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Research Article

Nutrient Profiling and Health Benefits of Finger Millet (*Eleusine coracana* L.) in Kenya

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Abstract

Finger millet (*Eleusine carocana* L.) is a climate resilient cereal crop considered to be nutritionally rich with higher health benefits. However, there is limited information on the nutrients in Finger millet. Further, growing public awareness on nutrition and health care research substantiates the potential of finger millets as alternative crop. The objective of this study was to determine the macro and micro-nutrient profiles of 25 local and commercial varieties and new breeding lines from Egerton University, ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), KALRO (Kenya Agricultural and Livestock Research Organization), Gene bank and local landraces. Laboratory experiment was conducted at University of Cologne Germany in 2023.Complete randomized design with 4 replications was used. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis was used to determine the concentration of nutrients. Data was analyzed using Statistical analysis software and the treatment means separated using least significant difference at p≤0.05. The results showed that the highest content of macro nutrients P (Phosphorus), K (Potasium), Mg (Magnesium), Ca (Calcium) and S (Sulfur) was 641.76, 1241.65, 402.03, 904.74 and 245.86 mg/100g for genotypes KAL ATARI, KNE 628, KAL ATARI, KAL ATARI and KNE 628, respectively. The micronutrient elements B (Boron), Mn (Manganese), Fe (Iron), Cu (Copper), Zn (Zinc), Mo (Molybdenum) and Al (Aluminium) was found to range from 0.94-1.26, 4.33-45.02, 2.69-10.43, 0.05-1.18, 2.58-10.41, 0.09-0.20, 0.12-3.85 and 0.19-0.29 mg/100g respectively. The most nutrient dense genotypes were KNE 628, KAL ATARI, KNE 628, KAL ATARI, KNE628, ICFX1420314-6-5, NKRFM1 and ICFX1420293-1-1-1-1, respectively. These genotypes recorded high levels of both macro and micronutrient elements. The study provided useful information on the potential health benefits of finger millets and the most nutritious genotypes that could be used for breeding to improve nutrient status of finger millet varieties in breeding programs.

Keywords

Finger Millet, Climate Resilient Cereal, Nutrient Dense, Inductively Coupled Plasma Mass Spectrometry (ICPMS), Breeding Programs

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1. Introduction

Finger millet is a climate resilient with high nutritional values [1]. The extraordinary nutraceutical properties, its ability to grow in arid and semi-arid lands with long storage ability makes it a major cereal crop in Eastern Africa and Southern Asia. Millets dietary fiber of 12-20% has been found to be higher than Rye 16.8%, Rice 3.5%, Oats 11.8%, Barley 14.5% and wheat 12.2% [2]. High value proteins which contain amino acids (21%) like glutamic acid [3] was found to be a precursor of y-aminobutyric acid which is important in maintaining proper neural function [4]. [5] reported that millet based value-added products boosted the functional food market due to high nutritional profile, hence the need to determine the concentrations of nutrients in the existing genotypes.

Global population of 8.1 billion depend on 60% of dietary foods like maize, wheat and rice which are vulnerable to changing climate. Non- conventional food crops like finger millet have been preferred to meet dietary gap and for genetic improvement [6]. Therefore, information on nutrient concentrations of millets on existing genotypes will be of importance to breeders and for dietary purposes. Hunger, micro-nutrient malnutrition and poor health are worldwide challenges [7]. The world population of two billion people have been reported to suffer from micronutrients deficiency of elements such as iron and zinc [8]. Deaths due to diet related diseases in low and middle-income countries was found to be up to 77% [9]. Finger millet being nutritionally dense should be consumed with knowledge of the exact quantity of nutrients a specific variety entails to solve deficiency problems.

Finger millet is an important genetic resource crop for the uncertain future [10]. The crop is nutritionally rich, adapts to adverse weather conditions and requires minimal input for production [11] it provides food security to the marginalized farmers in the arid and infertile lands of Asia and Africa [12]. Inductively coupled plasma mass spectrometry technique which contains a multi-element character, and a high sample throughput was used to determine nutrients concentration. Specific concentrations of the both the macro and the micro elements of the 25 genotypes was obtained. ICP-MS was used because of its suitability in analyzing low concentrations without large interferences [13].

