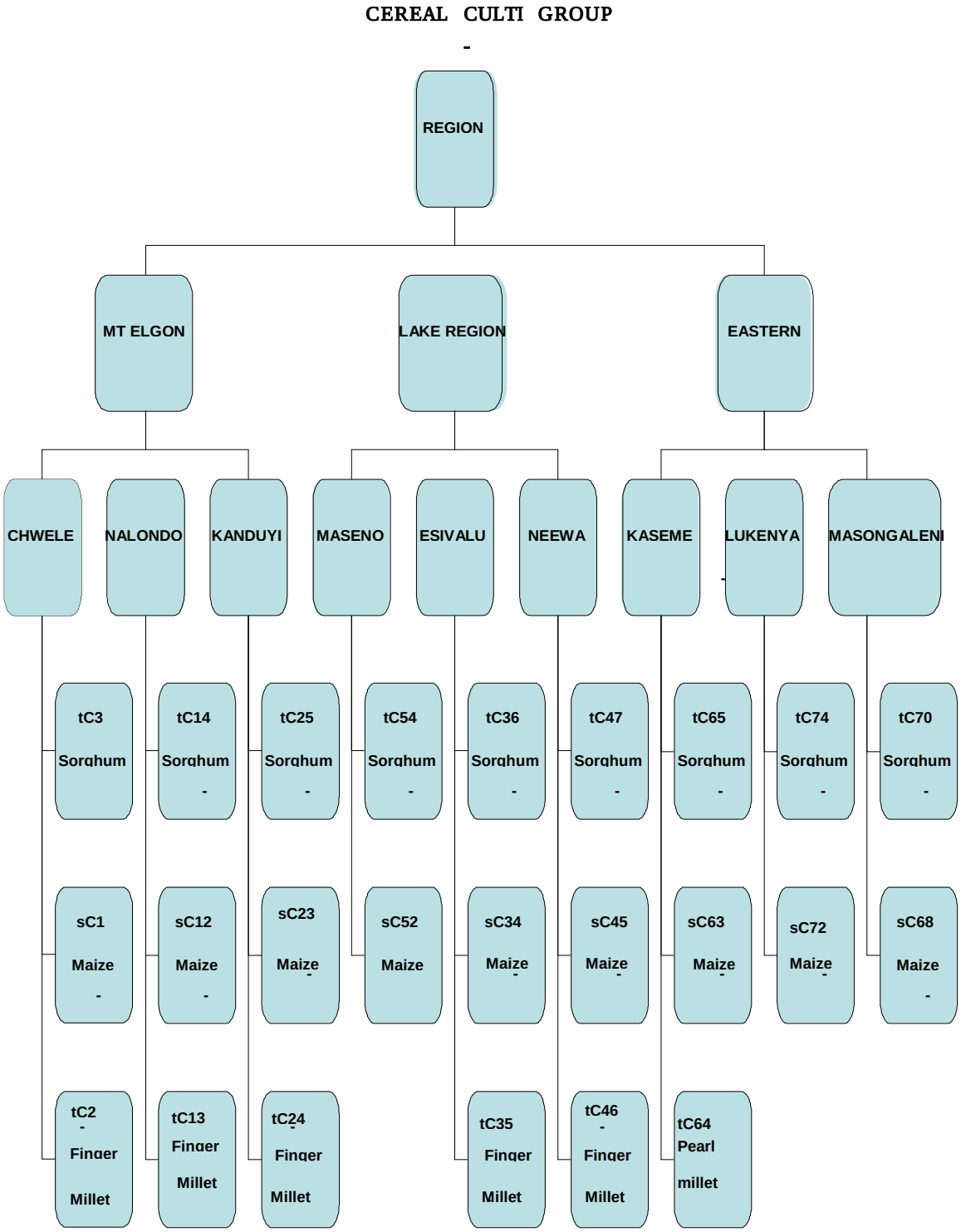

Figure 1: Germplasm sampling design

Energy Dispersive X-ray Fluorescence (XRF) Analysis

Samples were oven-dried at 80°C for 18-20 hours. Each sample was repeatedly ground to less than 50 µm sieve-size and weighed to between 100 - 200 mg cm^{-2}, from which three pellets of 2.5 cm diameter were made using a pellet-pressing machine under 10 - 15 ton of pressure. Each pellet was irradiated with a primary radiation from a Cd-109 radioactive source for a period of 2500 seconds. The characteristic x-rays emitted by the elements in the sample were detected by a liquid nitrogen cooled Si(Li) detector. The resolution of the Si (Li) detector used was 195 eV for manganese (Mn) Kα line at 5.9 keV. A computer-based multichannel analyser was used for spectral data collection and storage, while the Quantitative X- ray Analysis System (XQAS/AXIL), a software programme supplied by the International Atomic Energy Agency (IAEA), was used for data deconvolution. For each pellet, two irradiations were done; sample alone