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Nutritional Composition and Anti-Nutrient Levels in Raw and Processed Varieties of Finger Millet Promoted for Nutritional Security

Nyabuti George[1], Nawiri Mildred[1], Everlyne Wanzala[1], Judith Munga[1], Chrispus Oduori[2], John Kinyuru[3], Nyambaka Hudson[2]

[1]Department of Chemistry, Kenyatta University, Nairobi, Kenya
[2]Kenya Agricultural and Livestock Research Organization, Kisumu, Kenya
[3]Department of Food Technology, Jomo Kenyatta University of Science and Technology, Nairobi, Kenya
Email: georgeohingo@gmail.com

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Abstract

Finger millet (FM) is rich in nutrients such as minerals, vitamins, and amino acids. However, the levels of nutrients and their bioaccessibility depend on the variety, the levels of ant nutrients, the chemical form of nutrients, and the type of processing methods used. The study determined the levels of selected nutrients, anti-nutrients, and bioaccessibility in raw and processed varieties of finger millet being developed by the Kenya Agricultural and Livestock Research Organization (KALRO) in Kenya. Raw finger millet seeds from KALRO Centers in Kenya were processed by malting for 60 hours and roasting at 110˚C for 5 minutes as the optimal conditions. Levels of minerals were determined by AAS and AES, anti-nutrients by UV-visible spectrophotometer, proteins by the Pierce kit method, and vitamins by HPLC. The IE4115 and IE3779 showed the highest levels of nutrients and lowest levels of antinutrients hence preferred for processing and bioaccessibility studies. The level (mg/100 g) of selected minerals; K, Cr^{3+}, Mg, Ca, P, Fe, and Zn were found to be highest in the following varieties of the FM; IE3779 (688.519 ± 1.57), IE 4115 (1.29 ± 0.07), IE4115 (294.38 ± 1.93), IE3779 (466.67 ± 4.17), IE4115 (250.92 ± 0.33), KERICHO P (16.98 ± 0.05) and IE4115 (64.10 ± 2.35) respectively. For β-carotene, vitamin B, B2, B3, B6 and B9 the levels were highest in the following varieties of FM; KAKW3 (0.023 ± 0.02), IE4115 (14.85 ± 0.16), IE4115 (12.998 ± 0.04), IE4115 (5.843 ± 0.07), IE3779 (0.06 ± 0.04) and KAKW4 (9.832 ± 0.08). Phytates, tannins, phenols, and oxalates were found to be lowest in the following varieties: IE3779 (14.20 ± 2.90, IE4115 (27.83 ± 0.73), NKFM1 (9.69 ± 0.07) and IE4115 (0.25 ± 0.01). The highest bioaccessibility values reported for K, Mg, Ca, P, Cr^{3+}, Fe, and Zn were 89.53% (malting, IE3779), 49.28% (malting, IE4115), 60.41% (Malting, IE4115), 69.40% (malting, IE4115), 12.9% (malting, IE4115), 59.84% (malting, KAKW3) and

66.89% (roasting, IE3779) respectively (**Table 8**). For beta carotene, vitamin B1, B2, B3, B6 and B9 the values were 73.33% (malting, p224), 78.84% (malting, IE4115), 78.34 (malting, IE3779), 97.63% (malting, IE4115), 91.64% (malting, IE4115), and 77.52% (roasting, IE4115) (table The result on levels and bioaccessibility showed that IE4115 and IE3779 varieties were more nutritious and therefore should be promoted for nutritional security.

Keywords

Nutrients, Ant Nutrients, Finger Millet (FM), Malting, Roasting

1. Introduction

Finger millet can be cultivated in arid and semi-arid areas (ASALs) with limited rainfall and can adapt to various agrochemical conditions [1]. The ASALs of Kenya cover over 80% of the total land area and a home to about 38% of Kenya's population. Therefore, there is a need to step up the efforts towards the improvement of FM production to boost food and nutritional security. The annual production of FM worldwide is approximately 5 million tons; India is the largest producer with over 2.5 million tons annually. In Africa, FM is mainly cultivated in Ethiopia, Kenya, Nigeria, Malawi, Tanzania, Uganda, Zimbabwe, and Zambia [2]. According to Chrispus Oduori, KALRO principal researcher based in Kisumu more than 30,000 ha of land in western region of the country is under finger millet and that more than 65,000 ha are under the crop nationally. Finger millet is commonly grown in Kisii, Migori, Busia, Homabay, Kisumu, Siaya, Machakos and Kericho counties. In terms of regions the crop is mainly produced in Nyanza, Eastern, Rift valley, Western, and coastal provinces of Kenya [3]. Finger millet grains are gluten-free, nonacid-forming, easy to digest, and low glycemic index food. Its low glycemic index makes it a good choice for people with non-communicable diseases (NCDs) like cardiovascular diseases, cancer, obesity, T2D, and high blood pressure. The grain also contains dietary fibers, carbohydrates, and minerals like Fe, Ca, Mg, P, K, and Cr^{3+} in higher amounts than other cereals [4]. Finger millet has a crude protein value of 10.28 ± 0.01% (w/w), a zinc value of 22 mg/100g, an iron value of 11 ± 0.01 mg/100g, a calcium value of 113 mg/100g, a potassium value of 1419 mg/100g and sodium value of 686 mg/100g. [5] reported that brown finger millet contains 360 mg/100g of tannins and a phytate content of 150 mg/100g. Tannins reduce the digestibility of proteins and energy. Phytates interfere with mineral absorption especially calcium and Zinc while oxalates affect calcium, magnesium, and protein metabolism. Finger millet also contains important amino acids such as isoleucine, leucine, methionine, phenylalanine, and aspartic acid. These amino acids are often absent in starch-based diets of some subsistence cereals [1]. Potassium is important in the regulation of water and electrolyte and acid-base balance in the body, nerve action, and functioning of muscles, sodium aids the transmission of nerve impulses as well as the maintenance of the osmotic balance of cells, Zinc is es-

sential in the activation of certain enzymes such as dehydrogenase, alkaline phosphatase, and carboxypeptidase. Zinc aids in wound healing and the metabolism of nucleic acids and insulin, and magnesium helps reduce blood pressure, diabetes, and heart attack. Phosphorous is important for energy production and an essential component of adenosine triphosphate (ATP). It forms an essential part of the nervous system and cell membrane. Calcium is important for bone and teeth formation and development. Iron is essential in the formation of hemoglobin in red blood cells [6]. However, finger millet grains contain antinutrients such as phenols, oxalates, and phytates which are known to lower the bioaccessibility of the nutrients, [7]).

From both local and world germplasm collections, FM varieties have been improved over the years. Among the medium-maturing varieties; P224, Gulu. E, Serere, and KA-2 have shown a yield potential of more than 2000 kg/ha under good management [2]. These varieties are recommended for medium potential areas above 1500 meters above sea level. Ekalakala is a local variety that although has a lower yield potential, its early maturing and drought tolerance make it suitable for dry areas like along the lake shores [1]. The local varieties have important traits like Enyakundi and Enyandabu are high yielding and resistant to blast. The improved varieties under study by KARLO before being released to farmers for better production, early maturity and resistance to pests and diseases (see **Table 1**)

However, these antinutrients can be removed by processing methods like roasting and malting which are known to reduce the influence of anti-nutrients and increase the bioaccessibility of the nutrients [8]. Roasting was preferred because it enhances the nutty flavor of the finger millet, reduces the moisture content hence extending the shelf life of the finger millet flour while malting was used because during malting enzymes are activated which assist in breaking down complex compounds into simpler forms. This process enhances vitamins, minerals, and proteins availability. Malting also softens the grain making them easier to chew and digest. This is important for infants, elderly and people with digestive issues. Processing also promotes the consumption of FM among the population [9]. Many people especially in developing countries have limited access to foods that contain the required nutrients such as animal food products which are known to have high levels of proteins, minerals, and vitamin A, hence the need to promote and consume highly nutritious FM food products [10]. To promote nutritional security, the Kenya Agricultural and Livestock Research

Table 1. Categories of finger millet.

Local Early Maturing	Local medium maturing varieties	Improved varieties under study by KARLO	Released Improved varieties
GuluE, Serere, KA-2 P224, Ekalakala	Ikhulule, Khayoni, obokoro Emumware, Aran, Ebinit Endere, morogi, marege Omokoni, Amatugi, Enyandabu Enyakundi	EUFM401, EUFM 502, EUFM503, IE3779, IE4115, IKHLULE, KAKW1, KAKW3, KAKW4, KATF1, KERICHO PEEK, KNE815, MASENO, NKFM1, SEC 915 and SNAPPING P	KNE 479, KNE-1034, IE1010, EKR-227, P283, Okhale-1 and U-15

Organization (KALRO) in Kenya is currently developing various varieties of FM that can be grown in different ecological zones and contain high levels of nutrients. The study determined the levels of nutrients and ant nutrients in raw and processed varieties of FM being developed at the KALRO center.