2. Materials and Methods

2.1. Experimental Location and Plant Material

The laboratory experiment was conducted in 2023 at the Biozentrum of University of Cologne, (50.935173 ° N and 6.953101 ºE), Germany. The plant material consisted of seeds from 25 genotypes of finger millet which is a self-pollinated plant, advanced breeding lines where from Gene bank, Icrisat, Kalro and Egerton University. Commercial varieties where from Kalro, Egerton and Icrisat together with local landraces.

Table 1. *Genotype description of finger millet under study.*

Genotype	Source	Description
IE 2872	ICRISAT	Advanced breeding line
ICFX 1420314-6-5	ICRISAT	Advanced breeding line
ICFX 1320412-SB-5-1-4-1	ICRISAT	Advanced breeding line
ICFX 1420432-2-3-1-1	ICRISAT	Advanced breeding line
KIBOKO LOCAL/Wote local	Local	Local landrace
ICFX 1420439-12-3-1-1	ICRISAT	Advanced breeding line
ICFX 1420293-1-1-1-1	ICRISAT	Advanced breeding line
KAL ATARI	Local	Local landrace
ICFX 1420/KACIMMI 22	ICRISAT	Advanced breeding line
ICFX 1420414-2-1-1-1	ICRISAT	Advanced breeding line
U-15	KALRO	Commercial variety
Snapping purple variety	Egerton University	Commercial variety
2080 CI	ICRISAT	Advanced breeding line
Ikhulule	Local	Local landrace

Genotype	Source	Description
Kal pader	Local	Local land race
Snapping green Early P.S.A	Egerton University	Advanced breeding line
Kat FM1	KALRO	Commercial variety
GBK 027189A	Gene Bank	Advanced breeding line
P224	Kenya Seed	Commercial variety
NKRFM1	Egerton University	Commercial variety
IE 615	ICRISAT	Advanced breeding line
Kal 2 pader	Local	Local land race
KNE 741	Egerton University	Commercial variety
Kat FM1 X U-15 1.7.8.2.1	KALRO	Advanced breeding line
KNE 628	ICRISAT	Advanced breeding

Notes: ICRISAT: International Crops Research Institute for the Semi-Arid Tropics; KALRO: Kenya Agricultural and Livestock Research Organization

2.2. Experimental Design and Nutritional Traits Under Study

The experiment was conducted using Completely randomized design with 4 replications. The seeds were obtained from plants at plant maturity stage. The nitric acid digestion method as described by [74] with slight modification was used for the analysis of micronutrients (B, Fe, Mn, Zn, Cu, Mo, Al and Ni), macro nutrients (P, K, Ca, Mg and S).

2.3. Sampling and Nutrient Analysis

Finger millet seeds where then grounded into fine powder using a bead ruptor. About 10 mg of grounded millet was weighed into 15 ml digestion tubes with known weights. The final volume of digestion tubes and sample was noted. In the fume hood, 0.5 ml of 67% nitric acid was added into the tubes and left to digest overnight. The next day, the samples were placed in 95 ℃ water bath for 30 minutes together with a blank with the lids unscrewed and left loosely covering the tubes. Thereafter, the samples were left to cool down for 10-15 min. The samples were placed on ice and 4.5 ml milliQ water was added to make a final acid concentration of 5%. The total weight was then recorded to determine the dilution factor. Samples were centrifuged at 4 ℃, 4000 rpm for 30 min. Clear supernatant of about 1 ml was transferred using a pipette into a new tube for measurement using Inductively coupled plasma mass spectrometry. The measurements obtained from the ICP-MS analysis was multiplied by the dilution factor to obtain the concentrations of the elements in mg/kg.

Dilution factor= (Final weight-empty falcon weight)/sample dry weight.

2.4. Statistical Analysis

Analysis of variance was done using Statistical analysis system (SAS) version 9.4 and mean separation done using least significant difference at a probability of ($p \leq 0.05$). The standard deviation value was also calculated for all elements. The data for macro nutrients was log transformed while micronutrient data was transformed using square root before analysis. The Pearson correlation coefficients analysis was done to determine the correlation of all the elements.

3. Results and Discussions

Table 1 shows the macronutrient concentrations of twenty-five genotypes of finger millet studied. Magnesium, phosphorus, sulfur, potassium and calcium contents showed significant differences at ($P \leq 0.05$).