and sample with a molybdenum target on top. These two measurements were then used to calculate the absorption corrections. For each accession with its surrounding soil, a gamut of element concentrations was thus XRF- generated.

Computation of geometric means and accession scores based on mineral concentrations of samples

As a first step, data were subjected to a Clustered Bar Graphing (CBG) test so as to identify variation-picking element(s) (Figure 2). By CBG test, a given element's concentration data range was placed along the X-axis upon which species/accessions' density categories along the Y-axis were graphed as series in rows giving way to density variation comparisons. Where no such density variations were visible, the element was disregarded as non-variation-picking. Second, Analysis of Variance (ANOVA) tests were made, with each variation-picking element treated as an independent variable upon which the cereal accession density differences

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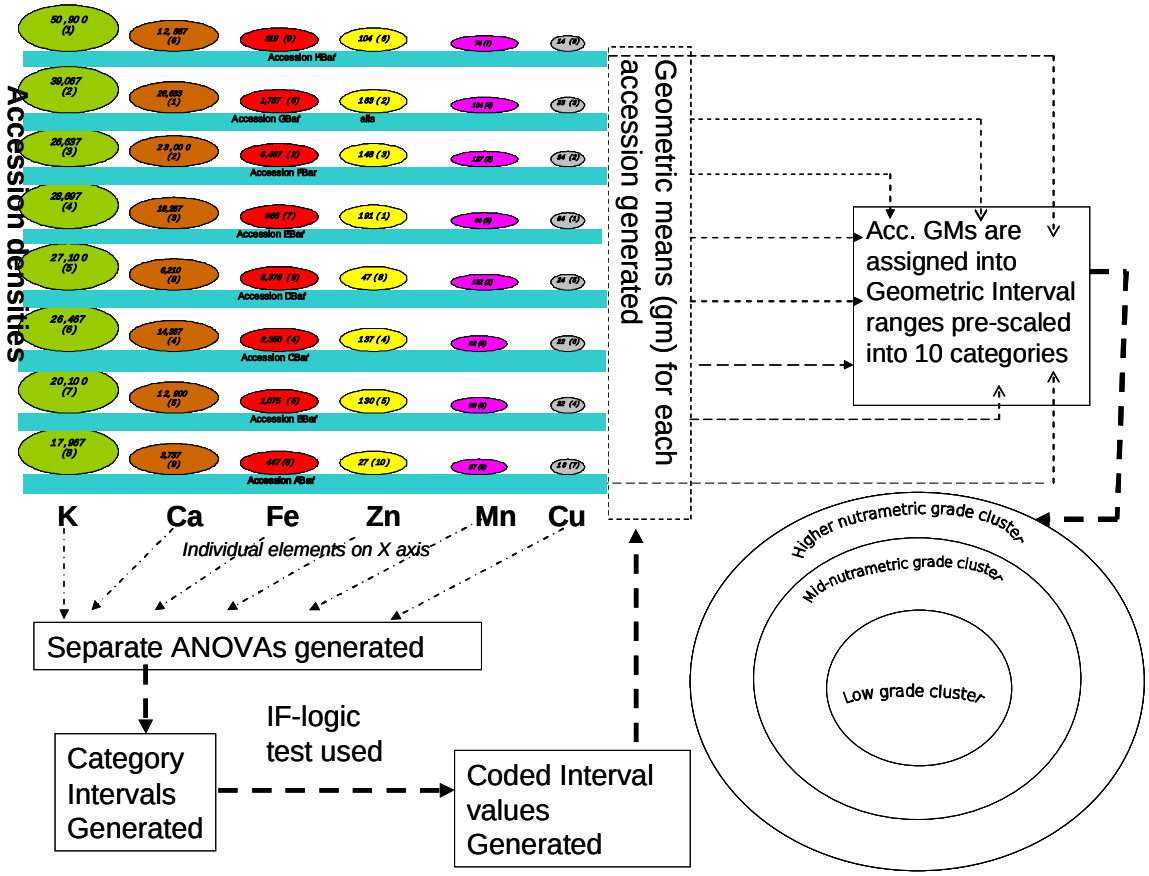

