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Research Article

Bioacessility of selected nutrients from raw and processed finger millet (eleusine coracana)

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Abstract

Finger millet (*Eleusine coracana*) is a nutrient-rich crop widely consumed in developing countries for its potential to combat nutritional deficiencies. However, factors like antinutrients influence nutrient bioaccessibility. This study evaluated the nutritional composition of eighteen varieties (N=18) of finger millet grown at the Kenya Agricultural and Livestock Research Organization (KALRO) in Kisii County, Kenya to identify a variety with the highest levels of Cr^{3+} and K. The samples were obtained using a randomized complete block design. Mineral content (Cr^{3+}, K, Fe, Zn, Mg, Ca, P) was determined via ICP-MS, while antinutrient levels were assessed using Pierce kits and titration methods. Bioaccessibility was measured through in vitro digestion using Caco-2 cells. The IE3779 FM and IE4115 FM varieties contained significantly higher levels ($p<0.05$) of Cr^{3+} and K respectively hence identified for processing. After processing IE3779 FM variety was identified for bioaccessibility studies due to its higher Cr^{3+} levels than other varieties. Potassium and chromium are important in T2D diabetic patients if consumed in the recommended amounts. Chromium (iii), Cr^{3+} and K have been reported to increase insulin sensitivity, lower blood pressure, and boost the immune system. Processing through malting and roasting reduced antinutrients, including tannins, phytates, phenols, and oxalates. Processing decreased tannins, phytates, phenols, and oxalates by 29.11,3.71 %,42.65 %, and 10.71 % on malting and by 24.67 %,8.86 %, 63.29 %, and 7.14 % on roasting IE3779FM variety respectively. Bioaccessibility of Cr^{3+} and K increased by 2.41 % and 3.5 % on malting, 2.82 % and 31.21 % on roasting. These results underscore the importance of processing to improve nutrient bioaccessibility, making finger millet a valuable food in combating micronutrient deficiencies.

1. Introduction

Nutrient deficiency is a global challenge affecting over 1.6 billion people in almost all nations. This has led to a surge in non-communicable diseases, especially T2D. According to Sun et al. (2023), over 537 million people worldwide are living with T2D, with 0.9 million of them living in Kenya [1].
Some of the devasting effects of T2D include damage to small vessels which can lead to heart attack and stroke, diabetic foot and foot amputation (Atlas, 2019)WHO and FAO 2003).
Finger millet (Eleusine coracana), a tropical and sub-tropical drought-resistant crop, is cultivated in countries including Kenya. Finger millet has enormous but underexplored nutritional benefits that can help address nutrient deficiencies prevalent in many developing countries [4].
To promote nutritional security and the utilization of finger millet in Kenya, the Kenya Agricultural and Livestock Research Organization (KALRO) is currently studying eighteen finger millet varieties for agronomic traits. These varieties can be grown in wider ecological zones [5], [6] and thrive on various substrates, maturing quickly and being less affected by pests [7].
According to Verma et al. (2013), finger millet grains are rich in essential minerals such as zinc (22 mg/100g), iron (11±0.01 mg/100g), calcium (113 mg/100g), and potassium (1419 mg/100g). They also contain carbohydrates (81.5%), dietary fiber

(18-20%), starch (65-75%), proteins (9.8%), fat (1-1.7%), and crude fiber (4.3%). This nutritional profile makes finger millet valuable in addressing non-communicable diseases (NCDs) like type 2 diabetes (T2D) [8]. There are two forms of chromium: Cr^{3+} and Cr^{6+}. Chromium (VI) ions are typically found as a chemical by-product in the environment and are carcinogenic [9]. The recommended daily allowance (RDA) for Cr^{3+} is 3.5 mg/kg/day [9]. Therefore, FM could contribute 26.27 % to the recommended RDA. Studies have shown that adequate levels of Cr^{3+} potentiate the activity of insulin, increase the insulin receptors on the cell surface, and revamp the binding and sensitivity of β cells in the pancreas, improving their functionality in controlling blood sugar [10]

However, finger millet grains also contain antinutrients such as phenols, oxalates, and phytates [11]. These anti-nutrients are known to reduce mineral bioaccessibility [12]. Finger millet cannot be consumed raw due to its hard texture and tightly packed nutrients, so it must be processed before consumption.

