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Research Article

Bioacessility of Selected Minerals from Raw and Processed Finger Millet (*Eleusine Coracana*)

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Abstract:

Finger millet (Eleusine coracana) is a staple crop in developing countries, offering essential minerals for managing non-communicable diseases, such as chromium (Cr^{3+}) and potassium (K), which support insulin sensitivity and lower blood pressure. Despite its nutritional value, finger millet (FM) remains underutilized due to the poor bioaccessibility of its nutrients, influenced by factors such as millet variety, antinutrient content, and processing methods. This study analyzed the levels of selected minerals in 18 finger millet varieties being developed by Kenya Agricultural and Livestock Research Organization (KALRO), Kenya. The superior variety, IE3779FM, in terms of mineral content, was used for further studies on antinutrient and nutrient bioaccessibility. Mineral content (Cr^{3+}, K, Fe, Zn, Mg, Ca, P) was determined using ICP-MS, antinutrients (tannins, phytates, phenols, oxalates) were measured by titration and BCA kits, while bioaccessibility was determined using a Caco-2 cell procedure. The different variety of finger millet contain significant mineral levels (0.56–653 mg/100g), exceeding RDA values. Processing of the IE3779FM variety reduced antinutrients by 3.71%–42.65% during malting and 7.14%–63.29% during roasting. Mineral levels were not significantly different between raw and processed forms, attributed to the heat stability of minerals, while proximate composition was minimally altered by processing. Bioaccessibility studies revealed that malting and roasting generally increased mineral bioaccessibility by 0.56%–53.62 % and 0.92-29.39 % respectively. The study concluded that finger millet is rich in essential minerals, and that malting and roasting reduce antinutrients while significantly enhancing mineral bioaccessibility, making it a valuable nutritional source for food formulation for T2D patients.

Key words: bioaccessibility; caco-2 cell; finger millet; antinutrients; processing, mineral content

1.Introduction

Finger millet (Eleusine coracana), a tropical and sub-tropical drought-resistant crop, is cultivated in many countries in the developing world including Kenya. Finger millet offers enormous but underexplored nutritional benefits that can address nutrient deficiencies prevalent in many developing countries (Ramashia et al., 2019; Sahoo et al., 2024). Verma and Patel, (2013) reported that finger millet grains are rich in essential minerals such as zinc (22 mg/100g), iron (6.3 mg/100g),calcium(344mg/100g),Magnesium(228),potassium(1419mg/100g),phosphorous(250mg/100g) as well as carbohydrates (81.5%), dietary fiber (18–20%), starch (65–75%), proteins (9.8%), fat (1–1.7%), and crude fiber (4.3%).

To promote nutritional security through the utilization of finger millet in Kenya, the Kenya Agricultural and Livestock Research Organization (KALRO) is studying 18 finger millet varieties for agronomic traits. These varieties thrive across wider ecological zones (Mgonja, 2007; Onyango, 2016) and grow on various substrates, maturing quickly with reduced pest susceptibility (Devi et al., 2014).

This nutritional profile makes finger millet valuable in addressing non-communicable diseases (NCDs) such as type 2 diabetes (T2D). The prevalence of T2D is rising globally, with over 539 million people worldwide have T2D, including 0.9 million in Kenya (International Diabetes Federation (IDF) Report, 2022). The devastating effects of T2D

include damage to small vessels, leading to heart attacks, strokes, and diabetic foot complications (Atlas, 2019; WHO and FAO, 2003). The growing prevalence of T2D underscores the need for urgent interventions (Ebere et al., 2019).

Food-based approaches, such as formulating functional foods, have been proposed to supplement drug therapy. However, these approaches face challenges such as cost and resistance (Ramashia et al., 2019). Certain microelements in finger millet, like chromium (III) ions, enhance insulin activity, increasing insulin receptor sensitivity and pancreatic β-cell functionality to regulate blood sugar levels (Pechova and Pavlata, 2007). Finger millet-based formulations could thus aid in managing T2D in developing countries.