Figure 2: Steps following the Laboratory Phase for relating Various Accession concentrations (densities) to selected elements. Horizontal bars represent various accessions upon which the eyeball displays of respective concentration are stacked

depended. Third, clustering patterns of sampled material were computed according to the association principle described by Cooper and Schindler [16] in four steps as follows; 1st: the series of sampled accessions (for plants and soils, separately per site) were arranged in ascending order to obtain the range of mineral concentration values from smallest to largest concentration values for interval categorisation; 2nd: Microsoft Excel IF logic test was then used to generate **5** interval categories along the minimum-maximum range of data as arranged in step 1 in 5 categories with interval code **5** = 1000-1999 ppm; interval code **4** = 2000-2999 ppm; interval code **3** = 3000-3999 ppm; interval code **2** = 4000-4999 ppm and interval code **1**>5000 ppm); 3rd: The codes assumed the place of the actual concentration values with code **1** representing the highest density up to the lowest as **5**; 4th: Using this as a last step, exclusively developed by the Institute, the gamut with definitive variation-picking elements for each accession was subsequently collapsed into a single nutrametric valuation (NMV) or grading test via a series of the later steps shown in Figure 2.

RESULTS

Generally, significant differences ($p \leq 0.001$) among site soils were detected for each of the elements; namely, K, Ca, Fe, Cu and Zn taken one at time into ANOVA as a source of variation revealed highly significant differences ($p_{0.001}$) in content across sites (Tables 1a to 1c). Data show the typical nature of soil content heterogeneity common to soil in a place. Calcium had a 102 % Coefficient of Variation, possibly due to large minimum and maximum ranges from which means were computed. Potassium, for instance, with a soil concentration of 27,800 ppm, was highest on a soil adjoining the tC35-Finger millet collection at Esivalu. The sC34-Maize soil within the same Esivalu had only half (i.e. 13,133ppm K) of the soil content. At another place for another element, a Neewa soil adjoining tC47-Sorghum had 76,233 ppm of Fe compared with 56,200 ppm Fe on tC46-Finger millet soil. A Neewa soil adjoining sC45-Maize accession, on the other hand, had 10,667 ppm Fe within the same Neewa area. Soil manganese (8,717 ppm) was also highest in Neewa on a tC-47 sorghum but only 851ppm and 597 ppm on sC45-Maize and tC46-Finger millet soils, respectively.

Significant differences ($p \leq 0.001$) also also detected among cereal accessions' mineral micronutrient density variations for each of the variation-picking applied elements in individual ANOVA as a determinant (or source of variation). Table 2 shows that K ppm was highest in the well-known finger millet accessions (tC24, tC2 and tC53) from Chwele, Kanduyi and Maseno; respectively. A Kanduyi tC sorghum also elicited a significantly high Fe ppm relative to maize.

The CBG test revealed that all accessions were 'imperfect' in that none of them had the gamut elements in-all-top or in-all-low density; i.e. none of the accessions scored high 'As' or low 'Cs' in every elemental density case (Table 2). As an example, while a Kibwezi tC70-Sorghum accession collected from a Masongaleni site was highest in K, it was also not necessarily highest in other minerals at the same site (Figure 3). On the other hand, trace minerals indicated a consistent density pattern with Fe ppm (highest from Kanduyi in Bungoma) > Mn > Zn > Cu in that order. Sorghum manganese concentrations varied the least across the BMK transect.

For sorghum, the element uptake (EU) abilities were as follows: 2.4% for Fe (in accession tC74), 211% for Zn (in tC65), 332% for Cu (in tC36) and 408% for K (in tC70). Other EU % values are shown in Table 3.