The magnesium content ranged from 402.04-120.57 (mg/100g) for all the genotypes studied. This is within the recommended daily amounts for adults which ranges 310 and 420 milligrams (mg) [14]. The highest value was obtained from KAL ATARI (402.04mg/100g) and the lowest value obtained from Ikhulule (120.57mg/100g). Magnesium is important for support of immune system, muscle and nerve function, regulation of blood pressure and bone health. About 60% of adults have been diagnosed with magnesium deficiency [15]). Some of the highest sources of magnesium have been found in wheat germ (276mg/100g), dried beans (158mg/100g) [16], this is lower than most of the finger millet genotypes recorded.

Phosphorus content was significantly different among the varieties at ($P \leq 0.05$). Highest content was recorded at 641.76 mg/100g in KAL ATARI and the lowest amount recorded in

Kat FM1 X U-15 1.7.8.2.1 at 240.11 mg/100g on dry matter basis. This was slightly higher to results reported by [3] who reported a range of 130-250 mg/100g in finger millet and 296mg/100g in pearl millet. The recommended amount of phosphorus per day for an adult is 700 mg [17] and millet can supply this amount by taking up to 120 grams a day.

The sulfur content ranged from 245.86-111.80 mg/100g across all the genotypes. The highest content was recorded in KNE628 while the lowest in NKRFM1. Sulfur is an essential macro nutrient and amino acids such as cysteine and methionine have also been reported to be supplied by sulfur in millets [18]). The nutrient has anti-inflammatory, antioxidant and antimicrobial properties [19]. [20] also reported that meat and cereals contributed the highest amount of sulfur 29% and 19%, respectively. The sulfur level in wheat flour was found to be 370mg/100g and rice 360mg/100g this was slightly higher as compared to finger millet. The sulfur content found was however within the range reported for foxtail millet 171 mg/100g [21].

Table 2. *Macronutrient concentration in mg/100g of finger millet.*

Genotype	Mg	P	S	K	Ca
KAL ATARI	402.03±0.02a	641.76±0.02a	232.51±0.02ab	1067.75±0.02abc	904.74±0.02a
ICFX 1420314-6-5	346.24±0.02ab	535.00±0.02b	200.52±0.02cb	856.87±0.02de	876.14±0.02a
ICFX 1420/KACIMMI 22	325.15±0.02cb	509.36±0.12bc	184.50±0.12cd	830.18±0.12def	712.32±0.02a
ICFX 1420439-12-3-1-1	291.40±0.02cd	449.50±0.02bcd	172.71±0.02cde	831.40±0.12def	654.32±0.02bc
ICFX 1420414-2-1-1-1	281.04±0.02cd	435.69±0.12cd	160.83±0.12def	895.96±0.02cde	642.28±0.02bc
KNE 628	278.52±0.02cd	452.57±0.12bcd	245.86±0.12a	1241.65±0.12a	577.74±0.12cd
IE 2872	271.39±0.02ed	413.57±0.12d	148.00±0.12efg	611.49±0.12h	734.60±0.12b
ICFX 1420293-1-1-1-1	262.07±0.02def	397.10±0.12de	145.25±0.12efgh	649.46±0.12gh	581.97±0.12cd
ICFX 1320412-SB-5-1-4-1	255.49±0.02defg	394.69±0.12de	146.48±0.12efgh	710.91±0.12fgh	580.60±0.12cd
KIBOKO/Wote local	229.22±o.02efgh	338.07±0.02efg	123.06±0.02hij	646.86±0.02gh	529.28±0.02d
Kal 2 pader	226.00±0.02fgh	390.07±0.02def	207.21±0.02abc	1097.09±0.12ab	532.65±0.02d
ICFX 1420432-2-3-1-1	216.08±0.02ghi	327.08±0.02fg	118.91±0.02ij	613.51±0.02h	516.82±0.02d
GBK 027189A	200.10±0.02hij	329.83±0.02fg	166.57±0.02def	1080.44±0.02ab	417.11±0.12ef
Snapping green Early PSA	189.05±0.02ijk	290.58±0.02gh	157.28±0.02def	801.03±0.12ef	440.42±0.02e
Kat FM1	187.79±0.02ijk	292.29±0.12gh	159.03±0.02def	821.91±0.12def	413.58±0.12ef
Kal pader	178.00±0.02jkl	284.53±0.02ghi	160.86±0.02def	963.55±0.12bcd	390.19±0.02efgh
Snapping purple variety	167.30±0.02kl,	258.28±0.12hij	129.56±0.12ghij	857.55±0.12de	422.94±0.12ef
Kat FM1 X U-15 1.7.8.2.1	160.54±0.02klm	240.11±0.02ij	130.90±0.02ghij	826.46±0.02def	382.82±0.02efgh
U-15	157.83±0.02lm	259.28h±0.02hij	142.37±0.02efgh	832.68±0.12def	432.16±0.02e
IE 615	156.90±0.02lm	254.09h±0.12hij	153.01±0.02efg	822.67±0.02def	400.06±0.12efg
KNE 741	155.30±0.02lm	238.56±0.02ij	130.97±0.02ghij	890.85±0.02cde	339.47±0.02hi
P224	154.02±0.02lm	225.78±0.02jk	116.92±0.12j	773.49±0.02efg	369.68±0.02fghi
2080 CI	146.95±0.02m	271.50±0.02hi	120.13±0.12ij	983.53±0.02bcd	396.38±0.02efgh
NKRFM1	143.98±0.02m	218.63±0.02jk	111.80±0.12j	820.87±0.02def	342.57±0.02hij
Ikhulule	120.57±0.02n	198.31±0.02k	122.39±0.02hij	636.02±0.02h	321.81±0.02i