2. Materials and Methods

2.1. Sample Preparation and Pretreatment

Finger millet seeds from the 18 varieties were obtained from Kenya Agricultural and Livestock Research Organization (KALRO) centers in western Kenya and cleaned by removing foreign matter. The varieties were; EUFM401, EUFM502, EUFM503, IE3779, IE4115, IKHLULE, KAKW1, KAKW3, KAKW4, KATF1, KERICHO PEEK, KNE815, MASENO, NKFM1, P224, SEC 915, SNAPPING P and U-15. The whole millet grains were dehulled using a seed *buro* separated by a seed blower and stored in the cold room at 4˚C.

2.1.1. Malting Finger Millet Flour

Malting was done according to the method [11] with modifications. About 100.390 g of FM grain was soaked in distilled water at 24˚C for 12 hours. The water was carefully decanted then grains were put on a perforated tray covered with cotton wool at 28˚C - 36˚C on a wire mesh for 36 hours with occasional turning in the first 24 hours, for sprouting to occur. The seeds were malted for 36 hours to obtain a sprout measuring about 1.5 cm. The malted grains were then sun-dried to a moisture content of 12% at 28˚C for 2 days. The grains were extruded at 105˚C - 110˚C to achieve a moisture content of 8% followed by grinding into fine powder. The powder was then subjected to extraction and dry digestion processes.

2.1.2. Roasted FM Flour

This was done according to the method by [12]. Approximately 10.65 g of FM grains were soaked in distilled water for 6 hours and then roasted (FZ94 pro-lab Roaster) for 5 minutes at 110˚C. The roasted grains were cooled to room temperature and then 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.

2.2. Reagents and Solvents

All the reagents and solvents used were of analytical grade. Acetone (3:2 V/V), 0.1% Butyl Hydroxy Toluene (BHT), 1M KOH, 10% sodium chloride, Anhydrous sodium sulfate, HPLC grade methanol, 100 ml n-hexane, 50% acetonitrile, 10 ml glacial acetic acid. Commercial standards for K, Se, Zn, Fe, Mg, Ca, P, Cr, thiamin, riboflavin, niacin, pyridoxine, and folic acid and beta carotene. The standards were obtained from Sigma-Aldrich. Acetone and Sep-Pak C 18 (500 mg) cartridges were obtained from Sigma-Aldrich, Germany.

2.3. Instrumentation

UV-VIS spectrophotometer (Model VIS-130) was used for antinutrients analy-

sis, AAS (AA Shimadzu 6200 model) for minerals analysis, HPLC (Shimadzu -62452 Shimadzu) consists of a column oven (Model CTO-10 AS VP), FZ94 pro-lab Roaster Model, Degasser (Model DGU-20A5R), UV-visible detector (Model SPD - 20 A), an autosampler (Model SIL - 20 AHT) and C-18 column (Phenomenex C 18, 250 × 4.6 mm, µm particle size, Luna 5 u) was used in vitamins analysis.

2.4. Proximate Analyses

2.4.1. Determination of Moisture Content

Moisture content was determined using the oven drying method as described in AOAC method number 934.01 [13]. One gram of the sample was weighed using the analytical balance in triplicate a pre-weighed crucible and dried in the hot air oven at 105˚C for 3 hours. The samples were then cooled in a desiccator and reweighed. The percent moisture will be calculated using Equation (1).

$$\%\ \text{moisture} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (1)$$

where, W_1 is the weight of the cleaned dried, and cooled crucible, W_2 is the total weight of the crucible and the sample before Oven heating at 105˚C and W_3 is the weight of the crucible and the dried sample after cooling in airtight desiccators.

2.4.2. Determination of Ash Content

Ash content was determined according to AOAC (Association of Analytical Chemists) method number 923.03 [14]. Two grams of the sample were added into a pre-weighed crucible and incinerated in a muffle furnace at 600˚C for 5 hours. Ash content was determined using Equation (2).

$$\%\ \text{Ash} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (2)$$

where, W_1 is the weight of the cleaned dried, and cooled crucible, W_2 is the total weight of the crucible and the sample before incinerating at 600˚C and W_3 is the weight of the crucible and the incinerated sample after cooling in airtight desiccators.

2.4.3. Determination of Protein Content

Protein content was determined using the Bicinchoninic acid (BCA) protein Assay protocol (Pierce kit). A sample weighing 0.0748 g was weighed into a microtube. A volume of 1000 µl of water was added. The sample was sonicated for about 60 seconds at an amplitude of 10 and placed in an ice-cold mixture. The sample was placed on a centrifuge at 4˚C; 12,000 rpm for 15 minutes. Using a pipette 500 µl of supernatant was transferred into a clear micro tube in an ice-cold mixture. The Bovine serum albumin (BSA) standard was prepared in rows A and B on a 96-well plate (see **Table 2**). In well 1A 65 µl of BSA (2 mg/mL) was pipetted. In wells 2 A to 7 A 25 µl of deionized water was pipetted. This was repeated for wells 1 B through 7 B to have duplicates. A volume of 40 µl

Table 2. Shows a 96 well plate for BCA protein Assay standard.

Well	1A	2A	3A	4A	5A	6A	7A
Conc. (mg/mL)	2	1.23	0.75	0.47	0.28	0.17	0.0
Well	1B	2B	3B	4B	5B	6B	7A

BSA was removed from well 1 A and transferred to well 2 A while gently mixing by pipetting up and down. The pipette tips were switched and the BSA serially diluted up to 6 A on the plate. The well 7A was left to have only 25 µl of water. This resulted in the following concentration of BSA [15]

The sample was diluted such that its concentration fell into the range of the bovine serum albumin (BSA) standard at a ratio of 1:10. The BCA protein assay reagent was mixed with reagent B at a ratio of 50:1 respectively enough to ensure 200 µl per sample. The 200 µl of the sample was then added to each sample and then mixed by pipetting up and down. Finally, the plate was allowed to develop on a shaker at 37˚C for 30 minutes The absorbance at 450 nm was measured by a microplate reader (Biotech Cytation 3, Winooski, VT, USA) [16]

2.4.4. Determination of Crude Fat

Crude fat was determined according to AOAC method number 920.3 [17]. A moisture sample (1.0056 g) was wrapped in filter paper, placed in a fat free thimble and then introduced in the extraction tube. A cleaned weighed and dried beaker was filled with petroleum ether and fitted into the apparatus. The water and the heater were turned on for the extraction process to start. After 5 siphoning the ether was allowed to evaporate and the beaker disconnected before the last siphoning. The extract was transferred into a clean glass and washed with the ether. The ether was evaporated on a water bath. The dish was then placed in an oven at 105˚C for 2 hours and cooled in a desiccator. The percentage crude fat was determined using Equation (3).

$$\%\ \text{Crude fat} = \frac{\text{wt. of ether extract}}{\text{wt. of sample}} \times 100\% \quad (3)$$

2.5. Minerals Analysis

2.5.1. Standard Preparation and Mineral Determination

Standard solutions of K, Zn, Fe, Mg, Ca, P, and total Cr minerals were prepared by serially diluting commercially prepared 1000 ppm stock solution. The stock solutions were prepared in 1% nitric acid to ensure the metal remains in a free ionic state. The serial dilution made working standards of 2 ppm, 4 ppm, 6 ppm, 8 ppm, and 10 ppm for each of the minerals [18].

Approximately 2 g of each sample was weighed using an analytical balance. The sample was placed in a porcelain crucible and placed in a muffle furnace. The sample was heated at 550˚C for 5 hours until white or grey ash was obtained. The residue was dissolved in 10 ml of HNO_3 (25% V/V) to dissolve the residue. The solution was then, filtered using Whatman no. 42 filter paper,

transferred into a 50 ml volumetric flask, and made up to the mark. The blank digest was prepared the same way. The mineral content (Zn, Fe, Mg, K, and total Cr) was determined using ICP MS. In the case of calcium, lanthanum chloride (0.2% of the final volume) was added to avoid interference from phosphorous before determining its content using UV spectroscopy. The concentration in mg/100g was determined by Equation (4).

$$\text{Concentration of element}\left(\text{mg/100 g}\right)=\frac{C\times V\times D\times 100}{W\times 1000} \quad (4)$$

C—Concentration of the sample (mg/l), *V*—Total volume (mL), *D*—Dilution factor;

W—the weight of the sample (g), 1000—conversion of mL to L.