Soil Cu significantly ($p \leq 0.05$) was correlated with leaf Cu with $r = 0.64$ as soil Fe was with leaf Fe ($r = 0.57$) (see Table 4).

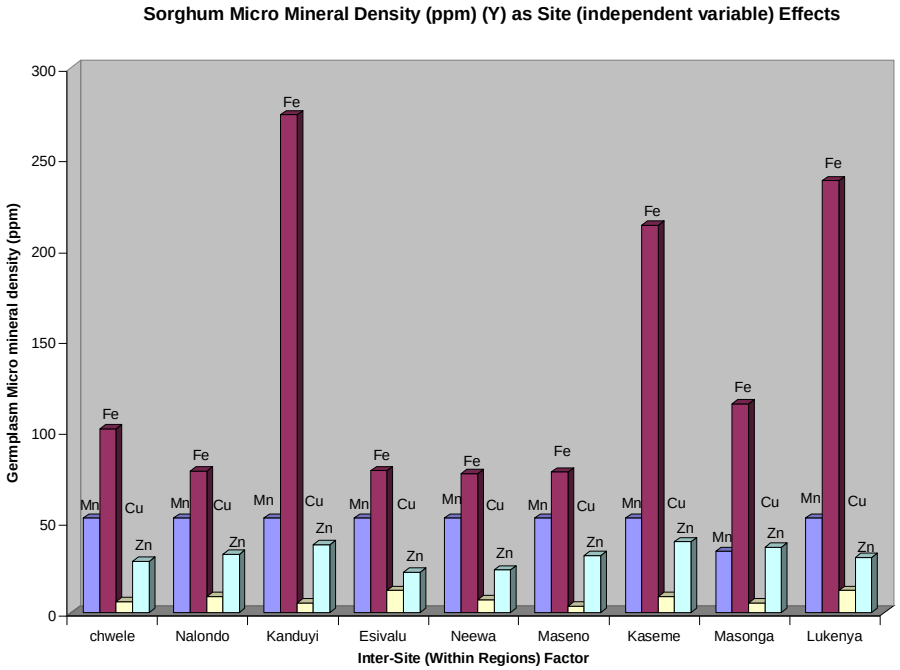

Figure 3: Trace mineral density variations in sorghum according to sites of germplasm collection

Using the nutrametric valuation (NMV) test (Figure 4), only sorghum accessions were unique in scoring within the uppermost nutrametric grade cluster (7-8) and also spreading their variation range into the lower grade orbits 6, 7, 5, 4 and 3. Fourteen others including maize and finger millet, relative to sorghum accessions, occurred in the less than uppermost orbit, and so were considered to be relatively less variable among and within one another. Data indicate that the grades obtained with the NMV test were clustered without regard to effects of BMK environment.

DISCUSSION

Soil mineral results strongly suggest a need to evaluate plant mineral micronutrient density variation closely linked to soil factors (see Tables 1a to 1c). The significant soil Fe and leaf Fe, as well as soil Cu to leaf Cu, suggests a simplistic conclusion that Fe and Cu uptake-ability in sorghum accessions and hence the concentration in the plant is a function of the amount of the mineral nutrients in the soil.