However, finger millet grains also contain antinutrients, such as phenols, oxalates, and phytate (George et al., 2023), which reduce mineral bioaccessibility (Arzoo et al., 2024). Processing methods like roasting and malting mitigate these effects, reducing antinutrients and enhancing nutrient bioaccessibility (Onyambu et al., 2021). Roasting improves flavor and shelf life while malting activates enzymes that degrade complex compounds, increasing nutrient bioaccessibility (Pragya Singh, 2012b, 2012a)

Mineral bioaccessibility can be accessed via in vivo or in vitro methods. Ethical restrictions limit in vivo studies (Parada and Aguilera, 2007), making in vitro methods, such as those using Caco-2 cells, more practical. These methods simulate digestion and absorption processes, measuring nutrient concentrations in final extracts (Kus et al., 2023). This study investigated the effects of roasting and malting on mineral levels, antinutrients, and bioaccessibility in finger millet, with the intention of promoting it in food formulation.

2.0 Materials and Methods

2.1 Source of the materials

All the eighteen-finger millet (FM) varieties were obtained from the KALRO Center in Kisii Kenya. The chemicals used in this study were of analytical grade (99.99% purity) manufactured by Sigma Aldrich Company and supplied by Kobian Kenya Limited, Nairobi and ANGUS chemical company in Japan.

2.2 Finger Millet preparation

The finger millet grains were dehulled using a seed buro and separated by a seed blower before being stored in the cold room at 4°C.

2.3 Processing of finger millet

2.3.1 Malting

Malting of finger millet (FM) was conducted following a method adopted by (Chandrasekara and Shahidi, 2012) with modifications. Approximately 100 g of FM grain was soaked in excess distilled water at 22°C for 12 hr. The water was then carefully decanted and the grains were put on a perforated tray covered with cotton wool at 28°C for 4 days with occasional turning at the first 24 hours for sprouting to occur. Samples were withdrawn from the germination bed after 48 and 60 hours. Any ungerminated seeds were manually removed and discarded. The germinated grains were then sun-dried to a moisture content of 12% at 25 – 28°C for 2 days. Subsequently, the dried grains were extruded at 105 – 110°C to a moisture content of 8 % before being ground to fine powder.

2.3.2 Roasting

This was done according to the method by Arzoo et al (2024). Approximately 10.65 g of FM were soaked in 5% W/V for 6 h and then roasted in a toaster for 5 minutes at 120°C and another sample for I min at 180°C. They were then cooled to room temperature and ground by a coffee grinder. The flour was passed through a sieve of 200 µm and stored in the freezer at 4°C for further analysis (Azad et al., 2019).

2.4 Mineral analysis

The mineral composition (K, Fe, Zn, Mg, Ca, P) of the finger millet varieties was determined using a method described by Kumari (2017). The inductively coupled plasma-optical emission spectroscopy (ICP-OES; 9820 series) which utilized a standard mixture for all the elemental analysis was used to obtain calibration curves. All analyses were carried out in triplicates (Kumari and Platel, 2017)

2.4.1 Chromium (III) ions

The difference between the total chromium and chromium (VI) was used to get chromium (III) ions. The procedure to analyze Cr6+ was aimed at selectively determining Cr6+ in samples by adopting a method described by Kumari and Patel (2017) and Moema et al. (2024) with modification. Approximately 1.00 g sample was weighed and placed in a 10.00 mL polypropylene tube, followed by the addition of 9 mL of 0.01M NaOH solution. The tubes were then horizontally placed in an oscillating agitator for 17 h at 300 oscillations per minute at room temperature to selectively extract the Cr6+. After extraction, 1.00 mL of 1.00 M NH_4NO_3 solution was added, and the sample was shaken briefly and centrifuged for 30 min at 12,500 rpm. The concentration of Cr6+ in the sample was measured by ICP-OES (9820 series). Alkaline Cr6+ standard solutions and the blank reagents underwent the same pretreatment procedure for comparison. Additionally, the pH of the samples was determined to avoid any potential effect on Cr6+ measurement by suspending aliquots of 10.00g of the sample in 100.00 mL of distilled water, followed by centrifugation for 30 min at 12,500 rpm, and the pH measurement of the supernatant (Ogo et al., 2011; Kumari and Platel, 2017; George et al., 2023; Moema et al.,2024)

To obtain chromium (III) the equation below was used.