Processing methods like roasting and malting help reduce antinutrients and enhance nutrient bioaccessibility [13]. Roasting enhances the nutty flavor of finger millet and extends its shelf life, while malting activates enzymes that break down complex compounds, improving the bioaccessibility of minerals [14]. Malting also softens the grains, making them easier to chew and digest, especially for infants, the elderly, and the sick.

Mineral bioaccessibility can be assessed using in vivo or in vitro methods [15]. Ethical restrictions and protocol constraints limit in vivo studies [16], making in vitro methods, such as those using Caco-2 cells, more practical and widely used. In vitro, methods simulate digestion and absorption processes (for bioaccessibility), with the response measured as the concentration of nutrients in a final extract [17].

This study aimed to investigate the effects of roasting and malting on the levels of minerals and antinutrients, as well as the bioaccessibility of selected minerals (Cr^{3+}, K, Fe, Zn, Mg, Ca, and P). The bioaccessibility was assessed using a static-modified gastrointestinal digestion model followed by absorption using the Caco-2 cell cultures [17].

2.0 Materials and Methods

The IE3779 finger millet variety samples were obtained from KALRO centers in western Kenya and cleaned by removing foreign matter. The finger millet grains were dehulled using a seed *buro* separated by a seed blower before being stored in the cold room at 4°C.

2.1Processing of finger millet and formulation

2.1.1 Malting

Malting of finger millet was conducted following a method adopted by [15] with modifications. Approximately 100 g of FM grain was soaked in excess distilled water at 22°C for 12 h. After that, the water was carefully decanted and the grains were put on a perforated tray covered with cotton wool at 28°C for 60 h with occasional turning for the first 24 h, for sprouting to occur. Samples were withdrawn from the germination bed at12,24,36, 48h, and 60 h. 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 achieve a moisture content of 8 % before being ground to fine powder. The ground was then subjected to extraction and digestion process. The above processing was carried out in triplicates. The control was raw un germinated FM [18]

2.1.2 Roasting

This was done according to the method by [19] Approximately 10.65g of FM grains were soaked in 5% W/V for 6 h and then roasted in a toaster for 5 minutes at 120°C and 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[20].

2.2 Mineral analysis

The method adopted was described by Kumari (2017) using inductively coupled plasma-optical Emission spectroscopy (ICP-OES;9820 series). All analyses were carried out in triplicates [21]

2.2.1 Chromium (III) ions

The difference between the total chromium and chromium (VI) gave chromium (III) ions. The procedure to analyze Cr^{6+} was aimed at selectively determining Cr^{6+} in samples by adopting a method described by Kumari and Patel (2017) with modification. Approximately 1.0 g sample was weighed and placed in a 10 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 Cr^{6+}. After extraction,1 mL of 1 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 Cr^{6+} in the sample was measured by ICP-OES (9820 series). Alkaline Cr^{6+} 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 Cr^{6+}

measurement by suspending aliquots of 10g of the sample in 100 mL of distilled water, followed by centrifugation for 30 min at 12,500 rpm, and the pH measurement of the supernatant [11], [21], [22].
To obtain chromium (III) equation 2.5 was used as follows.

$$Chromium\ (\quad)(III)\ ions\ = Total\ chromium - chromium\ (VI)\ ions$$

2.3 **Antinutrients**

2.3.1 Phytates content

Phytic acid was determined as described [23]. The sample (0.5g) was weighed into a flask,25 mL of 2% HCl was added and allowed to stand for 3 h, after which it was filtered using 900 mm Advantech filter paper, 6.25 mL of the filtrate was placed in a separate 50mLconicol flask with 1.5 mL of 0.3% ammonium thiocyanate solution as the indicator.26.5 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:

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

2.3.2 Oxalate Content

Oxalates were determined using a modified titration method [24]. The pulverized sample (1.00 g) was weighed in a 100 mL conical flask. An accurately measured volume of 75 mL of 3M H_2SO4 was added and the solution stirred intermittently with a magnetic stirrer for about 1 hour, followed by filtering using Whatman No. 1 filter paper. The sample filtrate (25 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 $KMnO_4$ 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.

$$1\ mL\ of\ 0.05 molesper\ litre\ of\ \ KMno4 = 2.2\ \text{mg}\ \ \text{Oxalates}$$

2.3.3 Phenols content

The phenol content was determined using the method described by Piece (2020). Distilled water (10 µL) was added into 1A to 6A of the 96-well plate. In well 7A 20µL of the gallic acid standard was added prepared by dissolving 320 µg of gallic in 1 mL of distilled water. From well 7A, 10 µL was transferred and placed in well 6A while pipetting. This process was repeated up to wells 2A. Well, 1A contained only distilled water. The sample (1-14) was placed in wells 1B up to well 2C and 50 µL of 10% phenolic solution was added in all the wells used. A 40 µL of 7.5 % aqueous sodium carbonate solution was added to all the used wells. The well was placed on a shaker at room temperature for 60 minutes. Finally, absorbance was measured at 765 nm with a microreader [25].