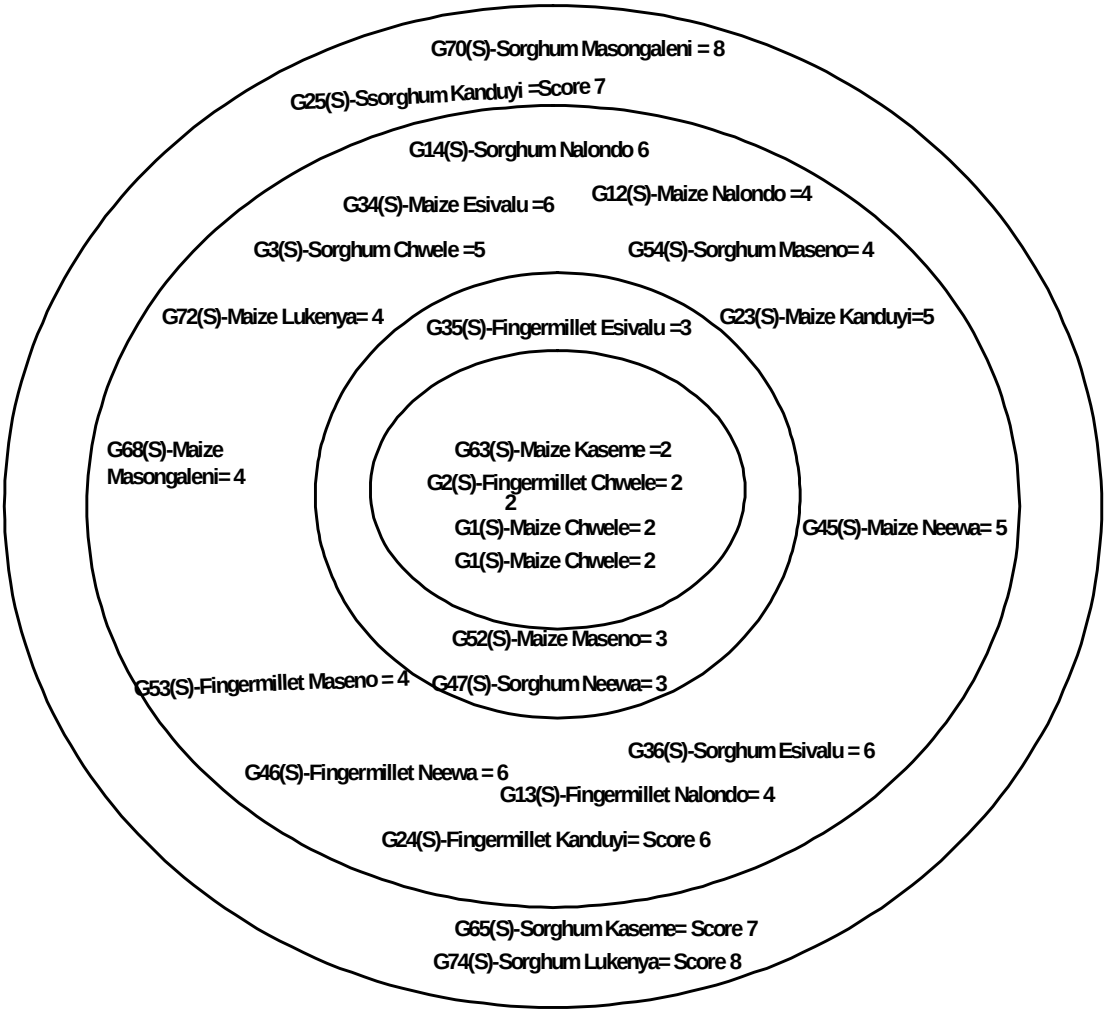

Figure 4: Nutrametric Graded layers for clustering similar phenotypic shades of mineral micronutrient density variations among 25 cereal accessions

A soil content defined by the site, or a phyto-regional eco-physio-genetic setting, thus likely accounts for mineral micronutrient density variations within the principle of a genotype-environment interaction. It is the main source of nutrients for plants, therefore, the presence of nutrients in the soil is a primary indicator of their availability. However, the total concentration of nutrients is not strongly linked to their availability [17]. This is because the soil variables that influence the sorption and desorption of nutrients are varied [18]. It is not surprising, then, that the mineral content in the soils sampled in this study are not correlated with site or region. The proportions by % reported in Table 3, however, showing the uptake-ability under specific soil conditions, may suggest a trace mineral uptake efficiency of a sort associated with water use efficiency, as is the case with sorghum. The latter uniquely elicited a high micro-element uptake % across Cu, Fe and Zn relative to other cereals.

As a part of the Water Use Efficiency dynamics, Fe uptake from soil Fe+++ form to plant Fe++ is pH dependent and may account for the uptake variations in Figure 2.

Iron, copper and zinc data for maize, sorghum and finger millet might have similar nutrient content, and therefore a displacement of coarse grains with maize in cropping systems nutritionally is of little consequence. Not quite so. The indigenous cereals have the advantage of growing in any part of the country, and more so in semi-arid areas, where they are the only ones which can withstand unpredictable rainfall patterns. Therefore, even though farmers have continued to prefer maize as a major food crop instead of finger millet and sorghum, it is time to reverse this considering that these indigenous cereals in the single mineral context are even more nutritious [1]. Considering the popularity of maize as a food crop, and in order to enable consumers to capture the best in each cereal, we need to encourage farmers not only to grow all three cereals, but also to blend them when they are preparing their foods.