Phosphorous was determined following the method described by [19] with slight modifications. Supernatant clear ash digest solution (5 ml) was pipetted into a 50 ml volumetric flask. About 20 ml of distilled water was added to the flask before 10 ml of ascorbic acid was added and the solution was made to 50 ml using distilled water. The procedure above was replicated for the blank solution. The solutions were left to stand for one hour to permit full-color development. The standard and the sample were measured at 880 nm wavelength using a calorimeter. The total phosphorous was obtained by Equation (5).

$$P\text{ in the sample}=\frac{c\times v\times f}{w} \quad (5)$$

c—Corrected concentration of *p* in the sample, *v*—volume of the digest, and *f* is the dilution factor.

2.5.2. Determination of Chromium (III) Ions

This was done by first determining the concentration of chromium (VI) followed by subtraction from the total chromium as shown by Equation (6).

Chromium (vi) ions

Cr (VI) ions were determined by a method developed by [20] with modifications. Approximately 0.25 g of FM was weighed and transferred into a 100 ml glass beaker. Twenty-five milliliter of 0.1 mol·L^{-1} Na_2CO_3 was added and the content of the beaker was boiled on a hot plate for 15 min. The contents of the beaker were cooled, and after cooling the sample was filtered through Whatman no. 1 filter paper and diluted to a final volume of 25.0 mL with ultrapure water. The solution was kept for the determination of Cr (VI) by AAS.

To obtain chromium (III) Equation (6) was used as follows:

$$\text{Chromium}\left(\text{III}\right)\text{ions}=\text{Total chromium}-\text{chromium}\left(\text{VI}\right)\text{ions} \quad (6)$$

2.6. Vitamin Analysis

2.6.1. Analysis of Beta Carotene

The stock solution of beta carotene was prepared by dissolving 0.100 g of accurately weighed 95% UV β-carotene Type 1 (Sigma Aldrich) in a 100 ml volumetric flask and the solution was made to the mark using 100 ml n-hexane to give a

concentration of 100 ppm. Working standards were freshly prepared by diluting the stock solution with n-hexane to appropriate concentrations ranging from 2 - 10 ppm. The absorbance of the standard solutions (2 - 10 ppm) at 452 nm was used to prepare the calibration curve [21]. The Beta-carotene standard curve was obtained by plotting the peak area against various concentrations of the standard. The concentration of the β-carotene in the sample was obtained by extrapolation from the regression equation.

Beta-carotene was extracted according to the method described by Carbonell-Capella *et al.* (2014). Five grams of the finely ground dry finger millet were accurately weighed using analytical balance and ground using a motor and pestle and then transferred into a 250 ml conical flask, 50 ml mixture of acetone-hexane (3:2 v/v) containing 0.1% Butylated Hydroxy Toluene (BHT) was then added. The BHT was used to ensure no oxidation of the β-carotene in the sample. The mixture was then stirred for 10 minutes using a magnetic stirrer at a moderate speed followed by centrifuging the solution for 10 minutes at 1000 rpm to separate the mixture into organic layer and aqueous layers. The organic layer was transferred into a separating funnel and 25 ml of 0.5M methanolic potassium hydroxide was added to saponify the interfering oils. The solution was shaken and allowed to settle for 30 minutes followed by washing with 100 ml of 10% sodium chloride solution followed by distilled water (three times) to remove the acetone while discarding the aqueous layer continuously. The extract was then filtered over anhydrous sodium sulfate and concentrated in a rotary evaporator at 45˚C [22]. The filtrate was reconstituted using methanol to a 10 ml volumetric flask mark. The volumetric flask was covered with aluminum foil to minimize the destruction of β-carotene by light [23] [24].

Beta–carotene was identified and quantified according to the method described by Bansode *et al.* (2018) with slight modifications. Exactly 20 µl of standard and sample solution was injected into the reverse phase column High-pressure Liquid Chromatography instrument and separation was achieved using a mobile phase of acetonitrile, dichloromethane, and methanol in the ratio of 70:20:10 at the rate of 2 ml per minute. Detection of β-carotene was achieved using a UV-detector at 452 nm [25].

2.6.2. Analysis of Vitamin B Series

The stock solutions of vitamin B_1, B_2, B_3, B_5, B_6, and B_9, were prepared by dissolving 0.01 g of each standard in 100 ml of the extracting solution consisting of 50 ml of acetonitrile and 10 ml of glacial acetic acid made up of 1000 ml with double distilled water. Serial standards were prepared in the ranges of 2 - 10 ppm; by appropriate dilutions with extraction solution and then filtered using 0.45 µm. A calibration line was obtained by plotting the peak area values as a function of the concentration of the vitamin. All stock standard solutions that were not in use were stored at 5˚C [26].

Each sample, 10.00 gm was weighed and transferred into a conical flask. Extracting solution (25 ml) was added and kept on the shaking water bath at 70˚C

for 40 minutes. Thereafter, the sample was cooled down and filtered using a vacuum filter before topping up using the extracting solution. The sample was then filtered through 0.45 µm filter tips. An aliquot of 20 µl from this solution was injected into the HPLC by using an auto-sampler [26] and separated on a reverse phase C18 column with a linear gradient of buffer to methanol (96:4) at a constant flow rate of 1m/min and detected at 210 nm. All analytical solutions were degassed by sonication before injection into the chromatographic system [8].

2.7. Anti-Nutrients Analysis

2.7.1. Determination of Phytates Content

An indirect colorimetric method by Azim *et al.*, (2007) was adopted for phytates content determination. About 2.52 g of the sample was extracted with 10 mL of 3% trichloroacetic acid (TCA) as ferric phytates and converted to soluble sodium phytates by adding 2 mL 1.5 M NaOH. The precipitate was dissolved in hot 3.2 M HNO_3 acid, and its absorbance immediately read at 480 nm. The standard was prepared from Fe $(NO_3)_3$ and the iron content was extrapolated from the Fe $(NO_3)_3$ standard curve. The phytates concentration was calculated from iron concentration determined from the samples assuming a 4:6 Iron: phosphorous molecular ratio [27].

2.7.2. Determination of Oxalate Content

Oxalates were determined according to a method described by [28]. The sample (1.023 g) was weighed in a 100 mL conical flask and 75 mL of 3M H_2SO_4 added, and the solution was stirred intermittently with a magnetic stirrer for about 1 hour, before filtering using Whatman No. 1 filter paper. The sample filtrate (25 mL) was collected and titrated against hot 0.1 M $KMnO_4$ solution at 80˚C to the point where a faint pink color appeared and persisted for at least 30 seconds. The concentration of the oxalates in each sample was determined using Equation (7).

$$1 \text{ mL of } 0.1 \text{ M KM no4} = 0.006303 \text{ g Oxalates} \quad (7)$$

2.7.3. Determination of Phenolic Content

In the preparation of the standard solution for total phenols, gallic acid was accurately weighed (1.101g) and transferred into a 1000 mL volumetric flask, 750 mL of distilled water was added and sonicated in an ultrasonic bath containing about 3 cm^3 of water for 10 minutes until the solid dissolved. The solution was then topped up to the mark to get a 1000 ppm concentration. Serial dilution was used to make working standards.

One (1.00) g of the sample was accurately weighed and transferred into a 100 mL volumetric flask. Distilled water (75 mL) water was added and sonicated in an ultrasonic bath containing 3 cm^3 water for 10 min until the solid dissolved. The solution was made to the mark using distilled water. A volume of 5.0 mL of this solution was pipetted into a 100 mL volumetric flask mixed well and topped up to the mark. A Series 5 test tube each containing 15 mL distilled water and 1 mL Folin-c phenol reagent was set. To the test tubes, 1.00 mL of the sample was

added. The contents were thoroughly mixed and allowed to stand for 6 minutes. Sodium carbonate solution (3 mL) was added to each test tube and mixed well before placing them in a heating block for 120 minutes. The absorbance of total phenol standard solutions, as well as samples, was obtained by using a UV-VIS spectrophotometer wavelength 765 nm. The concentration of the total phenols from the sample was determined through the extrapolation of the standard curve.

The total phenolic content in % w/w was calculated using Equation (8).

$$\text{Total phenolic content } \% \ w/w = \left[(A-b)/m\right]\times\left[(V\times D)/(W\times 1000)\right]\times 100 \quad (8)$$

where,

A—Absorbance of the sample test solution at 765 nm, *b*—y-intercept of the calibration curve, *m*—slope of a calibration curve, *w*—Dry weight of the sample (mg), *D*—Dilution factor (20).

2.7.4. Determination of Tannin Content

The tannin content of the flour samples was determined using the methods described by [29]. The sample (0.215 g) was placed in a 50 mL beaker followed by the addition of 20 mL of 50% methanol. The mixture was then homogenized and placed in a water bath at 80˚C for one hour and the contents were stirred with a glass rod to prevent lumping. The mixture was then filtered using a double-layered Whatman No. 1 filter paper into a 100 mL volumetric flask. The filtrate was then made up to the mark with water and thoroughly mixed. One milliliter extract was pipetted into a 50 mL volumetric flask and 20 mL distilled water, 2.5 mL Folin–Denis reagent (give more details), and 10 mL of 17% Na_2CO_3 were added and mixed. The mixture was then made up to the mark with distilled water, thoroughly mixed, and allowed to stand for 20 min until a blue-green coloration developed. The standard tannic acid solution in the range of 2 - 10 ppm was treated similarly and was used to obtain a standard curve. The absorbances of the tannic acid standard solutions and samples were obtained by a UV-VIS spectrophotometer at 760 nm. The concentration of the tannins from the sample was determined through the extrapolation of the standard curve. The concentration was expressed as catechin equivalent (mg CEQ/g dry weight).

