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Effect of processing on the microbiological, proximate, antinutritional and mineral profile of selected yellow cassava varieties and sorghum malt as potential raw materials for alcoholic beverage production

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Abstract

Sorghum and yellow cassava can be regarded as the top two raw materials in the production of value-added food products due to their rich nutritional and food properties. Thus, this study was carried out to study the effect of these processing methods on the microbiological, proximate, antinutritional, and mineral composition of these raw materials. The raw materials involved two cassava varieties and one sorghum variety. Steeping, germination, and malting decreased the aerobic plate count from values of $2.40 \times 10^6 \pm 0.22$ cfu/g and $1.53 \times 10^6 \pm 0.32$ cfu/g in the sorghum to values of $2.51 \times 10^3 \pm 0.05$ cfu/g and $1.21 \times 10^3 \pm 0.02$ cfu/g respectively ($p < 0.05$). For both cassava varieties, the values ranged between $5.37 \times 10^4 \pm 0.26$ cfu/g and $9.40 \times 10^4 \pm 0.17$ cfu/g in the fresh roots to values of $2.49 \times 10^2 \pm 0.35$ cfu/g and $1.31 \times 10^2 \pm 0.23$ cfu/g in the cassava flours. Significant differences were observed for the values ($p < 0.05$). Malting increased the crude protein to values of 13.51% ± 0.25% and 14.84% ± 0.42% respectively in the sorghum ($p < 0.05$). Processing of cassava roots into flour reduced the protein content from values of 3.12% ± 0.33% and 3.36% ± 0.15% to 2.20% ± 0.18% and 2.44% ± 0.13% respectively. Steeping, germination, and malting decreased the phytate (from 42.37% ± 0.89% to 7.2% ± 0.28%), oxalate (76.97% ± 1.63% to 20.54% ± 0.92%) and tannin (2.85% ± 0.02% to 0.4% ± 0.02%) ($p < 0.05$). It was concluded from the results that steeping, germination, malting, milling, and drying could be used singly or in combination as a processing regime to affect the nutritional profile as well as reduce the antinutritional factors of sorghum and cassava which could be utilized as potential raw materials in the provision of nutritious value-added food products especially in alcoholic beverage production.

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Introduction

Within the grass family Graminae, Sorghum is a cereal crop that comes in over 10,000 identified varieties[1]. Sorghum is a major food crop on multiple continents, including Africa, America, and Asia, and it ranks fifth in the world's grain output rankings[2]. Sorghum is a substantial source of protein, energy, and minerals, which is consumed by millions of underprivileged individuals in Africa and Asia[3]. Together with the B-group vitamins thiamine, niacin, and riboflavin—all of which are present in the aleurone layer, sorghum is abundant in minerals (ash), protein, and fats[4]. The primary components of the endosperm are starch granules, storage proteins, and cell wall components[5]. Numerous traditional dishes, both fermented and non-fermented, such as unleavened bread, porridges, biscuits, cakes, cereal extracts, and malted alcoholic and non-alcoholic beverages, are made with sorghum[6]. Even though sorghum grain has a remarkable variety of nutrients, dishes made from it have remained relatively substandard and ineffective in terms of both nutrition and organoleptic properties[7]. This is primarily because certain food constituents are bound into complexes by anti-nutritional factors (ANF) such as tannin, phytic acid, polyphenol, and trypsin inhibitors, which renders them unsuitable for human nutrition[8]. For instance, these anti-nutritional substances inhibit the corresponding proteolytic and amylolytic enzymes, which reduce the digestibility of proteins and carbohydrates[9]. They also establish the bioavailability of divalent mineral elements, which are essential for the transportation of cofactors in metabolic pathways, the stabilisation of enzymes, and other vital physiological processes[10]. Mature seeds mostly store phosphorus in phytic acid, also known as myoinositol hexaphosphate, which is found

in most plant materials as phytate salt[11]. When it binds to proteins, it chelates metal ions to create protein-mineral-phytate complexes that are extremely insoluble at the normal pH of the human gut[12]. Several techniques have been widely used to enhance the nutritional value and organoleptic properties of dishes made using grain[13]. These include genetic engineering, fortifying foods with amino acids, enhancing diets with sources high in protein, and using processing methods including milling, fermentation, and malting[14]. Additional methods to improve cereal starch digestibility include steaming, pressure cooking, flaking, puffing, or micronizing[15]. The least expensive conventional processing method for removing the nutritional barriers from sorghum-based meals was malting[16]. To extract fermentable materials, a biotechnological process called malting is used[17]. It involves the careful germination of a cereal grain to activate enzyme systems that catalyze the hydrolysis of polymerized reserved food materials, particularly proteins, starches, and cell-wall substances[18].