Values are means ± standard deviation. means within a column followed by different letters are significantly different at $p \leq 0.05$.

Potassium concentration was found to range from 1241.65 to 611.49mg/100g. KNE 628 recorded the highest concentration while IE 2872 recorded the lowest. This is higher compared to foxtail millet 250mg/100g and whole wheat

284mg/100g [21]. Potassium is important for blood pressure control and may improve heart health. In maize kernel 2.4 to 5.2 mg/100g have been reported [75] and this is quite lower than finger millet. Increased potassium intake has been found to reduce urinary calcium excretion, management of kidney stones and hypercalciuria and decreased Osteoporosis [22]. Increasing potassium intake also prevents the development of diabetes that occurs with prolonged treatments of thiazide diuretics [22]. The recommended levels of potassium per day is at least 3510 mg per day [23] and it has been found that most people do not consume enough potassium. Foods fond to be rich in potassium include beans and peas which contains approximately 1300mg/100g, nuts (600 mg/100g), vegetables (550 mg/100g), fruits like bananas, dates and papayas (300mg/100g) [24]. Therefore, this makes millet to be one of the best sources of potassium.

Calcium was also found to be significantly different among the accessions at (P≤0.05). The concentrations ranged from 904.74 to 321.81mg/100g this was observed in variety KAL ATARI and Ikhulule. This is similar to reports by [25] who found a concentration of 344 mg/100g. Calcium concentrations of Teff was found to be 78.8-147 mg/100g [26]. Pearl millet 42mg/100g, proso millet 14mg/100g, Foxtail millet 31mg/100g and wheat 41mg/100g [25] Brown Rice 33mg/100g, Corn 26 mg/100g, Sorghum 25 mg/100g [27] White rice 10mg/100g [25]. This shows finger millet contains up to 30 times the amount of calcium contained by other cereals. The calcium content in millet has been reported to be three times higher than milk [28]. Finger millet is a super crop for humans [29] and researchers have suggested that its consumption will help in alleviating calcium deficiency [28].

Table 2 shows the micronutrient concentrations of twenty-five genotypes of finger millet studied. Manganese, iron, copper, zinc, molybdenum, aluminium and nickel except boron showed significant differences at (P≤0.05).

Boron did not differ significantly at (P≤0.05). The mean value was 1.06 mg/100g. Boron plays an important role in osteogenesis and its deficiency results to adverse effect on bone regeneration and development [30]. It plays a role in production and activation of steroid hormone and hence involved in prevention of calcium loss and demineralization of bones [31]. Boron also regulates sex hormones, and its supplementation result to increased sex steroids for both male and female [32, 33]. Prostate cancer was also reported to be 52% lower in males with increased boron intake of 1.8mg/day compared to 0.9mg/day [34].