Chromium (III) ions = Total chromium-chromium (VI) ions

2.5 Determination of the proximate composition of IE339 FM variety

The proximate composition of raw, malted, and roasted FM was determined according to the method of the Association of Official Analytical Chemists (Association of Official Analytical Chemists. et al., 2006)

2.6 Antinutrients

2.6.1 Phytates content

Phytic acid was determined as described by Olatunde et al. (2018). The sample (0.50 g) was weighed into a flask, 25.00 mL of 2% HCl was added and allowed to stand for 3 h, after which it was filtered using 900 mm Advantech filter paper, and 6.25 mL of the filtrate was placed in a separate 50.00 mL conical flask with 1.50 mL of 0.30% ammonium thiocyanate solution as the indicator. Exactly 26.50 mL of distilled water was added to give the desired acidity. This was then titrated with the standard iron (III) chloride (0.00195 g of iron per mL) until a brown, yellow color persisted for 5 minutes. Phytic acid was calculated:

Phytic acid (%) = titrevalue x 0.00195 x 1.19 x 100

2.6.2 Oxalate Content

Oxalate was determined using a modified titration method by Unuofin et al., (2017). The pulverized sample (1.00 g) was weighed in a 100 mL conical flask, an accurately measured volume of 75.00 mL of 3M H_2SO_4

was added and the solution was stirred intermittently with a magnetic stirrer for about 1 hour, followed by filtering using Whatman No. 1 filter paper. The sample filtrate (25.00 mL) was collected and heated to 80°C. This filtrate was always kept above 70°C. The hot aliquot was titrated continuously with 0.05 mol/L against hot 0.05 M KMnO4 solution until the endpoint revealed by a light pink color which persisted for 15 seconds was reached. The concentration of the oxalates in each sample was determined using the following calculation.

1 mL of 0.05molesper litre of KMno4 = 2.2 mg Oxalates

2.6.3 Phenols content

The phenol content was determined using the method described by Piece (2020). Distilled water (10.00 µL) was added into 1A to 6A of the 96-well plate. The volume of 20.00 µL of the gallic acid standard prepared by dissolving 320.00 µg of gallic in 1 mL of distilled water was added in well 7A of the 96-well plate. 10.00 µL of the solution from 7A of the 96 well plate was transferred into well 6A up to well 2A while pipetting. Well, 1A contained only distilled water. The sample (1-14) was placed in wells 1B up to well 2C. A volume of 50.00 µL (10% phenolic solution) was added to all the wells used. A 40.00 µL of 7.5 % aqueous sodium carbonate solution was then added to all the used wells. The 96-well plate was placed on a shaker at room temperature for 60 minutes for color development. Finally, absorbance was measured at 765 nm with a microreader (Pierce, 2020).

2.6.4 Tannin content

The tannin content was determined following a method described by Das (2020). Initially, 0.1001 g of the sample was mixed with 20.00 mL of 50 % methanol in a 50.00 mL beaker, homogenized, and heated in a water bath at 80°C for one hour with continuous stirring. After filtration with a double-layered Whatman No. 1 filter paper into a 100.00 mL volumetric flask, the filtrate was diluted with water to the mark and thoroughly mixed. Then, 20.00 mL of distilled water, 2.50 mL Folin–Denis reagent, and 10.00 mL of 17 % Na2CO3 were added and mixed. The mixture was topped up with distilled water, mixed, and allowed to stand for 20 min until a blue-green coloration developed. To quantify tannin content, the absorbance of both tannic acid standard solutions and the samples was measured using a microplate reader at a wavelength of 540 nm (Das et al., 2020)