Some specific sorghum varieties have the potential to be used in beer because they have good malting qualities (high diastatic power and extract yield) and multiple brewing enzymes (α-amylase, β-amylase, and proteinases)[19]. Research institutes have discovered and are currently developing a number of enhanced sorghum varieties with comparatively superior brewing potential[20]. Also, sorghum has been reported to be used in a wide variety of nutritious food products in different parts of the globe[21]. However, sorghum has been shown to contain several antinutritional factors such as phytates and tannins[22]. It is therefore imperative that research be conducted to devise means of either reducing or eliminating these unwanted entities[23].

The largest producer of cassava worldwide is Nigeria. The third-largest source of sustenance for humans worldwide is cassava[24]. Through the joint efforts of the International Institute for Tropical Agriculture (IITA), the National Root Crops Research Institute (NRCRI), and other research institutes, scientific institutions, and government agencies, yellow cassava varieties have been genetically bred, developed, and grown in Nigeria[25]. Beta-carotenes are used to biofortify yellow cassava, which is also a very rich source of vitamin A[26]. Therefore, it is essential that a source of carbohydrates be derived from yellow cassava, an underutilized crop up until now[27]. This would not only be more cost-effective, but it might also help solve some of the looming nutritional deficiencies that are common in Nigeria, particularly those related to vitamin A insufficiency[28]. The importance of the use of yellow cassava in alcoholic beverages cannot therefore be over-emphasized due to its numerous benefits[29].

Thus, this study focused on the effects of several processing regimes on selected varieties of yellow cassava and sorghum which could be used as potential raw materials for the production of nutritious value-added food products.

Materials and methods

Collection of samples and preparation

Yellow cassava varieties *IBA 070539* and *IBA 070593* (5 kg of each variety) were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, Nigeria while Sorghum seeds were obtained from Food and Agro-allied Industries, Sango-Otta, Ogun State, Nigeria, and all the samples were transported to the Biotechnology laboratory of the Federal Institute for Industrial Research Oshodi (FIIRO), Lagos State, Nigeria. Five kilograms of fresh cassava roots from each variety were weighed and prepared individually. Using a Quadrumat Jr. Laboratory mill (Brabender, Duisburg, Germany), the roots were carefully cleaned, peeled, and ground into a thin slurry. The hydrocyanic acid content of the slurry was decreased by pressing and squeezing it. After that, it was dried using a tray dryer (Model HV-105, Delhi, India) and kept at 28 ± 2 °C in a plastic bag until it was used or subjected to additional analysis.

Microbiological analyses of sorghum and yellow cassava varieties

Five grams of samples were weighed into sterile bags and homogenized for 30 s in 90 ml of 0.85% NaCl and 0.1% peptone. To count total aerobic counts, yeasts, molds, and lactic acid bacteria (LAB), respectively, tenfold serial dilutions were produced and the corresponding dilutions spread-plated in triplicate onto Plate Count Agar (PCA), Potato Dextrose Agar (PDA), and MRS (de Man Rogosa and Sharp) agar. For coliforms, the pour plate approach with the second agar overlay was used with Violet Red Bile agar (VRB). For a duration of 24 to 48 h, PCA plates were incubated at 35 °C, MRS plates at 30 °C, VRB plates at 37 °C, and PDA plates at 25 °C. All media preparations were carried out in accordance with the study by Lefyedi et al. [30].