Manganese is a trace mineral and a known vasodilator since it enlarges veins and hence carries blood to tissues in the brain. The concentration was found to range from 45.02 to 4.33 mg/100g, KAL ATARI recorded the highest concentration while 2080 CI recorded the lowest. The daily mean intake for manganese was reported to range 2.5 to 6.6 mg in men and 2.0 to 5.5 mg in women with most mean values around 3mg/day according to national dietary surveys of Austria [35-37]. Also, intake levels of 8 mg/day was established for adults ≥ 18 years (including lactating and pregnant women) and 2 to 7 mg/day for other population groups [38].

Therefore, finger millet can readily supply the recommended concentrations. The results obtained where like those of [3] who recorded a concentration of 17.61-48.43 mg/100g in finger millet. Manganese content of barnyard millet was observed to range from 3.13 to 3.63 mg/100g [18]. Further, a range of 17.61 mg/100g to 48.43 mg/100g was reported on improved and local varieties in Ethiopia [39], maize manganese content of 190.9-240.5 mg/100g was recorded by [40].

Iron showed significant difference at (P≤0.05). The concentrations ranged at 10.43 to 2.69 mg/100g in genotype KNE628 and Kiboko local respectively. Iron is an element important in oxygen transport, electron synthesis and deoxyribonucleic acid synthesis [41].

Table 3. *Micronutrient concentration in mg/100g of finger millet.*

Genotype	B	Mn	Fe	Cu	Zn	Mo	Al	Ni
KAL ATARI	1.15±0.53a	45.02±1.52a	6.02±0.82cb	1.18±0.12a	5.49±0.72bcde	0.19±0.12ab	0.34±0.32bc	0.28±0.12ab
ICFX 1420314-6-5	1.14±0.67a	40.84±0.42a	5.44±0.42cb	0.92±0.02a	4.62b±0.12bcdefg	0.20±0.02a	0.74±0.42bc	0.26±0.02abcd
ICFX 1420/KACIM MI 22	1.09±0.53a	42.57±1.02a	5.05±0.32bcd	0.84±0.12a	5.47±0.32bcde	0.18±0.12abc	0.27±0.12bc	0.24±0.02abcde
ICFX 1420439-12-3-1-1	1.04±0.69a	43.16±0.32a	4.27±0.22cd	0.61±0.12bcd	4.54±0.22bcdefg	0.12±0.02defghi	0.34±0.12bc	0.27±0.02abc
ICFX 1420414-2-1-1-1	1.08±0.55a	35.96±1.12ab	4.92±0.42bcd	0.62±0.12ab	4.94±0.42bcdef	0.16±0.12abcde	0.44±0.22bc	0.27±0.12abc