2.7 In vitro Gastrointestinal Digestion (GID)

The in vitro gastrointestinal digestion (GID) process followed the method outlined by Chandraseka and Shahidi (2011). The whole process involved three stages, oral, gastric, and intestinal stages. In the oral stage, 2.50 g of the FM sample was homogenized and mixed with 2.50 mL of salivary fluid in a 1:1 ratio and stirred for 5 minutes at a pH of 6.6. The gastric stage involved adding 5.00 mL of gastric acid with pepsin, adjusting the pH to 3, and incubating at 37°C for 2 h with pH checks and adjustments every 30 minutes (Chandrasekara and Shahidi, 2011). The intestinal stage commenced by adding 7.50 mL of the simulated intestinal fluid, increasing the pH to 6-7, and introducing pancreatic fluid. The digestion tubes were incubated at 37°C with pH checks and adjustments after every 30 minutes for 2 hours. Enzyme activity is deactivated by placing samples in an ice bath for 10 minutes at pH 9.

2.8 Caco2- cell culture

Caco2 cells were obtained from RIKEN BioResource Research Center in Japan. Seeding of the Caco2 cells was carried out at a density of 50,000 cells/mL in twelve well plates treated with collagen. The cells for mineral bioaccessibility were grown in MEM (Minimum Essential Medium) containing 20% FBS (Fetal Bovine Serum), 100 units/mL penicillin, and 100.00 µg/mL streptomycin (Sigma Aldrich). The cells were maintained at 37°C in an incubator with a 5% CO2 and 95 % air atmosphere maintained at constant humidity and the medium changed every 2 days for 21 days before experiments. For vitamins and amino acids, the cells were cultured using HBSS (Hank`s Balanced Salts Solution) medium (Elzinga et al., 2023).

2.9 Bioaccessibility

A sample (0.25 mL) was added to the top chambers containing caco2 cells and 0.50 mL of the medium to the lower chamber of the cell separately and kept in the incubator. After 24 h, 0.50 mL from the lower chamber was collected for analysis. To assess bioaccessibility, 0.10 mL of the sample digest was combined with 1.40 mL of 0.10 M HNO3 in a microtube bringing the total volume to 1.50 then topped to 4.00 mL using 0.10 M HNO3 acid. Sonication was done for 5 minutes followed by centrifugation at 12,000 rpm for 10 minutes to obtain a supernatant and precipitate. This process was repeated for the medium. Both the precipitate and supernatant were kept for analysis (Kus et al., 2023)

$$\%\ Bioaccessibility = \frac{\text{Bioaccessible levels}}{Levels\ in\ raw\ FM}\ X\ 100$$

2.10 Statistical analysis of data

All experiments were carried out in triplicates and the data expressed as mean ± SD using Min tab version 20.4. One-way ANOVA was performed to compare the means of the different levels of minerals in various varieties of FM, and levels of minerals, antinutrients, proximate composition and bioaccessibility in processed FM. All the significant tests were done at a 95 % confidence level. The analyzed data was presented in tables and figures.

3. Results and Discussion

3.1. Mineral levels in raw and processed finger millet varieties

The mean levels of selected minerals in finger varieties are presented in Table 1. The eighteen finger millet varieties were grown in the same climatic and soil conditions. The study primarily analyzes essential minerals in the body like Fe, Zn, Mg, Ca, and P. The levels of minerals in the FM were found to be significantly different across the eighteen FM varieties and the values exceeding the RDA. For instance, Cr3+ ranged from 0.53±0.08 (Ikhulule) to 1.29±0.05 (IE3779), with a mean value of 0.92 mg/100 g DW while potassium levels ranged from 341.93 to 643.0 mg/100gDW with IE3779FM variety containing the highest levels of Cr3+ and K among the 18 varieties. Other varieties that were promising nutritionally include IE4115 which showed significant levels of Cr3+ (1.25±0.17) and K (643.0±34.1) mg/100g. KATF1 contained significantly high levels of Zn (135.02±3.25) and Mg (292.30±3.12) mg/100g than the RDA while Snapping P and P224 were superior in Ca and P respectively. Similar findings were reported by Verma and Patel (2013) who found the levels of minerals as follows; Ca (344), Mg (228), Fe (6.3) and P (250) g/100g DW while Font et al., (2020) reported the levels of K (722mg/100g) and Zn (32.3 mg/100g) in snapping P finger millet variety to be 722mg/100g and 32.3mg/100g (Font et al., 2020). The variety IE3779 FM was chosen for further processing due to its nutritional superiority in terms of Cr3+ and K as targets for T2D and hypertension.