Proximate analyses of sorghum and yellow cassava varieties

Moisture

The method of AOAC (2016)[31] was used to determine the moisture content of the samples. Ten grams of sample was weighed using an analytical balance, which was then dried in an oven for 24 h at 105 °C until it reached a consistent weight. After letting the sample cool to 28 °C in a desiccator, the dry weight was determined by weighing it. Moisture content (given as a percentage) was calculated and found to be the cause of weight loss using the formula:

$$\text{Moisture} = \frac{W_2 - W_3}{W_2 - W_1} \times 100\%$$

Where, W_1 = Weight of empty crucible, in grams, W_2 = Weight of sample + Weight of crucible before drying, in grams, W_3 = Weight of sample + Weight of crucible after drying, in grams.

Crude protein

This micro-kjedhal method was used to determine the crude protein of the samples. It involves wet digestion, distillation, and titration as described by AOAC (2016)[31].

Digestion

In a digestion flask, a combinative mixture of 3 g of dried sample, one catalyst tablet (5 g K_2SO_4, 0.1 g $CuSO_4$, 0.15 g TiO_2) and an anti-bumping agent (5 ml of $Na_2S_2O_3$) was added. To this mixture, 25 ml of concentrated tetraoxosulphate (VI) acid was added followed by thorough shaking of the flask to maintain even wetness of the sample. Heating of the flask was done and stopped on the clearness of solution and termination of gas evolution. Cooling of the flask at 28 ± 2 °C was carried out and the constituents of the flask were transferred to a 100 ml volumetric flask. This was made up to the 100 ml mark using distilled water.

Distillation

Flushing of the distillation apparatus was performed for a period of 5 min. In a 250 ml flask, 25 ml of 2% boric acid was

placed followed by two drops of indicator. The steam trap was dried and the stopcock was left open. The conical flask was placed beneath the condenser to ensure the condenser's tip was completely embedded in the solution. To the same flask, measured 10 ml of the digested sample was added to the flask followed by 20 ml of 40% NaOH solution. This was then pipetted into the steam jacket. Thereafter, the funnel stopcock which was initially left open was closed so that the ammonia that was evolved could trip into the collection flask. A bluish-green color developed immediately and distillation was allowed to continue for a further 5 min. Thereafter the receiving flask was lowered in such a way as to allow the condenser tip to just rise above the liquid. The end of the condenser was rinsed with distilled water. Distillation was carried out for a further 1 min and the process was halted by removal of the burner from the steam generator.

Titration

The solution obtained from the distillation process was titrated against 0.1 N HCl solution. The endpoint was indicated by the solution turning colorless. The same procedure was carried out for the blank solution.

Calculation of the percentage nitrogen (% N) was done using the titre values and obtained using the formula:

$$\text{Percentage Nitrogen} = \frac{(V_{HCl} \times N_{HCl}) - (V_{BK} \times N_{NaOH}) - (V_{NaOH} \times N_{NaOH})}{1.4007} \times W$$

Where V_{HCl} = Volume in ml of standard HCl pipetted into titration flask for sample, N_{HCl} = Normality of HCl, V_{BK} = Volume in ml of standard NaOH needed to titrate 1 ml standard HCl minus B, B = Volume in ml of standard NaOH needed to titrate reagent blank carried through the method and distilled into standard HCl, N_{NaOH} = Normality of NaOH, V_{NaOH} = Volume in ml of standard NaOH needed to titrate the sample, 1.4007 = Milliequivalent weight of nitrogen × 100, W = Weight of sample, in grams.

Thereafter, the calculation of the crude protein (CP) was carried out using the formula:

$$CP = \%N \times 6.25$$

Crude fat

Crude fat was determined using the Soxhlet method as described by AOAC (2016)[31]. Determination of the crude fat was performed using exhaustive soxhlet extraction *via* petroleum ether on a soxhlet extraction system 20 (Foss Tecator). The dry weight of the sample was measured (W_1) and then oven-dried. It was later re-weighed in a crucible (W_2). To a round-bottomed flask three-quarter filled with petroleum ether at 40–60 °C, a soxhlet extractor was fitted with a reflux condenser to regulate the heat sources to prevent rapid boiling of the solvent. The crucible containing the sample was placed in the soxhlet extractor and extraction was carried out under reflux using petroleum ether for a period of 3 h. On completion of extraction, the crucible and extractor were removed. Both were transferred into the oven at 105 °C for 24 h. Cooling was done in the desicator and the new weight (W_3) was measured. The percentage of fat was derived by applying the formula:

$$\text{Fat} = \frac{W_2 - W_3}{W_2 - W_1} \times 100\%$$

Where, $W_2 - W_3$ = loss in weight of sample (extracted fat), $W_2 - W_1$ = Original weight of sample.