Genotype	B	Mn	Fe	Cu	Zn	Mo	Al	Ni
KNE 628	1.26±0.52a	21.96±0.92c	10.43a±0.62a	0.34±0.12cdef	10.41±0.62a	0.20±0.12a	0.89±0.32abc	0.24±0.12abcde
IE 2872	1.01±0.69a	11.14±0.52ef	5.07±0.42bcd	0.27±0.12efghij	5.36±0.42bcdef	0.13±0.02defgh	0.34±0.22bc	0.22±0.02bcde
ICFX 1420293-1-1-1-1	0.97±0.67a	24.36±0.62c	4.86±0.72bcd	0.64±0.12bcd	3.36±0.32efg	0.10±0.02ghij	0.77±0.42abc	0.29±0.12a
ICFX 1320412-SB-5-1-4-1	1.01±0.67a	35.11±0.62ab	3.90±0.22cd	0.53±0.12abc	3.98±0.32cdefg	0.14±0.02bcdef	0.21±0.12bc	0.25±0.02abcde
KI-BOKO/Wote Local	0.94±0.63a	28.88±0.42cb	2.69±0.12d	0.40±0.02cde	2.69±0.12g	0.10±0.02ghij	0.23±0.02bc	0.24±0.02abcde
Kal 2 pader	1.19±0.55a	12.48±0.72ef	7.95±0.42ab	0.34±0.02defg	6.88±0.42b	0.14±0.02cdefg	0.82±0.42abc	0.24±0.02abcde
ICFX 1420432-2-3-1-1	0.94±0.67a	21.49±0.32cd	2.69±0.12d	0.34±0.12cde	2.58±0.12g	0.09±0.02ij	0.12±0.12c	0.22±0.02bcde
GBK 027189A	1.06±0.63a	5.51±0.42hi	4.65±0.32cd	0.10±0.12fghijk	5.53±0.62bcde	0.13±0.02defghi	0.43±0.22bc	0.19±0.02e
Snapping green Early P.S.A	1.13±0.55a	13.43±0.52ef	4.17±0.32cd	0.11±0.02hijk	3.84±0.32cdefg	0.17±0.02abcd	0.34±0.22bc	0.20±0.02de
Kat FM1	1.03±0.69a	9.71±0.32efgh	6.68±0.22abc	0.07±0.02ijk	5.72±0.42bcd	0.11±0.02efghij	0.97±0.52abc	0.22±0.02bcde
Kal pader	1.04±0.69a	12.10±0.62ef	5.02±0.72cd	0.07±0.12ijk	4.32±0.62bcdefg	0.13±0.12defgh	0.32±0.32bc	0.21±0.02cde
Snapping purple variety	1.06±0.64a	10.38±0.42efefgh	4.89±0.42bcd	0.08±0.12k	3.39±0.32efg	0.14±0.02cdefg	0.45±0.22bc	0.24±0.02abcde
Kat FM1 X U-15 1.7.8.2.1	1.06±0.55a	9.17±0.52efgh	5.18±0.42bcd	0.15±0.02efghij	4.00±0.32cdefg	0.11±0.02fghij	1.67±1.32abc	0.24±0.12abcde
U-15	1.07±0.63a	14.50±0.32ed	5.81±0.82bc	0.29±0.02defgh	6.24b±0.72bc	0.14±0.02cdefg	0.96±0.72abc	0.28±0.12ab
IE 615	1.05±0.63a	10.22±0.32efg	4.45±0.52cd	0.14±0.02fghijk	3.70±0.32defg	0.09±0.02hij	0.40±0.12bc	0.21±0.02bcde
KNE 741	1.09±0.60a	11.24±0.22ef	5.37±0.52bc	0.11±0.02fghijk	4.41±0.22bcdefg	0.11f±0.02fghij	2.34±2.32ab	0.22±0.02bcde
P224	1.05±0.61a	8.32±0.22ghi	4.24±0.72cd	0.11±0.02fghijk	4.23±0.52cdefg	0.12±0.02efghij	0.40±0.32bc	0.24±0.02abcde
2080 CI	1.01±0.65	4.33±0.32i	3.82±0.12cd	0.06±0.12jk	3.27±0.12efg	0.13±0.02defghi	0.25±0.12bc	0.21±0.02cde
NKRFM1	1.01±0.60a	6.11±0.42ghi	5.462±0.62bc	0.11±0.12fghijk	4.40±0.32bcdefg	0.09±0.02j	3.85±2.52a	0.23±0.02abcde
Ikhulule	1.01±0.62a	10.75±0.22efg	3.75±0.52cd	0.05±0.02k	3.20±0.32fg	0.09±0.02ij	0.33±0.32bc	0.22±0.02bcde

Values are means ±standard deviation. means within a column followed by different letters are significantly different at $p \le 0.05$

Lack of iron in most countries results to anaemia cases [42], Children, adolescents and women at reproductive age are at a higher risk of suffering from iron deficiency [43]. Average adults' dietary uptake is about 1-3 mg a day [41]. Fermentation of finger millet increases iron content up to 49.7mg/100g [44]. Sorghum contains 3.01 mg/100g of iron [45]. Maize contains iron concentration of 10.5 to 39.5 µg/g [46]. Brown rice iron level ranged from 8.4 to 22.6 mg/kg [47].

Copper is an essential mineral for heart health and bone strength. The average copper level was found to range from 1.18 to 0.05 mg/100g on genotypes KAL ATARI and Ikhulule, respectively. Copper deficiency results to heart related issues when the arteries become narrow [14]. Copper daily intake of 10 milligrams is safe and excessive consumption of up to 1000mg is toxic and could result to organ failure and death [48]. [13] reported 0.54 mg of copper in millet, 0.22 mg in sorghum and 0.41 mg /100g in wheat. Further, [49] found levels of 0.0006 mg in millet and 0.0001mg/100g in rice. levels of 0.161mg/100g was reported by [13] in cooked millet. Dietary consumption of copper from finger millet is hence useful.