2.3.4 Tannin content

The tannin content of the samples was determined following a method described by Das (2020). Initially, 0.1001g of the sample was mixed with 20 mL of 50 % Methanol in a 50 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 mL volumetric flask, the filtrate was diluted with water to the mark and thoroughly mixed. Then,20 mL of distilled water, 2.5 mL Folin – Denis reagent, and 10 mL of 17 % Na_2CO_3 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 [26]

2.4 *In vitro* Gastrointestinal Digestion (GID)

The *in vitro* gastrointestinal digestion (GID) process followed the method outlined by Chandraseka and Shahidi (2011). The process involved three stages: Oral, gastric, and intestinal. In the oral stage, 2.5 g of the sample was homogenized and mixed with 2.5 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 mL of gastric with pepsin, adjusting the pH to 3, and incubating at 37°C for 2 h with pH checks and adjustments every 30 minutes[27]. The intestinal stage commenced by adding 7.5 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.

2.5 Caco2- cell culture

Caco2 cells were obtained from RIKEN BioResource Research Center. 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 µg/mL streptomycin (Sigma Aldrich). The cells were maintained at 37°C in an incubator with a 5% CO_2 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[28].

2.6 Bioaccessibility

Each sample (0.25 mL) was added to the top chambers containing caco2 cells and 0.5 mL of the medium to the lower chamber of the cell separately and kept in the incubator. After 24 h,0.5 mL from the lower chamber was collected for analysis. To assess bioaccessibility, 0.1 mL of the sample digest was combined with 1.4 mL of 0.1 M HNO3 in a microtube bringing the total volume to 1.5 then topped to 4 mL using 0.1M 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 [17]

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

2.7 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. 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 levels of minerals in FM varieties were significantly different across the varieties hence need to identify the variety with the highest levels of Cr^{3+} and K important for T2D. The levels ranged as follows; Cr^{3+}0.53±0.08 (Ikhulule) to 1.29±0.05 (IE3779), with a mean value of 0.92 mg/100 g DW. The levels were generally significantly higher than the RDA. A study by Kumari and Patel showed FM containing low levels of Cr (0.07± 0.004 mg/100g) (Kumari and Platel, 2017.
Potassium levels in FM ranged from 341.93 to 653.0 mg/100g(IE4115), with a mean of 520.09 mg/100g, contributing approximately 14.86 times to the recommended daily intake (RDA) of 35 mg/day. Finger millet IE3779 and IE4115 contained significantly higher Cr^{3+} and K respectively than the other varieties they were chosen for processing. Finger millet is a valuable source of essential minerals, significantly contributing to daily dietary requirements.

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	$1.29±0.05^{a}$	$646.49±3.29^{a}$	$10.724±0.1^{h}$	$51.31±6.97^{cd}$	$284.29±0.47^{ab}$	$466.67±7.22^{cd}$	$215.67±0.14^{d}$
IE4115	$1.25±0.17^{a}$	$653.0±34.1^{a}$	$10.33±0.11^{h}$	$52.74±5.32^{cd}$	$281.38±3.35^{ab}$	$337.50±12.50^{h}$	$250.91±0.57^{b}$
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	0.2	0.00	0.00
RDAWHO/FAO,1991 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) mg/100g DW

3.2 Mineral levels in raw and processed IE3779 FM variety

The results, presented in Table 2 show mineral levels (mg/100gDW) in raw (Control), malted, and roasted FM. The levels of the minerals in raw and processed were as follows; FM were Cr^{3+} 1.29, K 646.49, Fe 10.724, Zn 51.31, Mg 284.29, Ca 466.67 and P 215.67[11]. On malting after 60 h and roasting at 120°C levels were found to be; Cr^{3+} 1.31, K 648.04, Fe 10.8, Zn 51.54, Mg 284, Ca 469.27, P 216.23 and 1.28,648.67,10.72,51.23,285.58,467 and 216.57 respectively. The result indicated that malting for 60 h and roasting for 120°C led to a significant increase in levels of Cr^{3+}, K, Zn, Mg, Ca, and P in the IE3779 FM variety.