2.7.5. *In Vitro* Gastrointestinal Digestion (GID) (Bioaccessibility Studies)

The *in vitro* GID was carried out according to Chandrasekara and Shahidi (2012). The first stage was the oral stage where 2.5 g of the sample was weighed and then crashed using a motor to obtain fine particle sizes like real mastication. The homogenized sample was put in each of the five digestion tubes. Then 2.5 mL of salivary fluid will be added to the test tube in a ratio of 1:1. The samples were stirred using a magnetic stirrer to mix the salivary fluid with the food sample. This stage lasted for five minutes while maintaining a pH of 6.6.

The gastric stage was started with the addition of 5 mL of gastric fluid containing pepsin. This was to allow the sample to reach a pH equal to 3. Hydroch-

loric acid or sodium hydroxide was used to adjust pH to 3 before shaking and placing the tubes in the water bath at 37˚C for 2 hours. After every 30 minutes the tubes are removed from the water bath to check pH changes HCl and Na OH are used to readjust pH to 3 [30].

After 2 hours of gastric digestion, the intestinal stage was started with the addition of 7.5 mL of the simulated intestinal fluid (0.2M sodium bicarbonate and biliary salts). The addition of this fluid allowed for a pH increase to the physiological value of 6 or 7. The pH meter was used to adjust the pH value using HCl or Na OH solutions. At this point, pancreatic fluid previously dissolved in a necessary volume to target enzyme concentration in the digestion medium was added. The digestion tubes were shaken before being placed in a water bath maintained at 37˚C. After every 30 minutes the tubes are removed from the water bath to check pH changes. The sample pH value was readjusted to 6 or 7 using Na OH or HCl. After 2 hours the samples were taken out from the water bath and quickly introduced into an ice bath for about 10 minutes to inactivate the enzyme activity. The sample pH was adjusted to a value higher than 9 to guarantee enzymatic activity. All the solutions were made to a common volume by adding distilled water to 40 ml. The supernatant fraction containing the bioaccessible vitamin was separated by ultracentrifugation at 70,000 x g for 120 minutes using a Beck-man L7-65 ultracentrifuge. Both supernatant and precipitate were stored in the dark at 4 o C until analysis. Analysis was done by AAS (Se, Zn, Fe, Mg, Ca, P, Cr), FAS (K), HPLC (Beta carotene, Amino acids, B series), UV (Tannins, Phenols), Titration (Oxalates) and FTIR, XRD, SEM (chemical form). The filtrate was analyzed for the nutrients and calculation of bioaccessibility. Percentage bioaccessibility obtained using the Equation (9) described by [31].

$$\% \text{ Bioaccessibility} = \frac{\text{Bioaccessible levels}}{\text{Original content}} \times 100\% \tag{9}$$

2.8. Statistical Analysis

One-way ANOVA at a 95% confidence level was performed to determine whether the significant differences in levels of nutrients between the varieties of FM and between processing and raw were statistically different. Differences were considered significantly at $p > 0.05$.

3. Results and Discussion

3.1. Finger Millet Proximate Analysis

The proximate analysis levels of the 18 varieties of FM are shown in **Table 3** below. The proximate analysis in nutrition is essential for the determination of the nutritional value of food. It enables the determination of moisture, fat ash, and carbohydrate content. This information is crucial for making legitimate comparisons between different foods based on specific nutrients. Moisture or water in the body of an organism acts as a solvent, to transport materials and regulate

the body temperature among other functions [32]. The amount of water in cereals determines the shelf life. This implies that low moisture content in the seeds offers some storage advantages. The varieties IE3779 and IE4115, with a moisture content of 10.05% and 10.03% respectively had the lowest percentage of moisture content, hence better shelf life.

The ash content is the residue after ignition or complete oxidation of organic matter in a food sample. It represents the total mineral content in foods which is expected to speed up metabolic processes and improve growth and development. This is an important nutritional quality attribute for some food ingredients. The percentage ash content in the 18 varieties of FM ranged from 1.27% (KNE815) to 2.95% (KAKW1) with a mean value of 2.28%. The varieties IE4115 and IE3779 have a percentage ash content of 2.92% and 2.50% which represents a better ash content for mineral analysis.

The protein content ranged between 2.66% to 8.58% and a mean value of 6.63%. The results obtained are consistent with those reported which showed the protein content ranging from 5.6% to 12.70% with a mean value of 7%. The protein content for IE4115 and IE3779 were 4.051% and 2.89% respectively. IE 4115 showed higher levels of protein content compared to the other varieties (see Table 3) hence better variety for processing and formulation and should be promoted in Kenya due to its superior nutritional value.

Table 3. Proximate analysis of percentage levels of different varieties of Finger millet.

VARIETY	% ASH	% MOISTURE	% PROTEIN	% FAT	% CARBOHYDRATES
EUFM401	2.07 ± 0.06	12.39 ± 0.05	2.396 ± 0.05	1.25 ± 0.02	81.89 ± 0.01
EUFM502	2.08 ± 0.04	14.54 ± 0.03	2.537 ± 0.03	1.01 ± 0.01	79.83 ± 0.01
EUFM503	2.54 ± 0.16	12.44 ± 0.03	2.445 ± 0.04	1.07 ± 0.11	81.51 ± 0.06
IE3779	2.50 ± 0.08	10.05 ± 0.07	2.859 ± 0.10	1.39 ± 0.06	82.38 ± 0.07
IE4115	2.92 ± 0.002	10.03 ± 0.002	4.051 ± 0.07	1.54 ± 0.03	82.19 ± 0.04
IKHLULE	2.48 ± 0.12	11.87 ± 0.08	2.168 ± 0.09	1.36 ± 0.002	82.13 ± 0.01
K PEEK	2.30 ± 0.25	11.89 ± 0.08	2.199 ± 0.08	1.03 ± 0.002	82.57 ± 0.002
KAK W3	2.18 ± 0.02	10.86 ± 0.10	2.031 ± 0.01	1.16 ± 0.02	83.86 ± 0.001
KAKW1	2.95 ± 0.08	11.09 ± 0.05	3.099 ± 0.05	1.38 ± 0.015	81.47 ± 0.09
KAKW4	2.19 ± 0.06	14.45 ± 0.20	2.450 ± 0.20	1.25 ± 0.010	79.66 ± 0.01
KATF1	2.29 ± 0.07	14.31 ± 0.05	2.312 ± 0.05	1.311 ± 0.02	79.78 ± 0.03
KNE815	1.27 ± 0.03	10.23 ± 0.31	1.225 ± 0.31	1.23 ± 0.023	86.05 ± 0.001
MASENO	1.74 ± 0.09	12.58 ± 0.11	2.577 ± 0.11	1.69 ± 0.008	81.42 ± 0.02
NKFM1	1.55 ± 0.06	11.95 ± 0.05	1.950 ± 0.05	1.17 ± 0.011	83.38 ± 0.14
P224	2.81 ± 0.07	10.41 ± 0.02	2.406 ± 0.02	1.29 ± 0.04	83.09 ± 0.004
SEC915	1.80 ± 0.07	15.60 ± 0.20	1.609 ± 0.20	1.25 ± 0.001	79.73 ± 0.09
SNAPPING	2.62 ± 0.05	11.09 ± 0.07	2.092 ± 0.07	1.33 ± 0.070	82.87 ± 0.001
U-15	2.98 ± 0.005	13.22 ± 0.01	2.222 ± 0.01	1.36 ± 0.16	80.21 ± 0.03

3.2. Levels of Minerals in Raw Finger Millet (FM) Varieties

The mean levels of selected minerals in FM are presented in **Table 4**. The varieties IE 4115 and IE 3779 showed superior nutritional quality in terms of mineral composition compared to the local varieties like U-15. The nutritional profile for IE 4115 was as follows; K (643.48), Cr^{3+} (1.29), Mg (294.38), Ca (333.50), P (250.92), Fe (10.33), and Zn (64.10) mg/100g while that for IE3779 was; K (688.52), Cr^{3+} (1.16), Mg (284.29), Ca (466.67), P (215.67), Fe (10.72) and Zn (51.31) mg/100g (see **Table 4**).The high nutritional level must be related to the low amount of anti-nutrients (Tannins, phytates, phenols, and oxalates. The anti-nutritional content for the two superior varieties was relatively lower compared to the other local varieties with IE 4115 showing (**Table 4**); Tannins 17.10%, Phytates 27.83%, Phenols 15.38% and oxalates 0.38% and IE3779 showing; Tannins 46.09%, Phytates 54.012%, phenols 8.63% and oxalates 0.39%. The levels were significantly different between the varieties ($p < 0.001$). A study by

Table 4. Mean levels of selected minerals in raw finger millet (Mean ± SE) mg/100 g DW.