The importance of zinc in humans was discovered in 1961 [50]. Zinc plays an important role in healing damaged tissues, supporting healthy immunity, growth of cells and building proteins. The study showed that Zinc levels ranged from 10.41 to 2.58 mg/100g in genotypes KNE628 and ICFX 1420432-2-3-1-1 respectively. The recommended dietary allowance for adult men is 11 mg and 8 mg for women while 11 and 12 mg is for pregnant and lactating mothers, respectively [76]. Concentrations of 1.08 mg/100 g in rice, 2.24 mg/100 g in sorghum, 2.03 mg/100 g (whole chickpea) and 2.68 mg/ 100 g (decorticated chickpea) was reported by [51]. Phosphorus fertilizer application has been found to reduce grain zinc concentration by 16.6% in wheat, 20.2% in maize, and 0% for rice [52]. Similarly finger millet concentrations of 2.3mg/100g and pearl millet 3.1mg/100g was reported by [3].

Molybdenum is an essential trace element that activates antioxidants in the body and breaks down amino acids and offers protection to the cells. The average concentrations ranged from 0.20 to 0.09 mg/100g. Genotype ICFX 1420314-6-5 recorded the highest concentration while NKRFM1 recorded the lowest. The recommended dietary allowance is 0.045 MG/day [53] for adults and finger millet proves to supply it readily. Similarly, [54] found a concentration of 0.102mg/100g in finger millet. Legumes showed a considerably higher molybdenum content of 87 mg in Lima beans, 45 mg in small white beans, 13 mg in whole green peas, 20 mg in red beans and 8 mg/100g in Kidney beans [55]. The molybdenum level for millet is of required level to both human and livestock. This is because levels exceeding 10 mg/kg causes diarrhoea and toxicity in ruminants [56].

Aluminium level significantly varied within the genotypes with an average of 3.85 and 0.12mg/100g, this was observed in genotypes NKRFM1 and ICFX 1420432-2-3-1-1, respectively. The tolerable weekly intake was recorded to be 7mg/kg body weight per week [57]. This was however changed to 1.0 mg/kg body weight when lower concentrations were found to be toxic [58]. Aluminium toxicity affects three body organs the nervous system, the bones and hemopoietic system. It also plays a role in diseases such as cancer and Alzheimer's dementia [41]. Finger millet is found to have lower aluminium level compared to reports by [58] who reported a range of 50-100 mg/100g in milk, sausage, seafood, and vegetables. Similar studies reported corn concentration of 46.5-267.9 mg/100g, rice 14.9 to 22.1 and millet 75.6 and 80.7 mg/100g [59]. Aluminium is not essential in human body [60].

Nickel is an important micronutrient in human body since it increases hormonal activity and is involved in lipid metabolism [61]. The average concentrations obtained was 0.29 to 0.19 mg/100g for genotypes ICFX 1420293-1-1-1-1 and GBK 027189A, respectively. In U. S and Canada, the tolerable Upper Intake Levels for nickel in (milligrams/day) for children aged 1-3 years (0.2), 4-8 years (0.3), and 9-13 years (0.6) and for adults (1.0) [62]. Toxic effects of Nickel include teratogenicity, immunotoxicity, carcinogenicity and haematotoxicity [61]. Nickel concentration of 2.7, 4.3 and 0.7 mg/100g was detected in wheat, sorghum and maize [57]. Similarly, wheat flour was found to contain 2.5 mg/100g [63]. Higher concentration of 9.520 mg/100g was recorded in milled millet [64].

Table 4. *Pearson correlation coefficients heat map of micro and macro elements of finger millet.*

	B	Mn	Fe	Zn	Mo	Al	Ni	Mg	P	S	k
Mn	-0.289										
Fe	-0.029	0.097									0.90-0.99
Zn	0.09	0.200***	0.830***								0.70-0.89
Mo	0.019	0.579***	0.492***	0.626***							0.4-0.69
Al	-0.158	-0.164	0.456***	0.218*	-0.095						0.20-0.3