Ash

The ash content is defined as the inorganic residue that is left over after burning the organic matter of a sample. The procedure according to AOAC (2016)[31] was employed. Drying of the crucible was performed in an oven at a temperature of 105 °C for a period of 1 h. It was then weighed after cooling in the dessicator[32]. Thereafter, 1 g of sample was weighed and transferred to a muffle furnace (Carbolite, UK) set at 550 °C and allowed to stay overnight. Upon charring, the sample was taken out of the furnace. Cooling of the crucible was done in a dessicator and then the new weight was taken. The total ash content was obtained by applying the equation:

$$\text{Ash}\,(\%) = \frac{W_2 - W_0}{W_1} \times 100\%$$

Where, W_0 = Weight of crucible, W_1 = Weight of sample, W_2 = Weight of crucible and ash.

Antinutritional analyses of sorghum and yellow cassava varieties

Phytate and oxalate of the samples were determined using the method described by Filipiak-Szok et al.[33] with slight modifications while tannin, was by the Folin Denis spectrophotometric method[10]. The hydrogen cyanide of the samples was determined using the method described by Ojha et al.[8]. For hydrogen cyanide, a kjeldahl digestion flask was used to digest the sample, and the distillate was collected in a 250 mL volumetric flask containing NaOH (0.5 g in 20 ml) solution. It was first treated with 5% potassium iodide solution and titrated with 0.02 mol/L $AgNO_3$ solution.

Mineral analyses of sorghum and yellow cassava varieties

The calcium and magnesium content of the samples were determined by the versenate EDTA complexiometric titration method as described by Narola et al.[34]. Phosphorus was determined by the molybdoranadate (yellow) spectrophotometry method described by Ganesh et al.[35], while potassium and sodium were determined using a flame photometer as described by Garcia et al.[36].

Data analysis

Triplicate readings for each parameter were obtained and the average of triplicates was used for all the parameters. SPSS statistical package (version 20) was used to perform analysis of variance (ANOVA) to locate significant differences between the means of triplicates.

Results and discussion

Microbiological analyses of sorghum and yellow cassava varieties

The results of microbiological analyses of the sorghum and yellow cassava varieties are revealed in Tables 1 & 2. The aerobic plate count showed higher values of $2.40 \times 10^6 \pm 0.22$ cfu/g and $1.53 \times 10^6 \pm 0.32$ cfu/g respectively for both sorghum varieties but decreased on steeping to a value of $3.47 \times 10^5 \pm 0.24$ cfu/g and $1.47 \times 10^5 \pm 0.29$ cfu/g respectively. The values showed a steady increase during the germination period from $2.43 \times 10^6 \pm 0.34$ cfu/g and $3.48 \times 10^6 \pm 0.25$ cfu/g respectively for both sorghum varieties on the first day of germination to values of $1.89 \times 10^7 \pm 0.03$ cfu/g and $2.49 \times 10^7 \pm 0.05$ cfu/g respectively after the fifth day of germination. These values

Table 1. Microbiological analyses of processed sorghum varieties.