SAMPLE (n = 3)	K	Mg	Ca	P	Cr^{3+}	Fe	Zn
EUFM401	341.8 ± 45.1^{kl}	286.25 ± 2.17^{ab}	340.83 ± 4.17^{c}	194.00 ± 0.00^{i}	0.87 ± 0.09^{efg}	13.33 ± 0.12^{e}	35.83 ± 0.71^{h}
EUFM502	608.91 ± 9.05^{def}	286.16 ± 2.69^{ab}	437.50 ± 7.22^{b}	169.42 ± 0.08^{o}	0.58 ± 0.03^{hi}	12.37 ± 0.12^{gh}	31.30 ± 0.90^{h}
EUFM503	279.0 ± 0.0^{m}	289.68 ± 4.88^{ab}	287.50 ± 7.22^{g}	213.42 ± 0.17^{e}	1.16 ± 0.09^{bcd}	11.41 ± 0.041^{i}	39.11 ± 1.61^{gh}
IE3779	688.519 ± 1.57^{bc}	284.29 ± 0.271^{ab}	466.67 ± 4.17^{cd}	215.67 ± 0.08^{b}	1.16 ± 0.04^{bcd}	10.72 ± 0.07^{j}	51.31 ± 4.02^{ef}
IE4115	643.48 ± 10.80^{cd}	294.38 ± 1.93^{ab}	333.50 ± 7.22^{h}	250.92 ± 0.33^{b}	1.29 ± 0.07^{a}	10.33 ± 0.06^{j}	64.10 ± 2.35^{b}
IKHULULE	392.03 ± 5.13^{jk}	286.09 ± 3.32^{ab}	345.83 ± 4.17^{cd}	201.83 ± 0.17^{g}	0.55 ± 0.05^{i}	11.92 ± 0.05^{hi}	34.77 ± 2.62^{h}
KAK W3	520.0 ± 26.5^{lm}	283.16 ± 2.69^{ab}	345.83 ± 4.17^{cd}	205.83 ± 0.17^{f}	1.13 ± 0.03^{bcd}	7.93 ± 0.03^{m}	41.181 ± 0.37^{ef}
KAKW1	615.4 ± 0.0^{de}	285.71 ± 4.04^{ab}	416.67 ± 4.17^{ef}	163.17 ± 0.33^{q}	1.19 ± 0.17^{bcd}	9.73 ± 0.07^{k}	39.67 ± 1.69^{de}
KAKW4	555.9 ± 0.0^{fg}	289.22 ± 2.83^{ab}	241.67 ± 4.17^{de}	176.92 ± 0.08^{n}	0.81 ± 0.02^{fg}	8.59 ± 0.08^{l}	48.90 ± 2.78^{efg}
KATF1	428.6 ± 19.9^{ij}	292.30 ± 1.80^{a}	400.00 ± 0.00^{fg}	129.50 ± 0.00^{r}	0.82 ± 0.04^{g}	12.32 ± 0.15^{d}	35.02 ± 1.88^{a}
KERICHO	630.18 ± 13.14^{cde}	292.32 ± 0.403^{a}	466.67 ± 4.17^{cd}	188.83 ± 0.08^{k}	0.91 ± 0.04^{efg}	16.98 ± 0.05^{d}	36.18 ± 1.40^{h}
KNE814	499.15 ± 1.99^{gh}	287.07 ± 3.46^{ab}	470.83 ± 4.17^{c}	191.75 ± 0.00^{j}	0.82 ± 0.02^{fg}	10.59 ± 0.0731	39.09 ± 2.83^{gh}
MASENO	452.05 ± 10.00^{hi}	287.83 ± 0.71^{ab}	458.33 ± 4.17^{cd}	200.42 ± 0.17^{h}	0.52 ± 0.03^{gh}	13.64 ± 0.036^{c}	43.12 ± 2.38^{b}
NK FM1	489.2 ± 0.0^{h}	287.87 ± 3.72^{ab}	412.50 ± 0.00^{fg}	166.00 ± 0.00^{o}	0.75 ± 0.06^{gh}	12.24 ± 0.124^{gh}	47.846 ± 0.69^{fg}
P224	588.5 ± 24.6^{ef}	289.65 ± 1.57^{ab}	445.83 ± 4.17^{cd}	321.67 ± 0.08^{a}	0.76 ± 0.05^{gh}	19.395 ± 0.135^{a}	56.637 ± 0.159^{ef}
SEC915	578.4 ± 23.4^{ef}	288.32 ± 1.86^{ab}	387.50 ± 7.22^{g}	180.17 ± 0.1^{m}	1.05 ± 0.03^{cde}	9.579 ± 0.10^{k}	35.33 ± 1.51^{h}
SNAPPING	492.9 ± 31.5^{h}	286.18 ± 2.87^{ab}	475.00 ± 0.00^{a}	117.83 ± 0.17^{s}	1.21 ± 0.03^{bc}	12.98 ± 0.123^{ef}	34.27 ± 0.05^{h}
U-15	630.1 ± 22.0^{b}	279.99 ± 1.83^{b}	387.50 ± 7.22^{g}	235.33 ± 0.17^{c}	0.99 ± 0.04^{def}	10.423 ± 0.145^{j}	51.74 ± 3.07^{ef}
p-value	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$		$p < 0.001$	$p < 0.001$
(RDI) mg/day	3500	320	1000	500		30	150

Mean values followed by the same small letter(s) within the same column do not differ significantly (SNK-test, $\alpha = 0.05$). RDI Recommended Daily Intake, n is the number of replicas, DW Dry weight.

Font *et al.* (2020) showed Snapping variety has a better nutritional value compared to the local variety U-15 hence prefared to prepare the baby formulation from finger millet and pigeon peas [5] Ramashia *et al.* (2019) reported the levels of P, K, Mg, Ca, Na, Fe, and Zn to be 140, 480, 201, 398, 47, 14.89 and 2.3 mg/100g respectively. In another study, selah *et al.* (2013) reported that FM has a crude protein value of 10.28% ± 0.01% (w/w), a zinc value of 22 mg/100g, an iron value of 11 ± 0.01 mg/100g, calcium value of 113 mg/100g, potassium value of 1419 mg/100g and sodium value of 686 mg/100g.

Minerals have a vital role in maintaining important functions in the human body and their provision in diets in the required amounts is crucial. Studies have shown that some minerals like chromium potentiate the activity of insulin, increase the insulin receptors on the cell surface, and revamp the binding and sensitivity of β cells in the pancreatic improving its functionality in controlling blood sugar [33]. Calcium which is present in FM plays an important role in people suffering from NCDs such as T2D and obesity. The deficiency of calcium in the body can be mitigated by consuming FM and its formulated products. Phosphorous contributes to the development of the body, tissues, and energy metabolism [2]. Iron and magnesium are known for the reduction of high blood pressure and the risk of heart attack [34]. Iron and magnesium are known for the reduction of high blood pressure and the risk of a heart attack. The potassium levels were generally high in all eighteen varieties of FM. Lower potassium levels are also associated with a higher risk of T2D in some studies [35]. Adequate potassium intake, according to the US panel on dietary reference intake is 4.7 g (120 mmol/day) for adults [36] [37].

3.3. Level of Vitamins in Raw Finger Millets

The mean levels (mg/100 g) of selected vitamins in FM are presented in **Table 5**. The IE4115 and IE3779 varieties showed significantly high levels ($p < 0.05$) of vitamins compared with the other varieties. The IE4115 showed B1 (14.85), B2 (12.68), B3 (5.84), B6 (0.62) and B9 (6.07) while IE3779 showed B1 (13.95), B2 (12.98), B3 (5.74), B6 (0.62) and B9 (7.60) mg/100 g per dry weight (see **Table 5**). The recommended daily intake of the B1, B2, B3, B6, B9 is 1.2, 1.4, 16, 1.7 0.4 mg/day respectively. [38] reported that FM is a poor source of β carotene (range between 0 to 0.01 mg/100g) but rich in vitamin B series especially thiamine (B_1)compared to other types of millet. The vitamin B series are important in homeostasis and cellular metabolism; they act as co-enzymes in the metabolism of food to produce energy [39]. The B vitamins also play a role in maintaining healthy skin and muscle tone as well as enhancing immune and nervous function [8]. The deficiency of vitamin B causes diseases such as; beriberi, peripheral neuropathic, pellagra, and genital lesions [39]. Other symptoms of vitamin B deficiency include depression, muscle weakness, asthma, low sperm count, AIDS, multiple sclerosis, lack of coordination, tinnitus, diabetic neuropathy, and in severe cases, death [8].