Variety	Cr^{3+}	K	Fe	Zn	Mg	Ca	P
EUFM401	0.91±0.06^{cd}	341.93±3.0^{i}	29.39±0.23^{a}	35.88±1.24^{f}	286.25±3.76^{ab}	470.83±7.22^{c}	194.0±0.01^{i}
EUFM502	0.59±0.01^{ef}	605.84±6.4^{abc}	12.37±0.21^{f}	31.30±1.57^{f}	286.16±4.66^{ab}	537.50±12.50^{b}	169.41±0.14^{n}
EUFM503	1.12±0.01^{ab}	278.00±7.5^{j}	11.41±0.07^{g}	39.11±2.80^{ef}	289.68±8.45^{ab}	387.50±12.50^{g}	213.42±0.28^{e}
IE3779	1.29±0.05^{a}	646.49±3.29^{a}	0.724±0.1^{h}	51.31±6.97^{cd}	284.29±0.47^{ab}	466.67±7.22^{cd}	215.67±0.14^{d}
IE4115	1.25±0.17^{a}	643.0±34.1^{a}	10.33±0.11^{h}	52.74±5.32^{cd}	281.38±3.35^{ab}	337.50±12.50^{h}	250.91±0.57^{b}
IKHLULE	0.53±0.08^{f}	392.61±2.94^{hi}	11.92±0.08^{f}	34.77±4.54^{f}	286.09±5.75^{ab}	445.83±7.22^{cd}	201.83±0.29^{g}
KAK W3	1.15±0.01^{ab}	518.33±7.64^{de}	9.73±0.12^{i}	51.18±0.64^{cd}	286.16±4.66^{ab}	445.83±7.22^{cd}	205.83±0.29^{f}
KAKW1	1.15±0.09^{ab}	615.43±9.90^{ab}	7.93±0.04^{k}	59.67±2.93^{c}	285.71±6.99^{ab}	416.67±7.22^{ef}	163.16±0.58^{p}
KAKW4	0.82±0.01^{cd}	551.97±10.56^{cd}	8.59±0.14^{j}	48.9±4.81^{cde}	289.22±4.91^{ab}	441.67±7.22^{de}	176.92±0.14^{m}
KATF1	0.81±0.02^{cd}	426.20±5.41^{gh}	26.32±0.26^{b}	135.02±3.25^{a}	292.30±3.12^{a}	400.0±0.0^{fg}	129.5±0.021^{q}
KERICHO	0.91±0.02^{cd}	630.06±5.00^{ab}	16.98±0.09^{d}	36.18±2.43^{f}	292.32±0.69^{a}	464.67±7.22^{cd}	188.83±0.14^{k}
KN814	0.81±0.02^{cd}	495.96±8.65^{ef}	10.59±0.13^{h}	39.09±4.90^{ef}	287.07±6.00^{ab}	470.83±7.22^{c}	191.8±0.0^{j}
MASENO	0.56±0.08^{ef}	451.0±50.5^{fg}	23.64±0.05^{c}	93.12±4.12^{b}	286.19±2.52^{ab}	458.33±7.22^{cd}	200.42±0.28^{h}
NKFM1	0.73±0.04^{def}	483.46±11.09^{ef}	12.24±0.22^{f}	47.846±1.19^{de}	287.87±6.45^{ab}	412.5±0.0^{fg}	166.0±0.031^{o}
P224	0.76±0.08^{de}	584.6±18.3^{bc}	13.33±0.21^{e}	57.637±0.28^{cd}	289.65±2.72^{ab}	445.83±7.22^{cd}	321.67±0.144^{a}
SEC915	1.12±0.08^{ab}	577.13±3.67^{bc}	9.58±0.18^{i}	35.33±2.61^{f}	288.32±3.22^{ab}	387.50±12.50^{g}	180.17±0.28^{l}
SNAPPING	1.25±0.061^{a}	483.0±23.6^{ef}	12.98±0.21^{e}	34.27±0.09^{f}	286.18±4.97^{ab}	575.0±0.0^{a}	117.83±0.29^{r}
U-15	0.96±0.09^{bc}	626.7±25.2^{ab}	10.42±0.25^{h}	94.10±4.08^{b}	279.99±3.16^{b}	387.50±12.50^{g}	235.33±0.29^{c}
P values	0.00	0.00	0.00	0.00	0.02	0.00	0.00
WHO and FAO, 2003)g/100g	0.035	34	0.18	0.15	4.2	10	5