Sample code	APC (cfu/g)	LAB count (cfu/g)	Fungi count (cfu/g)	Coliform count (cfu/g)
RSA	2400000 ± 217944.90c	33466.70 ± 2000.80a	16000 ± 2291.30b	13766.70 ± 1594.80d
RSB	1530000 ± 320468.40b	45866.70 ± 3000.60a	24333.30 ± 3013.90c	14666.70 ± 2254.60d
SSA	346666.70 ± 23629.10a	4550 ± 360.60a	2533.30 ± 325.30a	5700 ± 2981.60c
SSB	146666.70 ± 29297.30a	5406.70 ± 400.70a	3373.30 ± 335.60a	14766.70 ± 3523.30d
SG1A	2430000 ± 337194.30c	1073466.70 ± 1798332.80a	24000 ± 4272c	1456.70 ± 218.30a
SG1B	3483333.30 ± 251661.10d	4626666.70 ± 250066.70b	38500 ± 4000d	2466.70 ± 354.70ab
SG2A	6463333.30 ± 234591.80e	7816666.70 ± 301385.70c	55533.30 ± 3126.20e	4345.70 ± 3173.30bc
SG2B	10400000 ± 264575.10f	8307666.70 ± 7094475.10c	83333.30 ± 2081.70f	936.70 ± 30.60a
SG3A	15266666.70 ± 208166.60g	173333.30 ± 2516.60a	113000 ± 2000g	167.70 ± 10.70a
SG3B	16300000 ± 458257.60h	213666.70 ± 2516.60a	174000 ± 2000h	224.70 ± 16.20a
SG4A	16166666.70 ± 351188.50h	237666.70 ± 3511.90a	197000 ± 5567.80i	1299.70 ± 1689a
SG4B	18733333.30 ± 550757.10i	355000 ± 3605.60a	210000 ± 3605.60j	403 ± 6a
SG5A	18933333.3 ± 305505i	281666.70 ± 3055.10a	221333.30 ± 8621.70k	50.70 ± 3.50a
SG5B	24933333.30 ± 450925j	419333.30 ± 3511.90a	333333.30 ± 6027.7l	42 ± 1a
FMA	2510 ± 55.70a	158.70 ± 4.20a	1163.30 ± 15.30a	–
FMB	1213.30 ± 20.80a	65 ± 5a	–	–

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where RSA = Raw sorghum variety 1, RSB = Raw sorghum variety 2, SSA = Steeped sorghum variety 1, SSB = Steeped sorghum variety 2, SG1A = Germinated sorghum variety 1 after day 1, SG1B = Germinated sorghum variety 2 after day 1, SG2A = Germinated sorghum variety 1 after day 2, SG2B = Germinated sorghum variety 2 after day 2, SG3A = Germinated sorghum variety 1 after day 3, SG3B = Germinated sorghum variety 2 after day 3, SG4A = Germinated sorghum variety 1 after day 4, SG4B = Germinated sorghum variety 2 after day 4, SG5A = Germinated sorghum variety 1 after day 5, SG5B = Germinated sorghum after day 5, FMA = Finished malt of sorghum variety 1, FMB = Finished malt of sorghum variety 2, ND = Not detected.

Table 2. Microbiological analysis of raw/fresh roots of yellow cassava varieties.

Sample code	APC (cfu/g)	LAB count (cfu/g)	Fungi count (cfu/g)	Coliform count (cfu/g)
RY53	53666.70 ± 2565.80b	335000 ± 23643.20b	45900 ± 2882.70c	5433.30 ± 388.90b
RY59	94033.30 ± 1680.30c	831000 ± 21166c	15100 ± 3143.20b	1440 ± 196.70a
FY53	248.70 ± 35.10a	2340 ± 272.20a	247.30 ± 33.60a	–
FY59	130.70 ± 22.50a	1480 ± 206.60a	124.30 ± 8.10a	–

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where APC = Aerobic Plate Count, LAB = Lactic Acid Bacteria, RY53 = Raw/fresh roots of yellow cassava variety *IBA070539*, RY59 = Raw/fresh roots of yellow cassava variety *IBA070539*, FY59 = Flour of Yellow cassava variety *IBA070593*, FY53 = Flour of Yellow cassava variety *IBA070539, ND* = Not detected.

dropped sharply to values of $2.51 \times 10^3 \pm 0.05$ cfu/g and $1.21 \times 10^3 \pm 0.02$ cfu/g respectively in the finished malt.