In the agro-processing context, the very fact that sorghum can have the highest K in one phyto-region (as was detected in tC70-Sorghum from Masongaleni in Kibwezi of Eastern region) and Fe in tC25-Sorghum in another (from Kanduyi of Bungoma) and Zn in Pearl millet tC64 from Kibwezi points to the need for possible blending of coarse grains for milling and/or by way of promoting on-farm germplasm exchange across the BMK phyto-regions [3].

It would have been time-consuming to have addressed piecemeal the density variation among 25 accessions by a detail of the kind that has been presented. The Nutrametric Valuation (NMV) test is, however, a novel development that was robust enough to meaningfully clustering the 25 accessional into various grades irrespective of species (Figure 4).

CONCLUSIONS

1) The CBG test among the cereal accessions appears to be invaluable for distinguishing within and among accessions in respect of their single element uptake-ability in terms of the flow of mineral nutrients across the soil-plant interface.

2) A single nutrametric value (NMV) or grade, on the other hand, appears to be a prudent way of describing a nutrametric phenotypic variant objectively as it seems to bypass the genotype-environment interaction dilemma. In effect, it appears to be a robust way of distinguishing various phenotypic mineral micronutrient diversity grading and offers opportunities for its mapping across phyto-regions as the BMK.

3) Both CBG and NMV tests are complementary because they can indicate the need to maintain crop mixes to improve dietary diversity as shown by the findings.

4) Some information provided in the study suggests the need to blend cereal for food preparation to improve nutrition.

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Table 1a: Gross Mineral content of Soils within (Bungoma) sites

Code	Site	K	Ca	Fe	Mn	Cu	Zn
tC25-Sorgh soil	Kanduyi	**16,769^{c}**	2,343^{fghi}	**46,333^{d}**	684^{edf}	6^{defg}	45^{fghi}
tC24-F.millet soil		15,500^{cd}	1,972^{ghi}	**44,267^{d}**	461^{efgh}	3^{g}	41^{ghij}
sC1-Mz soil	Chwele	10,370^{fghi}	4,571^{def}	10,853^{k}	294^{fgh}	10^{bcde}	**16^{m}**
tC2-F.millet soil		10,133^{fghij}	3,820^{defgh}	**24,067^{g}**	197^{gh}	7^{defg}	41^{ghij}
tC3-Sorgh soil		9,577^{ghijk}	2,747^{fghi}	21,100^{ghi}	345^{fgh}	2^{g}	34^{hijk}
sC23-Mz soil		9,757^{ghij}	1,507^{hi}	22,900^{gh}	403^{efgh}	5^{efg}	41^{ghij}
sC12-Mz soil	Nalondo	9,165^{hijkl}	2,330^{fghi}	17,150^{hij}	**94^{h}**	6^{efg}	51^{fg}
tC14-Sorgh soil		6,553^{jklmn}	2,263^{fghi}	20,633^{ghi}	441^{efgh}	**17^{a}**	58^{ef}
tC13-F.millet soil		6,083^{klmn}	1,611^{hi}	12,367^{kj}	277^{fgh}	8^{defg}	33^{ijk}

Numbers bolded are particularly significantly ($p \leq 0.05$) different from the others in the same column.

Table 1b: Gross Mineral content of Soils within (Maseno) sites

Code	Site	K	Ca	Fe	Mn	Cu	Zn
tC46-F.millet soil	Neewa	13,500^{cd}	2,089^{ghi}	56,200^{c}	597^{defg}	4^{efg}	53^{fg}
sC45-Mz soil		10,667^{efgh}	1,507^{hi}	38,233^{e}	851de	5^{efg}	53^{fg}
tC47-Sorgh soil		5,980^{klmn}	5,797^{cd}	**76,233^{a}**	**8,717^{a}**	9^{bcdef}	**158^{b}**
tC 53-F.millet soil	Maseno	6,927^{ijklm}	3,640^{defghi}	64,467^{b}	**3,377^{b}**	2^{g}	**205^{a}**
tC54-Sorgh soil		**2,869^{n}**	2,270^{fghi}	67,000^{b}	2,667^{c}	14^{ab}	**67^{e}**
sC52-Mz soil		3,887^{mn}	**1,336^{i}**	**44,267^{d}**	2,697^{c}	14^{ab}	**81^{d}**
sC34-Mz soil	Esivalu	13,133^{defg}	2,040^{ghi}	11,400^{kj}	224^{fgh}	8^{defg}	46^{fgh}