VARIETY n=3	Sample	Cr^{3+}	K	Fe	Zn	Mg	Ca	P
IE3779	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}
	MALT - 48HRS	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 - 60HRS	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}
	RT-120°C5min	1.28±0.02^{ab}	648.667±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}
	RT-180^{O}C1min	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
IE4115	RAW	1.24±0.02^{ab}	653.33±3.51^{a}	10.34±0.32^{a}	52.76±0.11^{a}	281.57±1.12^{a}	336.83±2.57^{c}	250.30±5.03^{a}
	MALT - 48HRS	1.24±0.02^{ab}	653.00±2.65^{a}	10.47±0.33^{a}	51.55±0.68^{a}	284.26±1.12^{a}	328.00±2.00^{c}	253.33±3.06^{a}
	MALT - 60HRS	1.27±0.03^{ab}	661.65±13.0^{a}	10.54±0.09^{a}	52.79±0.19^{a}	282.67±7.64^{a}	333.23±3.03^{c}	253.33±2.52^{a}
	RT-120^{O}C5min	1.26±0.03^{ab}	650.67±2.52^{a}	10.48±0.14^{a}	52.02±1.39^{a}	282.37±3.24^{a}	333.59±0.684^{c}	252.32±1.87^{a}
	RT-180^{O}C1mi	1.22±0.02^{b}	640.44±3.58^{a}	10.15±0.13^{a}	52.10±0.95^{a}	278.22±1.16^{a}	315.00±5.00^{c}	254.62±5.40^{a}
P values		0.16	0.19	0.29	0.35	0.44	0.36	0.72
RDA mg/100g/day	WHO/FAO, 1991	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 2: Mineral levels in raw, malted, and roasted FM varieties

3.3 Antinutrient composition of raw and processed finger millet (mg/100g Dw)

The result for the antinutritional composition of raw, malted, and roasted finger millet (FM) is presented in Table 5. Raw finger millet showed a tanning content of 17.17 Phenols 27.53, Oxalates 0.28 mg/100g and tannins 2.14, phenols 25.36, and oxalates 0.33 mg/100g respectively. The antinutrients cause the chelation of dietary minerals into the gastrointestinal tract reducing minerals bioaccessibility. Malting and roasting of FM significantly decreased the level of anti-nutrients in FM. On malting FM at 60 hours the antinutrients decreased as follows; Tannins decreased by 29.41%, phytates 42.65 %. Phenols by 3.75 and oxalates by 10.71% while roasting at 120°C for 5 minutes the decrease was tannins by 24.9 %,28.04 % phenols by 8.82 % 7.26 %, Phytates by 63.29 %,47.5 %, and oxalates by 7.1,6.06% in FM respectively. Malting and roasting led to decreased antinutrients in FM[19]. These findings align with previous research by effectively reducing anti-nutrients in finger millet, thus enhancing mineral value and bioaccessibility.

Food n=3	Sample	Tannins	Phenols	Phytates	oxalates
FM	RAW FM	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]
	RST120FM	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 3: Antinutrient composition in raw and processed FM and OM (mg/100g)/DW

3.4 Percentage bioaccessibility of minerals in raw and processed IE3779 FM variety

The results for minerals bioaccessibility in raw and processed FM and OM are presented in **Table 4.** Results revealed that the percentage bioaccessibility of Cr^{3+} in raw FM was 1404 %. This 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 after roasting at 120°C for 5 minutes. A similar trend was observed on OM. This effect of malting can be associated with the combined effects of soaking, germination, and heat treatment. The result indicated no significant change in the percentage bioaccessibility of calcium and cr^{3+} minerals on either roasting or malting. However, roasting leads to an increase in percentage bioaccessibility A study by Kalpana revealed that malting has been used in the preparation of weaning foods due to their ability to increase the bioaccessibility of iron.