Mean values followed by the same small letter(s) within the same column do not differ significantly from one another (SNK-test, α=0.05), n is the number of replicas

Table 1: Mean levels of selected minerals in raw FM varieties (Mean± SE, n=3) mg/100g DW

3.2 Proximate composition of raw and processed IE3779 finger millet variety

Table 2 gives the proximate composition of raw, malted IE3779FM variety. The ash content of roasted and malted IE3779FM variety was observed to decrease insignificantly compared to the ash content of raw IE3779FM. This decrease in ash content might be associated with the loss of outer covering and other parts of the grains during the soaking, germination, and drying process (Ramashia et al., 2019). The moisture content of malted FM (11.28%) was significantly higher than that of raw FM (10.03 %) and roasted FM (8.99 %). This increase in malted FM is associated with enhanced water absorption by FM during soaking before germination (Devi et al., 2014). Similar results were reported by Sahoo et al. (2024) who reported the percentage proximate composition in malted brown FM as follows; moisture (10.28), Carbohydrate (68.84),Fat (1.3),proteins (8.64),Total ash (1.94) and fibre (9.98).

The protein content of malted FM (8.99 %) and roasted FM (9.92 %) was significantly higher than that of raw FM that found to be 8.26 %). This is due to the breakdown of nitrogenous compounds to form amino acids and the activation of enzyme proteases to produce amino acids and peptides (Arzoo et al., 2024; Sahoo et al., 2024). The findings were similar to those reported by Ramashia et al. (2019). However, roasted FM (1.39 %) and malted FM (1.48 %) were found to contain significantly lower amounts of fat than raw FM (1.58 %). This might be due to the oxidation of fatty acids to carbon (iv) oxide and water to provide energy important for germination (Pragya Singh, 2012a).

The carbohydrate content of malted and roasted FM was significantly lower than that of raw FM. This might be due to the utilization of carbohydrates by microorganisms during malting and the loss of dry matter during roasting respectively (Arzoo et al., 2024). Similarly, the fiber content of finger millet decreased significantly during malting and roasting. This might be due to the mechanical loss of seed coat during soaking, germination, grinding, and sieving (Pechova and Pavlata, 2007).

Raw/Processed	Ash	Moisture	Protein	Fibre	Fat	Carbs
Raw	2.98±0.01[a]	10.03±0.03[b]	8.26±0.05[c]	4.36±0.01[a]	1.58±0.02[a]	68.89±0.02[a]
Malted	2.95±0.01[b]	11.28±0.03[a]	8.99±0.02[b]	4.21±0.02[b]	1.48±0.02b	68.77±0.02[a]
Roasted	2.90±0.01[c]	8.99±0.01[c]	9.92±0.05[a]	4.06±0.01[c]	1.39±0.01[c]	68.19±0.02[b]
P value	0.00	0.00	0.00	0.00	0.00	0.00