Table 5. Mean levels of vitamins in raw finger millet (Mean ± SE) mg/100 g.

SAMPLE ID n = 3	β CAROTENE	B1	B2	B3	B6	B9
EUFM401	0.01 ± 0.02^{c}	11.40 ± 0.36^{abcd}	8.73 ± 0.09^{e}	5.28 ± 0.02^{a}	1.24 ± 0.18^{d}	3.39 ± 0.03^{i}
EUFM502	0.01 ± 0.01^{c}	10.38 ± 0.31^{abcd}	11.91 ± 0.06^{d}	0.41 ± 0.01^{hij}	0.76 ± 0.07^{ef}	4.31 ± 0.02^{h}
EUFM503	<LOD	10.04 ± 0.27^{bcd}	7.8 ± 0.09^{f}	4.51 ± 0.01^{e}	0.57 ± 0.02^{f}	0.92 ± 0.09^{k}
IE3779	<LOD	13.95 ± 0.45^{abc}	12.68 ± 0.12^{c}	5.74 ± 0.22^{bc}	0.62 ± 0.04^{f}	7.60 ± 0.08^{c}
IE4115	<LOD	14.85 ± 0.16^{a}	12.98 ± 0.04^{b}	5.84 ± 0.07^{b}	0.62 ± 0.03^{f}	6.07 ± 0.023^{e}
IKHULULE	0.002 ± 0.01^{c}	12.22 ± 0.11^{abcd}	6.65 ± 0.18^{gh}	0.46 ± 0.01^{hi}	0.58 ± 0.06^{f}	<LOD
KAK W3	0.02 ± 0.02^{c}	10.37 ± 0.18^{abcd}	8.30 ± 0.06^{ef}	0.23 ± 0.01^{ijk}	2.89 ± 0.17^{a}	0.75 ± 0.001^{k}
KAKW1	0.01 ± 0.02^{c}	9.91 ± 0.06^{bcd}	5.13 ± 0.06^{i}	5.7 ± 0.08 ^{bc}	0.37 ± 0.02^{f}	3.52 ± 0.06^{i}
KAKW4	<LOD	12.054 ± 0.194^{abcd}	4.79 ± 0.06^{jk}	1.01 ± 0.01^{f}	0.768 ± 0.03^{ef}	9.8 ± 0.08^{b}
KATF1	<LOD	12.62 ± 0.18^{abc}	4.08 ± 0.02^{l}	5.42 ± 0.03^{b}	0.73 ± 0.04^{ef}	8.59 ± 0.18^{a}
KERICHO p	<LOD	7.901 ± 0.0708^{d}	6.88 ± 0.06^{gh}	0.48 ± 0.01^{hi}	0.66 ± 0.03^{f}	1.88 ± 0.01^{j}
KNE814	0.022 ± 0.015^{b}	9.460 ± 0.168^{bcd}	4.46 ± 0.14^{ki}	0.68 ± 0.02^{fgh}	0.72 ± 0.03^{ef}	6.40 ± 0.01^{e}
MASENO	0.02 ± 0.01^{b}	11.59 ± 0.25^{abcd}	4.69 ± 0.05^{jk}	5.57 ± 0.17^{a}	0.66 ± 0.01^{f}	6.14 ± 0.11^{e}
NK FM1	0.01 ± 0.02^{c}	11.38 ± 0.05^{abcd}	4.99 ± 0.14^{jk}	0.17 ± 0.01^{ijk}	0.49 ± 0.07^{f}	4.95 ± 0.046^{g}
P224	0.01 ± 0.009^{c}	11.29 ± 0.13^{abcd}	6.85 ± 0.05^{gh}	0.60 ± 0.01^{gh}	1.25 ± 0.18^{de}	7.06 ± 0.27^{d}
SEC915	<LOD	12.58 ± 0.49^{abcd}	5.616 ± 0.171^{i}	0.07 ± 0.003^{jk}	0.57 ± 0.02^{f}	1.607 ± 0.02^{j}
SNAPPING	0.003 ± 0.002^{c}	9.60 ± 0.240^{cd}	8.31 ± 0.08^{ef}	5.34 ± 0.06^{d}	0.63 ± 0.02^{f}	1.88 ± 0.02^{j}
U-15	0.003 ± 0.004^{c}	11.12 ± 0.04^{abcd}	5.667 ± 0.0273^{i}	0.67 ± 0.06^{fgh}	1.24 ± 0.07^{c}	0.87 ± 0.02^{k}
RDI (mg/day)		1.2	1.4	16	1.7	0.4
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Mean values followed by the same small letter(s) within the same column do not differ significantly from one another (SNK- Test, $\alpha = 0.05$). Where n is the number of replicates. LOD is Lower limits Of Detection.

3.4. Level of Anti-Nutrients in Raw Finger Millet Varieties

The mean levels (mg/100 g) of selected antinutrients in FM are presented in Table 6. The IE4115 and IE3779 varieties showed significantly low levels ($p < 0.05$) of anti-nutrients compared with the other varieties.

The varieties of the FM with the lowest level of tannins, phytates, phenols, and oxalates; IE3779 (14.20 ± 2/90), IE4115 (27.83 ± 0.73), NKFM1 (9.69 ± 0.07) and IE4115 (0.25 ± 0.01) respectively (see Table 6) The results show IE4115 and IE3779 are the best varieties as they contain the lowest level of the antinutrients hence preferred for processing and bioaccessbility studies. Phytates bind with minerals such as Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+}, and Cr^{3+} The formation of the insoluble complexes decreases the availability of these minerals.

The oxalic acid forms water-soluble salts with Na^{+} and K^{+} ions. Oxalic acid binds with Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+}, and Cr^{3+} rendering these minerals unavailable to animals. However, Zn^{2+} appears to be relatively unaffected. The mean daily intake of oxalates has been calculated to be 70 to 150 mg.

Table 6. Mean level of antinutrients in raw finger millet varieties (mg/100 g DW).

SAMPLES	Tannins	Phytates	Phenols	Oxalates
EUFM401	28.70 ± 5.02^{cd}	60.63 ± 1.68^{bcd}	19.87 ± 0.33^{fgh}	0.34 ± 0.02^{fg}
EUFM502	46.09 ± 5.02^{cd}	30.04 ± 0.99^{d}	16.24 ± 0.88^{ijk}	0.50 ± 0.01^{ef}
EUFM503	124.3 ± 34.8^{ab}	67.52 ± 0.73^{bc}	11.61 ± 1.52^{mn}	0.69 ± 0.01^{bcd}
IE3779	14.20 ± 2.90^{d}	54.01 ± 0.28^{cd}	8.63 ± 0.00^{n}	0.39 ± 0.01^{fg}
IE4115	17.10 ± 2.90^{bc}	27.83 ± 0.73^{d}	15.38 ± 0.06^{jk}	0.25 ± 0.01^{g}
IKHLULE	63.48 ± 5.02^{cd}	45.19 ± 0.729^{cd}	20.54 ± 0.57^{efg}	0.37 ± 0.04^{fg}
KAK W3	63.48 ± 5.02^{cd}	59.25 ± 0.73^{cd}	16.89 ± 0.33^{hij}	0.89 ± 0.01^{a}
KAKW1	64.9 ± 16.1^{a}	58.69 ± 0.48^{cd}	21.53 ± 0.57^{defg}	0.58 ± 0.06^{de}
KAKW4	19.20 ± 2.90^{d}	79.09 ± 0.55^{bc}	22.19 ± 0.66^{defg}	0.77 ± 0.01^{abc}
KATF1	46.09 ± 5.02^{cd}	78.81 ± 0.28^{bc}	22.85 ± 1.44^{def}	0.56 ± 0.03^{de}
KERICHO P	63.48 ± 5.02^{bc}	143.57 ± 0.28^{a}	13.92 ± 0.33^{jk}	0.59 ± 0.03^{de}
KNE814	28.70 ± 5.02^{cd}	50.98 ± 1.20^{cd}	29.79 ± 0.33^{ab}	0.329 ± 0.01^{g}
MASENO	40.29 ± 2.90^{cd}	96.18 ± 0.55^{b}	23.51 ± 0.57^{de}	0.57 ± 0.06^{de}
NKFM1	54.78 ± 5.02^{cd}	45.75 ± 0.28^{cd}	9.69 ± 0.07^{nm}	0.84 ± 0.02^{ab}
P224	40.29 ± 2.90^{cd}	50.15 ± 0.55^{cd}	27.15 ± 0.38^{bc}	0.89 ± 0.003^{a}
SEC915	37.391 ± 0.00^{cd}	78.54 ± 0.48^{cd}	13.09 ± 0.29^{klm}	0.38 ± 0.001^{fg}
SNAPPING	63.48 ± 5.02^{cd}	43.26 ± 1.10^{cd}	21.19 ± 0.33^{efg}	0.38 ± 0.01^{fg}
U-15	31.59 ± 2.90^{cd}	59.25 ± 1.20^{bc}	19.21 ± 0.33^{ghi}	0.66 ± 0.031^{cde}
p values	$p > 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$

Tannins are a group of phenolic non-nitrogenous organic constituents that are chemically impairing the digestion of proteins. The tannin–protein complexes may cause digestion enzyme inactivation and protein digestibility reduction caused by protein substrate and ionizable iron interaction [40].