Table 1c: Gross Mineral content of Soils within (Kibwezi) sites

Code	Site	K	Ca	Fe	Mn	Cu	Zn
tC69-F.millet soil	Masongaleni	15,933^{cd}	7,073^{bc}	23,233^{g}	228^{fgh}	**14^{a}**	24^{klm}
tC70-Sorg soil		6,607^{jklm}	3,830^{defgh}	16,033^{ijk}	300^{fgh}	14^{abc}	30^{jkl}
sC68-Maize soil		5,607^{lmn}	**9,277^{a}**	20,467^{ghi}	386^{fgh}	13^{abc}	41^{ghij}
sC72-Maize soil	Lukenya	14,233^{cde}	5,456^{cde}	10,713^{k}	170^{gh}	6^{defg}	4^{klm}
tC73-F.millet soil		13,600^{cdef}	4,583^{def}	12,067^{kj}	434^{efgh}	10^{bcde}	26^{klm}
tC74-Sorgh soil		11,500^{efgh}	4,157^{defg}	10,073^{k}	142^{gh}	8^{cdefg}	20^{klm}
tC65-Sorg soil	Kaseme	3,467^{mn}	3,203^{efghi}	9,940.00^{k}	166^{gh}	10^{bcdef}	19^{lm}
sC63-Maizez soil		5,477^{lmn}	8,353^{ab}	22,000^{gh}	411^{efgh}	12^{abcd}	48^{fg}
tC64-F.millet soil		3,673^{mn}	2,683^{fghi}	15,607^{ijk}	172.00^{gh}	7.5^{defg}	104.3^{c}

Means within columns followed by same letters are not significantly different.

Table 2: Net Tissue Mineral Density among 25 Cereal Accessions Nested within sites

	Sites	K	Fe	Cu	Zn
a) Bungoma sites within Mt Elgon Region					
tC2-Fingermillet	Chwele	8,743.3^{c}	66.1^{efghi}	5^{bc}	21.7^{jk}
tC3-Sorghum		4,103.3^{def}	101.2^{defg}	6.1^{bc}	28.4^{efghij}
sC1-Maize		2,340^{fgh}	38.8^{hi}	4.2^{bc}	28.7^{defghi}
tC24-Fingermillet	Kanduyi	8,216.7^{c}	228.3^{bc}	5.4^{bc}	26.7^{fghijk}
tC25-Sorghum		3,596.7^{defg}	**274^{b}**	5.4^{bc}	37.4^{bc}
sC23-Maize		3,293.3^{efg}	69.1^{efghi}	7.7^{abc}	35.2^{bcde}
tC13-Fingermillet	Nalondo	7,636.7^{c}	89^{efghi}	5.8^{bc}	27.6^{fghijk}
tC14-Sorghum		4,520^{de}	77.9^{efghi}	9^{ab}	32.1^{bcdefg}
sC12-Maize		2,010^{gh}	42^{ghi}	3.6^{bc}	33.9^{bcdef}
tC53-Fingermillet	Maseno	9,060^{c}	56.3^{fghi}	5^{bc}	27.6^{fghijk}
tC54-Sorghum		3,276.7^{efg}	77.5^{efghi}	3.7^{bc}	31.6^{cdefg}
sC52-Maize		2,950^{efgh}	46^{ghi}	4.6^{bc}	29.8^{defghi}
tC46-Fingermillet	Neewa	8,316.7^{c}	57.5^{fghi}	12.3^{a}	21.1^{k}
tC47-Sorghum		3,096.7^{efgh}	76.4^{efghi}	7.3^{abc}	23.6^{hijk}
sC45-Maize		3,563.3^{defg}	41.1^{hi}	8.7^{ab}	28.2^{efghij}
tC35-Fingermillet	Esivalu	5,153.3^{d}	64.3^{fghi}	6.8^{bc}	24.3^{hijk}
tC36-Sorghum		3,273.3^{efgh}	78.2^{efghi}	12.30^{a}	22.4^{jk}
sC34-Maize		1,646.7^{h}	36.1^{i}	12.3^{a}	32^{bcdefg}
tC70-Sorghum	Masongal	**26,966.7^{b}**	115^{def}	5.3^{bc}	36^{bcd}
sC68-Maize		2,596.7^{fgh}	115.2^{def}	7.1^{abc}	26.4^{ghijk}
sC72-Maize	Lukenya	3,486.7^{defg}	54.4^{ghi}	6.2^{bc}	28^{efghijk}
tC74-Sorghum		3,596.7^{defg}	237.7^{bc}	12.3^{a}	30.5^{cdefgh}
tC65-Sorghum	Kaseme	3,113.3^{efgh}	213.3^{c}	9^{ab}	39.1^{b}
sC63-Maize		2,023.3^{gh}	99.3^{defgh}	2.9^{c}	23^{ijk}