Table 2: Percentage proximate composition in IE3779 FM variety

3.3 Mineral levels in processed IE3779 FM variety

Table 3 shows mineral levels (mg/100gDW) in raw, malted, and roasted IE3779 FM variety. The variety IE3779 was chosen based on the nutritional superiority of Cr3+ and K minerals as a target for formulating foods for T2D patients. The result on levels of the minerals in raw and processed (malting for 60 h and roasting for 120°C) showed no significant increase in levels of Cr3+, K, Zn, Mg, Ca, and P in the IE3779 FM variety. This is attributed to the heat stability of minerals given that processing concentrates the existing minerals without introducing new ones (Arzoo et al., 2024).

	Sample n=3	Cr^{3+}	K	Fe	Zn	Mg	Ca	P
	RAW	1.29±0.07[ab]	646.49±3.29[bc]	10.724±0.06[a]	51.31±4.02[de]	284.29±0.27[ab]	466.67±4.17[bcd]	215.67±0.08[b]
	MALT48h	1.23±0.06[ab]	635.4±33.8[a]	10.51±0.64[a]	49.87±0.57[a]	278.03±1.60[a]	432.5±25[a]	204.0±20[b]
	MALT 60h	1.31±0.01[a]	648.04±1.94[a]	10.84±0.24[a]	51.54±0.55[a]	284.00±2.00[a]	469.27±5.83[a]	216.23±3.72[b]
	RT120^{O}C	1.28±0.02[ab]	648.67±1.53[a]	10.72±0.08[a]	51.23±0.37[a]	285.58±1.08[a]	467.00±1.0[a]	216.57±2.23[b]
	RT180^{O}C	1.26±0.02[ab]	648.00±2.0[a]	10.40±0.17[a]	52.82±5.94[a]	278.21±1.25[a]	461.80±5.16[a]	215.18±5.01[b]
P values		0.15	0.17	0.417	0.77	0.117	0.345	0.67
	RDA (WHO and FAO, 2003) mg/100g/day	0.035	34	0.18	0.15	4.2	10	5

Mean values followed by the same small letter(s) within the same column do not differ significantly from one another (SNK-test, α=0.05), n is the number of replicates

Table 3: Mean levels of minerals in processed IE3779FM variety (Mean± SE, mg/100g DW)

3.4 Antinutrient levels in processed IE3779 finger millet variety

Table 4 shows the levels of various antinutrients such as tannin, phenols, phytates, and oxalates of raw, malted, and roasted IE3779 FM. The antinutrients cause the chelation of dietary minerals in the gastrointestinal tract reducing minerals bioaccessibility. The decrease in the levels of antinutrients was not substantial except for phytates and tannins (George et al., 2023). The levels of phytates reduced significantly from 15.50±0.45 in raw to 5.69±1.04 mg/100g DW in roasted FM, a decrease of about 63.29%. This was due to the leaching of phytates during germination. The levels of tannins decreased in malted FM (12.13±0.95) as compared to raw FM (17.17±0.06) due to leaching and increased enzymatic activities of the enzyme Tannase. Malting and roasting led to decreased antinutrients in FM effectively reducing anti-nutrients in finger millet, thus enhancing mineral value and bioaccessibility. Arzoo et al. (2024) reported that soaking, boiling and germination reduced the levels antinutrients significantly similar to this study.

Food	Sample	Tannins	Phenols	Phytates	oxalates
FM	RAW	17.17±0.06[a]	27.53±1.409[a]	15.50±0.45[b]	0.28±0.01[bc]
	Malt 60	12.13±0.95[b]	26.51±0.900[ab]	8.89±0.23[c]	0.25±0.01[d]
	RT120	12.89±0.13[c]	25.09±0.998[ab]	5.69±1.04[d]	0.26±0.00[cd]
	P values	0.00	0.00	0.00	0.00

Mean values followed by the same small letter(s) within the same column do not differ significantly from one another (SNK-test, α=0.05), n is the number of replicas.