Among the millet varieties, finger millet is reported to contain a high amount of tannins ranging from 0.04% to 3.74% of catechin equivalents [40]. [41] also reported the tannins content of ragi from 0.04% to 3.74% with most of the values falling around 0.6 percent. White grain varieties of the finger millet had low levels of tannins (0.005%) compared with the brown and dark brown varieties (0.61%). The highest number of tannins was found in the two African varieties, IE927 and IE929 [7].

3.5. Level of Anti-Nutrients in Processed Finger Millet

The levels of antinutrients in selected FM varieties are shown in **Table 7**. The selected FM varieties IE4115 and IE3772 showed the lowest levels of antinutrients compared to the other varieties. The lower the levels of the ant nutrients the higher the nutrient [8]. The levels of ant nutrients decreased significantly upon malting for 60 hours in FM. Tannis in IE4115 and IE3779 decreased by 25.32% and 11.58% respectively. Phytates in IE3779 and IE3779 decreased by

Table 7. Mean level of antinutrients in processed finger millet varieties (mg/100 g DW).

TREATMENT	SAMPLES	TANNINS	PHYTATES	PHENOLS	OXALATES
MALTED FM 60 HOURS	IE3779	40.75 ± 3.74^{bcd}	48.15 ± 0.96^{c}	5.33 ± 0.20^{cd}	$0.36.01^{ab}$
	IE4115	12.77 ± 4.76^{b}	25.17 ± 0.74^{d}	8.63 ± 0.00^{e}	0.35 ± 0.06^{b}
	KAK W3	53.8 ± 27.7^{a}	53.68 ± 0.92^{a}	14.28 ± 0.80^{d}	0.73 ± 0.27^{a}
	KAKW1	61.14 ± 10.71^{bc}	54.69 ± 1.58^{b}	20.43 ± 0.17^{b}	0.53 ± 0.14^{ab}
	P224	36.290 ± 1.015^{cd}	48.25 ± 1.26^{b}	25.15 ± 2.23^{a}	0.64 ± 0.05^{ab}
ROASTED FM 110˚C -5 min	IE3779	43.14 ± 0.254^{a}	43.61 ± 2.77^{b}	7.61 ± 2.77^{a}	0.33 ± 0.01^{d}
	IE4115	13.21 ± 5.51^{a}	24.73 ± 5.34^{b}	13.040 ± 0.51^{a}	0.32 ± 0.02^{c}
	KAK W3	47.12 ± 2.23^{a}	46.89 ± 2.89^{a}	12.73 ± 5.34^{a}	0.40 ± 0.09^{a}
	KAKW1	47.68 ± 0.99^{a}	52.69 ± 4.64^{a}	20.8 ± 23.3^{a}	0.46 ± 0.16^{b}
	P224	26.02 ± 1.62^{a}	42.80 ± 2.29^{a}	21.467 ± 0.63^{a}	0.49 ± 0.05^{c}
	p values	**$p > 0.001$**	**$p < 0.001$**	**$p < 0.001$**	**$p < 0.001$**

10.85% and 9.56 respectively. Phenols in IE4115 decreased by 38% and 32.83% while oxalates in IE4115 and IE3779 decreased by 2.56 and 5.26 respectively. Similar observations were made on roasting. Roasting decreased the level of tannins in IE4115 and IE3779 by 6.4% and 22.75% respectively while phytates in IE4115 and IE3779 decreased by 11.14% and 19.26%. Phenols in IE4115 and IE3779 also decreased by 15.21% and 11.82% respectively. Oxalates decreased by 15.79% in both IE4115 and IE37799 (see **Table 7**). These results were like the findings of [9]. [9] reported that fermentation of FM showed a significant reduction of the phytates by 20%, tannins by 52%, and trypsin activity by 32% at the end of 24 hours [38]. This implies malting and roasting improve bioaccessibility by reducing anti-nutritional compounds in FM, thus increasing the health benefits of processing FM.

3.6. Levels of Nutrients in Raw and Processed Finger Millet (Mean ± SE) mg/100 g

The mean levels of nutrients (minerals and vitamins) in raw and processed FM are presented in **Table 8** and **Table 9** respectively. The FM varieties with high levels of minerals on malting and roasting are IE3779 (K), P224 (Mg), IE3779 (Ca), P224 (P), KAKW1 (Cr^{3+}), P224 (Fe), and IE3779 (Zn). The varieties with high levels of β-carotene and B series on (malting or roasting) are KAKW3 (β-Carotene), IE3779 (B1), IE4115 (B2), P224 (B3), KAKW3 (B6) and IE3779 (B6). The levels of minerals were slightly higher on malting but dropped slightly on roasting compared to the raw finger millet (see **Table 8**). This is because fermentation makes several enzymes active increasing the vitamin content [42]. During the fermentation process, the growing microorganisms produce acids or antibiotics as they break down starch. This process, in turn, inhibits spoilage and pathogenic microorganisms and improves the sensory quality and nutritional value of the grains.

Table 8. Mean levels of minerals in raw and processed finger millet (Mean ± SE) mg/100 g.

ID	TYPE	K	Mg	Ca	P	Cr3+	Fe	Zn
	RAW	688.52 ± 1.57^{bc}	284.29 ± 0.27^{ab}	466.67 ± 4.17^{cd}	215.67 ± 0.08^{b}	1.16 ± 0.04^{bcd}	10.72 ± 0.06^{j}	51.31 ± 4.02^{ef}
IE3779	MALT (60 Hrs)	688.7 ± 4.16^{a}	284.00 ± 2.00^{b}	465.8 ± 2.69^{a}	217.7 ± 2.52^{c}	1.16 ± 0.02^{ab}	10.57 ± 0.15^{b}	52.57 ± 0.15^{b}
	RT (110˚C–5 min)	689.5 ± 18.8^{a}	284.66 ± 1.53^{b}	468.00 ± 14.00^{a}	217.7 ± 2.52^{cd}	1.16 ± 0.023^{a}	10.567 ± 0.16^{b}	54.03 ± 2.57^{ab}
	RAW	643.48 ± 10.8^{cd}	281.38 ± 1.93^{ab}	333.50 ± 7.22^{h}	250.92 ± 0.33^{b}	1.13 ± 0.03^{bcd}	10.330 ± 0.1^{j}	51.74 ± 3.07^{ef}
IE4115	MALT (60 Hrs)	643.0 ± 1.27^{b}	281.00 ± 1.00^{b}	333.7 ± 12.34^{c}	253.0 ± 4.36^{b}	1.14 ± 0.14^{a}	10.63 ± 0.55^{b}	51.00 ± 1.00^{b}
	RT(110˚C–5 min)	651.4 ± 3.34^{a}	282.33 ± 1.53^{b}	333.97 ± 12.34^{b}	252.67 ± 4.62^{b}	1.16 ± 0.08^{a}	10.63 ± 0.51^{b}	51.00 ± 1.00^{b}
	RAW	520.0 ± 26.5^{lm}	283.16 ± 2.69^{ab}	345.83 ± 4.17^{cd}	205.83 ± 0.17^{f}	1.29 ± 0.07^{a}	7.93 ± 0.04^{m}	41.18 ± 0.37^{ef}
KAKW3	MALT (60 Hrs)	520.5 ± 0.82^{d}	283.65 ± 0.33^{c}	342.7 ± 0.52^{c}	220.0 ± 1.00^{c}	1.31 ± 0.06^{b}	9.65 ± 0.072^{c}	40.21 ± 0.28^{c}
	RT (110˚C–5 min)	525.3 ± 5.03^{c}	284.67 ± 1.53^{b}	345.16 ± 1.26^{b}	204.17 ± 1.04^{d}	1.19 ± 0.10^{a}	7.69 ± 0.22^{d}	42.97 ± 1.66^{c}
	RAW	588.5 ± 24.6^{ef}	289.65 ± 1.57^{ab}	445.83 ± 4.17^{cd}	321.67 ± 0.08^{a}	0.76 ± 0.05^{gh}	13.33 ± 0.1^{e}	56.64 ± 0.16^{ef}
P224	MALT (60 Hrs)	588.7 ± 1.0^{c}	288.0 ± 1.00^{a}	444.3 ± 1.42^{b}	322.81 ± 10.5^{a}	0.75 ± 0.05^{c}	13.37 ± 0.28^{a}	56.87 ± 0.81^{a}
	RT (110˚C–5 min)	588.8 ± 1.53^{b}	288.67 ± 0.58^{a}	444.27 ± 0.64^{a}	322.83 ± 10.5^{a}	0.753 ± 0.05^{b}	13.40 ± 0.50^{a}	56.80 ± 1.93^{a}

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). GM –Malting. RT-Roasting. n is the number of replicates.