Table 3: Mineral plant content expressed as a % over the soil content from which the accession was collected indicating element uptake-ability

Accessions	Site	K % uptake fraction	Fe % uptake fraction	Cu % uptake fraction	Zn % uptake fraction
tC70-Sorghum	Masongaleni	**408**	0.7	39	119
tC25- Sorghum	Kanduyi	21	0.6	83	83
tC74- Sorghum	Lukenya	31	**2.4**	155	152
tC14- Sorghum	Nalondo	69	0.4	53	56
tC3- Sorghum	Chwele	43	0.5	292	83
tC54- Sorghum	Maseno	114	0.1	26	47
tC65- Sorghum	Kaseme	90	2.1	95	**211**
tC47- Sorghum	Neewa	52	0.1	81	15
tC36- Sorghum	Esivalu	97	0.3	**332**	55
sC68-Maize	Masongaleni	46	0.6	52	64
sC1- Maize	Chwele	23	0.4	42	183
sC63- Maize	Kaseme	37	0.5	25	48
sC12- Maize	Nalondo	22	0.2	61	67
sC34- Maize	Esivalu	13	0.3	160	70
sC52- Maize	Maseno	76	0.1	32	37
sC45- Maize	Neewa	33	0.1	170	53
sC72- Maize	Lukenya	24	0.5	95	115
sC23- Maize	Kanduyi	34	0.3	150	85
tC2-Finger millet	Chwele	86	0.3	72	53
tC46-Finger millet	Neewa	62	0.1	292	40
tC24-Finger millet	Kanduyi	53	0.5	196	65
tC13-Finger millet	Nalondo	126	0.7	77	84
tC35-Finger millet	Esivalu	19	0.2	146	46
tC53-Finger millet	Maseno	131	0.1	218	13

Table 4: Pearson Correlation Coefficients, N=57, between leaf mineral densities and Soil mineral status

	Leaf K	Leaf Ca	Leaf Mn	Leaf Fe	Leaf Cu	Leaf Zn
Leaf K		N.S	N.S	0.31 0.01	N.S.	N.S
Leaf Ca			N.S	0.46 0.0003	-0.43 0.0008	-0.37 0.005
Leaf Mn				N.S.	0.41 0.0001	N.S
Leaf Fe						-0.48 0.0002
Soil K	N.S.	0.52 <0.0001	N.S	0.44 0.0006	0.51 <0.0001	0.43 0.0009
Soil Ca	N.S	N.S	N.S	N.S	0.38 0.007	0.36 0.006
Soil Mn	N.S	-0.35 0.007	N.S	0.54 <0.0001	0.58 <0.0001	0.41 0.002
Soil Fe	N.S.	0.66 <0.0001	N.S	**0.57** **<0.0001**	**0.62** **<0.0001**	0.52 <0.0001
Soil Cu	N.S	0.39 0.003	N.S	0.50 <0.0001	**0.64** **<0.0001**	0.31 0.02
Soil Zn		N.S	N.S	0.32 0.01	0.35 0.007	0.33 0.01

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