VARIETY	**Raw/processed n=3**	**Cr3+**	**K**	**Fe**	**Zn**	**Mg**	**Ca**	**P**
IE3779FM	RAW FM	14.04[a]	22.41[e]	5.91[d]	8.04[d]	20.03[d]	26.05[b]	0.59[c]
	MALT60	16.45[b]	25.05[d]	6.18[d]	8.13[d]	29.39[c]	29.05[a]	0.92[c]
	RT120 ^{O}C	16.86[b]	53.62[a]	28.30[a]	30.24[b]	35.16[a]	26.17[b]	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 4: Percentage of bioaccessibility of minerals in raw, malted, and roasted finger millet.

4. Conclusion

i. IE3779 FM contains significantly high levels ($p<0.05$) of selected minerals (Cr^{3+}, K, Fe, Zn, Mg, Ca, P) compared to the recommended daily intake hence recommended to provide nutritional security to NCD patients, especially T2D
ii. Processing decreased tannins, phytates, phenols, and oxalates by 29.11,3.71 %,42.65 %, and 10.71 % on malting and by 24.67 %,8.86 %,63.29 %, and 7.14 % on roasting IE3779FM variety.
iii. Bioaccessibility of Cr^{3+} and K increased by 2.41 % and 3.5 % on malting, 2.82 % and 31.21 % on roasting.

5. Conflict of interest

We declare that we have no conflict of interest.

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Authors contribution statement

Prof. Nyambaka Hudson Dr. Nawiri Mildred Dr. Everlyne Wanzala (Kenyatta University phD supervisors), for guidance on scientific writing, coordinating the various sections of the paper, and general formatting. Hirasaka Katsuya Department of Fisheries and Environmental Science, Nagasaki University, Japan gave guidance on Caco2- cell culture. Chrispus Oduori guided the selection and planting of finger millet seeds at the Kisii KALRO center. John Kinyuru and Judith Munga gave guidance on formulations using the Nitri survey software used in this research.

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Ethics statement

The project involves in-vitro procedure hence no constraints of ethical constraints.

References

1. H. Sun et al., “Erratum to ‘IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045’ [Diabetes Res. Clin. Pract. 183 (2022) 109119] (Diabetes Research and Clinical Practice (2022) 183, (S0168822721004782), (10.1016/j.diabres.2021.109119)),” Oct. 01, 2023, Elsevier Ireland Ltd.
2. I. D. F. D. Atlas, 463 PEOPLE LIVING WITH DIABETES million. 2019.
3. WHO and FAO, “Diet, Nutrition, and the Prevention of Chronic Diseases (Report of a joint WHO and FAO Expert Consulation),” WHO Technical Report Series, vol. 916, pp. 1–160, 2003, [Online].
4. S. E. Ramashia, T. A. Anyasi, E. T. Gwata, S. Meddows-Taylor, and A. I. O. Jideani, “Processing, nutritional composition and health benefits of finger millet sub-Saharan Africa,” Food Science and Technology, vol. 39, no. 2, pp. 253–266, 2019.
5. M. A. (Mary A.) Mgonja, Finger millet blast management in East Africa : creating opportunities for improving production and utilization of finger millet : proceedings of the First International Finger Millet Stakeholder Workshop, Projects R8030 & R8445 UK Department for International Development: Crop Protection Programme, held 13-14 September 2005 at Nairobi. International Crops Research Institute for the Semi-Arid Tropics, 2007.
6. A. O. Onyango, “Finger Millet: Food Security Crop in the Arid and Semi-Arid Lands (ASALs) of Kenya,” World Environment, vol. 6, no. 2, pp. 62–70, 2016.
7. P. B. Devi, R. Vijayabharathi, S. Sathyabama, N. G. Malleshi, and V. B. Priyadarisini, “Health benefits of finger millet (Eleusine coracana L.) polyphenols and dietary fiber: A review,” J Food Sci Technol, vol. 51, no. 6, pp. 1021–1040, 2014.
8. V. Verma and S. Patel, “Value added products from nutri-cereals: Finger millet (Eleusine coracana),” Emir J Food Agric, vol. 25, no. 3, pp. 169–176, Mar. 2013.
9. Institute of Medicine, Dietary reference intakes: The Essential Guide to Nutrient Requirements (2006), vol. 55, no. 9. 2006. [Online].
10. A. Pechova and L. Pavlata, “Chromium as an essential nutrient: A review,” Vet Med (Praha), vol. 52, no. 1, pp. 1–18, 2007.
11. N. George et al., “Nutritional Composition and Anti-Nutrient Levels in Raw and Processed Varieties of Finger Millet Promoted for Nutritional Security,” Food Nutr Sci, vol. 14, no. 12, pp. 1183–1205, 2023.
12. K. SI and B. CG, “Anti-Nutritional Factors in Finger Millet,” J Nutr Food Sci, vol. 06, no. 03, pp. 5–6, 2016.
13. Z. M. Onyambu, M. P. Nawiri, H. N. Nyambaka, and N. M. Noah, “In Vitro Bioaccessibility of the Vitamin B Series from Thermally Processed Leafy African Indigenous Vegetables,” vol. 2021, 2021.
14. Pragya Singh, “Finger millet for food and nutritional security,” African Journal of Food Science, vol. 6, no. 4, pp. 77–84, 2012.