Table 9. Mean level of vitamins in raw and processed finger millet (Mean ± SE) mg/100 g.

SAMPLE n = 3	TYPE	β-CAROTENE	B1	B2	B3	B6	B9
	RAW	<LOD	14.85 ± 0.06^{a}	5.52 ± 0.171^{i}	0.070 ± 0.003^{jk}	0.619 ± 0.04^{f}	7.601 ± 0.08^{c}
IE3779	MALT (60 HRS)	<LOD	14.95 ± 0.10^{a}	5.61 ± 0.171^{i}	5.616 ± 0.17^{i}	0.619 ± 0.04^{f}	7.601 ± 0.04^{c}
	RT (110˚C–5 min)	<LOD	14.80 ± 0.07^{a}	5.54 ± 0.06^{c}	0.06 ± 0.01^{b}	0.610 ± 0.01^{c}	7.46 ± 0.04^{a}
	RAW	<LOD	13.95 ± 0.45^{abc}	12.67 ± 0.2^{c}	0.228 ± 0.04^{ijk}	0.622 ± 0.03^{f}	6.066 ± 0.02^{e}
IE4115	MALT (60 HRS)	<LOD	13.95 ± 0.45^{abc}	12.67 ± 0.12^{c}	12.673 ± 0.119^{c}	0.622 ± 0.03^{f}	6.066 ± 0.03^{e}
	RT (110˚C–5 min)	<LOD	13.88 ± 0.07^{b}	12.61 ± 0.05^{a}	0.22 ± 0.01^{b}	0.618 ± 0.01^{c}	6.04 ± 0.03^{e}
	RAW	0.016 ± 0.03^{c}	10.37 ± 0.182^{abcd}	8.30 ± 0.06^{ef}	5.843 ± 0.07^{b}	2.880 ± 0.17^{a}	0.748 ± 0.001^{k}
KAK W3	MALT (60 HRS)	0.016 ± 0.03^{c}	10.37 ± 0.182^{abcd}	4.79 ± 0.06^{jk}	4.792 ± 0.06^{jk}	0.768 ± 0.03^{ef}	0.608 ± 0.00^{k}
	RT (110˚C–5 min)	0.013 ± 0.01^{a}	11.28 ± 0.01^{c}	6.81 ± 0.04^{b}	0.54 ± 0.06^{b}	1.116 ± 0.01^{a}	7.04 ± 0.01^{b}
	RAW	0.006 ± 0.01^{c}	11.31 ± 0.13^{abcd}	6.85 ± 0.05^{gh}	0.603 ± 0.05^{gh}	1.124 ± 0.18^{de}	7.05 ± 0.27^{d}
P224	MALT (60 HRS)	0.006 ± 0.01^{c}	11.29 ± 0.12^{abcd}	6.85 ± 0.09^{gh}	6.850 ± 0.05^{gh}	1.124 ± 0.18^{de}	7.05 ± 0.25^{d}
	RT (110˚C–5 min)	0.004 ± 0.02^{b}	10.32 ± 0.07^{d}	4.76 ± 0.06^{d}	5.49 ± 0.44^{a}	0.763 ± 0.008^{b}	0.66 ± 0.08^{d}
p-value		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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). GM –Malting. RT-Roasting n is the number of replicates.

Roasting and grinding processes render the grains digestible without the loss of nutritious components. Roasting removes tannins, phytates, phenols, and oxalates and increases storage life [43]. The levels of minerals in the malted and roasted FM did not change significantly compared to those of raw FM. This implies that fermentation and roasting did not affect the levels of the minerals but increased their bioavailability and bioaccessibility.

4. Bioaccessibility of Selected Minerals and *β*-Carotene and Vitamins B Series

The percentage bioaccessibility of nutrients (minerals and vitamins) in raw and processed FM are presented in Table 10 and Table 11 respectively. The highest bioaccessibility values reported for K, Mg, Ca, P, Cr^{3+}, Fe, and Zn were 89.53% (malting, IE3779), 49.28% (malting, IE4115), 60.41% (Malting, IE4115), 69.40% (malting, IE4115), 12.9% (malting, IE4115), 59.84% (malting, KAKW3) and 66.89% (roasting, IE3779) respectively (see Table 10). For beta carotene, vitamin B1, B2, B3, B6 and B9 the values were 73.33% (malting, p224), 78.84% (malting, IE4115), 78.34 (malting, IE3779), 97.63% (malting, IE4115), 91.64% (malting, IE4115), and 77.52% (roasting, IE4115) (see Table 11). The result shows that malting after 60 hours gave the best bioaccessibility result for nutrients (Both minerals and vitamin B series).

Table 10. Bioaccessibility of selected minerals in raw and processed finger millet varieties (%).

VARIETY	TYPE	K	Mg	Ca	P	Cr^{3+}	Fe	Zn
	RAW	69.33%	30.00%	31.77%	29.00%	5.29%	10.83%	24.829%
IE3779	MALT (60 HRS)	79.97%	37.32%	36.85%	43.30%	7.24%	20.36%	37.78%
	RT(110˚C -5 min)	80.9%	35.70%	39.47%	47.35%	8.22%	57.34%	56.79%
	RAW	72.93%	34.92%	53.37%	61.6%	8.84%	32.14%	47.19%
IE4115	MALT (60 HRS)	89.53%	49.28%	60.41%	69.40%	12.9%	33.16%	61.29%
	RT (110˚C -5 min)	88.07%	36.78%	59.85%	67.27%	9.59%	44.59%	66.89%
	RAW	59.64%	20.96%	24.72%	34.92%	7.132%	41.85%	55.08%
KAKW3	MALT (60 HRS)	79.65%	39.19%	31.96%	39.09%	9.334%	59.84%	58.49%
	RT(110˚C -5 min)	78.72%	22.60%	31.50%	37.29%	8.034%	47.97%	56.18%
	RAW	64.12%	31.49%	22.37%	20.50%	5.724%	27.72%	40.38%
P224	MALT (60 HRS)	79.69%	39.17%	34.35%	35.62%	7.57%	31.71%	44.75%
	RT (110˚C -5 min)	75.91%.	34.02%	37.67%	35.30%	7.81%	37.16%	49.40%

Table 11. Percentage bioaccessibility of *β*-carotene and vitamin B series in raw and processed finger millet varieties (%).

VARIETY	TYPE	*Β*-Carotene	B1	B2	B3	B6	B9
	RAW	LOD	74.32%	63.32%	80.00%	88.86%	58.67%
IE3779	MALT (60 HRS)	LOD	77.04%	78.34%	85.67%	86.22%	64.72%
	RT (110˚C -5 min)	LOD	76.6%	77.36%	83.33%	86.89%	64.24%
	RAW	LOD	77.49%	77.39%	60.87%	83.60%	67.76%
IE4115	MALT (60 HRS)	LOD	78.84%	77.24%	97.63%	91.64%	76.77%
	RT (110˚C -5 min)	LOD	76.26%	61.93%	64.4%	88.99%	77.52%
	RAW	55%	67.39%	63.25%	74.79%	25.34%	52.25%
KAKW3	MALT (60 HRS)	71%	68.47%	69.58%	96.03%	66.71%	60.91%
	RT (110˚C -5 min)	60%	49.29%	63.58%	85.19%	63.19%	57.96%
	RAW	53.33%	73.88%	75.33%	61.31%	51.85%	33.84%
P224	MALT (60 HRS)	73.33%	76.32%	76.35%	66.49%	61.64%	54.56%
	RT (110˚C -5 min)	55%	76.77%	64.202%	65.99%	61.58%	62.5%

5. Conclusion

Finger millet varieties IE3779 and IE4115 have the greatest potential to provide nutritional security to people suffering from NCDs, especially T2D, and should be g promoted. They are rich in essential minerals (Cr^{3+} and K) and vitamins B series), which are important in the management of T2D and other NCDs. The varieties also showed decreased levels of anti-nutrients after processing. This study has also shown that processing by roasting and malting lowers the level of the antinutrients namely tannins, phytates, and phenols, thus improving the nutritional quality of FM. The use of the food-based approach to the management of T2D and other NCDs will go a long way to supplement drug therapy. The use of FM has not been fully utilized due to the presence of tannins, phytate, phenols, and oxalates which can be lowered by processing.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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