Table 4: Antinutrient levels in processed IE3779 FM (Mean± SE, n=3) mg/100g DW

3.5 Percentage bioaccessibility of minerals in processed IE3779 FM variety

Table 5 presents the results for minerals bioaccessibility in raw and processed IE3779FM. Results indicated that the percentage bioaccessibility of the minerals increased significantly on processing. This is associated with the decrease of antinutrients in processing (Onyambu et al., 2021). For instance, Cr3+ in raw FM was 14.04 % and increased to 16.45 % after malting for 60 hours and 16.86 % after roasting at 120°C for 5 minutes. A similar trend was observed for Ca, with its bioaccessibility increasing after malting and roasting. However, K, Fe, and P percentage bioaccessibility generally increased during malting but declined on roasting at 120°C for 5 minutes. This effect on malting can be associated with the combined effects of soaking, germination, and heat treatment (Arzoo et al., 2024; Sahoo et al., 2024). The result indicated no significant change in the percentage bioaccessibility of Zn, Fe, and P minerals on malting. However, the bioaccessibility of Cr3+, K, Mg, and Ca decreased significantly. The beneficial effects of malting on the Zn,

Fe, and P bioaccessibility may be attributed to the phytate content (Platel et al., 2010). Processing does not significantly increase the levels of minerals due to their heat stability but increases minerals' percentage bioaccessibility in the gut (Pragya Singh, 2012a; Kus et al., 2023).

VARIETY	Raw/processed n=3	Cr3+	K	Fe	Zn	Mg	Ca	P
IE3779FM	RAW FM	(0.18)14.04^{a}	(144.89)22.41^{e}	(0.64)5.91^{d}	(4.16)8.04^{d}	(56.66)20.03^{d}	(120.04)26.05^{b}	(1.27)0.59^{c}
	MALT60 h	(0.22)16.45^{b}	(162.33)25.05^{d}	(0.67)6.18^{d}	(4.19)8.13^{d}	(83.46)29.39^{c}	(136.34)29.05^{a}	(1.99)0.92^{c}
	RT120℃	(0.23)16.86^{b}	(347.82)53.62^{a}	(3.03)28.30^{a}	(15.49)30.24^{b}	(100.39)35.16^{a}	(122.24)26.17^{b}	(10.89)5.03^{a}
	P values	0.003	0.00	0.00	0.00	0.00	0.00	0.00

Mean values followed by the same small letter(s) within the same column do not differ significantly from one another (SNK-test, α=0.05), n is the number of replicas.

Table 5: Percentage of bioaccessibility of minerals in processed finger millet.

4. Conclusion

The study concluded that different finger millet varieties contain significantly different levels of selected minerals Cr^{3+}, K, Fe, Zn, Mg, Ca, P (0.56–653) mg/100g that were above RDA levels. Processing through malting and roasting significantly decreased tannins, phytates, phenols, and oxalates which affects the nutritional bioaccessibility. The percentage bioaccessibility of minerals significantly increased on malting and roasting due to the combined effects of soaking, germination, and roasting improved leaching of minerals and enhanced enzymatic hydrolysis that decreased the antinutrients. Hence malting and roasting can be considered effective processing methods to enhance nutrient bioaccessibility of the finger millet. Finger millet can be used as a good source of nutrients for T2D patients.

5. Conflict of interest

The authors declare no conflict of interest. They bear responsibility for the content and composition of this paper

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Authors contribution statement

George Nyabuti was involved in collecting data and drafted the manuscript. Nyambaka Hudson, Nawiri Mildred, and Everlyne Wanzala formulated the study area and guided the scientific writing and coordinated the various sections of the manuscript. Hirasaka Katsuya gave guidance on Caco2-cell culture during data collection. Chrispus Oduori guided the selection and planting of finger millet seeds at the Kisii KALRO center, while John Kinyuru and Judith Munga gave guidance on optimal conditions for processing.

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Ethics statement

The entire project involving value addition to the growing of finger millet to processing and formulation of food products received ethical from the Kenyatta University Ethical Review Committee.

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