	B	Mn	Fe	Zn	Mo	Al	Ni	Mg	P	S	k
											9
Ni	-0.038	0.393***	0.551***	0.379***	0.220*	0.291**					0.01-0.19
Mg	-0.038	0.842***	0.397***	0.528***	0.768***	-0.093	0.362**				0 to -1
P	-0.016	0.815***	0.368**	0.522***	0.793***	-0.141	0.290**	0.986***			
S	-0.065	0.608***	0.514***	0.685***	0.810***	-0.145	0.213*	0.848***	0.872***		
k	-0.111	0.283**	0.510***	0.679***	0.732***	0.028	0.059	0.624***	0.675***	0.812***	
Ca	-0.043	0.853***	0.349**	0.464***	0.775***	-0.079	0.413***	0.942***	0.929***	0.766***	0.522***

Notes: B: Boron; Mn: Manganese; Fe: Iron; Zn: Zinc; Mo: Molybdenum; Al: Aluminium; Ni: Nickel; Mg: Magnesium; P: Phosphorus; K: Potassium; S: Sulphur; Ca: Calcium*=p≤0.05, **=p≤0.01, ***=p≤0.0001

Looking at correlation analysis, most elements showed varied correlation either negative with r^2 of -0.01 to -1, weak correlation with r^2 value of 0.2 to 0.39, moderate correlation with r^2 of 0.40 to 0.69, strong correlation with r^2 of 0.70 to 0.89 or very strong being highly with r^2 of 0.90 to 0.99.

A very strong correlation was observed between Magnesium and phosphorus, r=.986, p=.0001; for Magnesium and Calcium r=.942, p=.0001; for Calcium and Phosphorus, r=.929, p=. 0001. Magnesium, similarly, was reported by [65] to increase the phosphorus efficiency in wheat. Calcium and magnesium relationship has also been attributed to cell wall chemistry [66]. Synergistic effect similarly was observed in soybean for the uptake of Sulphur and phosphorus, while it contrasted with the correlation of sulphur and molybdenum which showed an antagonistic effect [67]. In mustard plants, strong positive correlation was found between soil nutrients and plant nutrients where Manganese showed a positive correlation between calcium, zinc, magnesium and iron [68].

Negative correlation was observed between Boron and Manganese r=-0.289, p=.7757, Boron and Iron r=-0.029, p=.7748; Boron and Aluminium r=-0.158, p=.1162; Boron and Magnesium r=-0.038, p=.7060; Boron and Phosphorus r=-0.016, p=.8745; Boron and Calcium r=-0.043, p=.6728. Aluminium and Magnesium r=-0.1, p=.3557; Aluminium and Phosphorus r=-0.1, p=.1598; Aluminium and Calcium r=-0.1, p=. 4367. In corn similarly, antagonistic effect has been observed with boron and zinc [69]. Also, tomato exhibited antagonistic effect between boron, calcium and phosphorus as an increase in calcium and phosphorus resulted to deficiency in boron [70]. Aluminium in the form of Al^{3+} also showed negative impact on base cations such as magnesium [71]. [72] similarly reported that aluminium toxicity resulted to increase Magnesium deficiency. Farming systems in China also exhibited similar results that adequate supply of magnesium was found to reduce abiotic stresses due to its antagonistic effect with cations such as aluminium [73].

4. Conclusions

The world population is anticipated to reach 10 billion by 2057. Feeding this population will be a challenge as a result of climate, increased conflict and even urbanization as malnutrition has been observed globally in one out of three people. To combat malnutrition in the future, strategies such as dietary diversification and food bio fortification with nutrient dense crops such as finger millet have to be employed. Finger millet is a wonder crop and from the results it is nutritionally rich compared to maize, wheat, rice and sorghum. The crop offers vast health benefits ranging from treatment of diabetes, cancer, heart diseases and arthritis. Therefore, this study offers information on the diversity of nutritional status of both macro and micronutrients that will be used for future bio fortification by breeders and to address malnutrition.

Abbreviations

ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
KALRO	Kenya Agricultural and Livestock Research Organization
P	Phosphorus
K	Potassium
Mg	Magnesium
Ca	Calcium
S	Sulphur
B	Borom
Mn	Manganese
Fe	Iron
Cu	Copper
Zn	Zinc

Mo	Molybdenum
Al	Aluminium

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Future Directions

To identify specific genes linked to nutrient elements and use it for bio fortification to improve the existing genotypes.

Author Contributions

Edinah Chepkemoi: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing - original draft, Writing - review & editing

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Conflicts of Interest

The authors declared no conflict of interest.

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