15. A. Chandrasekara and F. Shahidi, "Bioaccessibility and antioxidant potential of millet grain phenolics as affected by simulated in vitro digestion and microbial fermentation," J Funct Foods, vol. 4, no. 1, pp. 226–237, 2012.
16. J. Parada and J. M. Aguilera, "Food microstructure affects the bioavailability of several nutrients," J Food Sci, vol. 72, no. 2, Mar. 2007.
17. M. Kus, I. Ibragimow, and H. Piotrowska-Kempisty, "Caco-2 Cell Line Standardization with Pharmaceutical Requirements and In Vitro Model Suitability for Permeability Assays," Nov. 01, 2023, Multidisciplinary Digital Publishing Institute (MDPI).
18. C. Hotz and R. S. Gibson, "The Journal of Nutrition Symposium: Food-Based Approaches to Combating Micronutrient Deficiencies in Children of Developing Countries Traditional Food-Processing and Preparation Practices to Enhance the Bioavailability of Micronutrients in Plant-Based Diets 1," 2007. [Online].
19. Arzoo, Neeru, A. K. Shukla, S. Panwar, and A. Kumar, "Effect of processing techniques on functional, antioxidants, and structural properties of finger millet (Eleusine coracana) flour," Food and Humanity, vol. 2, p. 100305, May 2024.
20. M. O. K. Azad et al., "Effect of different processing methods on the accumulation of the phenolic compounds and antioxidant profile of broomcorn millet (Panicum miliaceum L.) flour," Foods, vol. 8, no. 7, Jul. 2019.
21. M. Kumari and K. Platel, "Bioaccessibility of trace elements and chromium speciation in commonly consumed cereals and pulses," Int J Food Prop, vol. 20, no. 7, pp. 1612–1620, 2017.
22. S. Đ. Ogo, S. R. Ć, and D. M. Ć, "Analysis of the bioavailability of Cr (III) and Cr (VI) based on the determination of chromium in Mentha piperita by graphite furnace atomic absorption spectrometry Available online at www.shd.org.rs/JSCS/," vol. 76, no. 1, pp. 143–153, 2011.
23. K. Olatunde, K. Adebayo, J. Muhumuza, and B. Bada, "Assessment of variability in proximate/anti-nutritive composition of cocoyam within Nigeria and Uganda," Journal of Applied Sciences and Environmental Management, vol. 22, no. 5, p. 737, Jun. 2018.
24. J. O. Unuofin, G. A. Otunola, and A. J. Afolayan, "Nutritional evaluation of Kedrostis africana (L.) Cogn: An edible wild plant of South Africa," Asian Pac J Trop Biomed, vol. 7, no. 5, pp. 443–449, May 2017.
25. Pierce, "BCA Protein Assay Kit 23225," no. 2161296, pp. 0–3, 2020.
26. A. K. Das, M. N. Islam, M. O. Faruk, M. Ashaduzzaman, and R. Dungani, "Review on tannins: Extraction processes, applications and possibilities," Dec. 01, 2020, Elsevier B.V.
27. A. Chandrasekara and F. Shahidi, "Determination of antioxidant activity in free and hydrolyzed fractions of millet grains and characterization of their phenolic profiles by HPLC-DAD-ESI-MSn," J Funct Foods, vol. 3, no. 3, pp. 144–158, 2011.
28. J. Elzinga, M. Grouls, G. J. E. J. Hooiveld, M. van der Zande, H. Smidt, and H. Bouwmeester, "Systematic comparison of transcriptomes of Caco-2 cells cultured under different cellular and physiological conditions," Arch Toxicol, vol. 97, no. 3, pp. 737–753, Mar. 2023.