For lactic acid bacteria count followed a similar trend from respective values of $3.34 \times 10^4 \pm 0.20$ cfu/g and $4.59 \times 10^4 \pm 0.30$ cfu/g in the raw sorghum varieties to values of $4.55 \times 10^3 \pm 0.36$ cfu/g and $5.40 \times 10^3 \pm 0.40$ cfu/g in the steeped sorghum varieties. The values dropped to $1.58 \times 10^2 \pm 0.04$ cfu/g and $0.65 \times 10^2 \pm 0.05$ cfu/g in the finished malt from higher values of $2.81 \times 10^5 \pm 0.03$ cfu/g and $4.19 \times 10^5 \pm 0.03$ cfu/g in the sorghum varieties after five days of germination.

No fungal colonies were detected in the finished malts of both sorghum varieties even though counts of $1.60 \times 10^4 \pm 0.22$ cfu/g and $2.43 \times 10^4 \pm 0.30$ cfu/g respectively were recorded in the raw sorghum samples which later decreased during steeping and further increased during germination to reach values of $2.21 \times 10^5 \pm 0.09$ cfu/g and $3.33 \times 10^5 \pm 0.06$ cfu/g respectively after day five of the germination period.

Coliforms were recorded in the fresh sorghum samples in the range of $1.38 \times 10^4 \pm 0.16$ cfu/g to $1.47 \times 10^4 \pm 0.23$ cfu/g and decreased during germination and malting, unlike aerobic bacteria, lactic acid bacterial, and fungal counts, so there were not detected in the finished malt.

For the cassava varieties shown in Table 2, the fresh cassava roots had higher aerobic, lactic acid bacteria, fungal and coliform counts compared to the flours of the cassava varieties. The aerobic plate count for both cassava varieties ranged between $5.37 \times 10^4 \pm 0.26$ cfu/g and $9.40 \times 10^4 \pm 0.17$ cfu/g in the fresh roots to values of $2.49 \times 10^2 \pm 0.35$ cfu/g and $1.31 \times 10^2 \pm 0.23$ cfu/g in the flours of the varieties.

The lactic acid bacteria counts ranged between $3.35 \times 10^5 \pm 0.24$ cfu/g and $8.31 \times 10^5 \pm 0.21$ cfu/g in the fresh roots to values of $2.34 \times 10^3 \pm 0.27$ cfu/g and $1.48 \times 10^3 \pm 0.21$ cfu/g in the cassava flours. For fungal count, the values ranged between $4.59 \times 10^4 \pm 0.29$ cfu/g and $1.51 \times 10^4 \pm 0.31$ cfu/g in the fresh samples to reduced values of $2.47 \times 10^2 \pm 0.34$ cfu/g and $1.34 \times 10^2 \pm 0.08$ cfu/g in the processed flours. No coliforms were detected in the cassava flours even though the fresh roots had coliform counts in the range of $5.43 \times 10^3 \pm 0.39$ cfu/g and $1.44 \times 10^3 \pm 0.20$ cfu/g respectively.

The higher microbial counts in the raw sorghum could be a result of contaminants picked up during harvesting and storage[37]. The aerobic plate count for bacteria for the sorghum varieties decreased during steeping but no significant difference was observed ($p > 0.05$). This could be a result of the leaching of the nutrients out of the grains into the steep water making it unavailable to the microorganisms[38]. The aerobic plate count showed a slight increase during germination the period from $2.80 \times 10^6 \pm 0.22$ cfu/g on day 1 to $24.85 \times 10^6 \pm 0.62$ cfu/g on the 5th day of germination. The values showed a prominent reduction in the finished malt probably as a result of the heat treatment and drying during the kilning process[39]. The same trend was observed for the lactic acid bacteria, fungal, and coliform count. In the finished sorghum malt, fungi,

and coliforms were not detected. The drop in fungal count during steeping was probably due to the higher moisture environment created which retarded the growth of the fungi[40]. The rise in microbial counts during germination was maybe a result of the suitable temperature and water activity which favored the growth of the microorganisms. It has been reported that dry conditions limit microbial proliferation[41]. The moisture content of the grains during steeping and germination could have contributed to the rise in microbial counts in this research. Low fungal counts in the malt could help improve the palatability of foods that could be made using them as well as increase consumer acceptability and subsequently increase the profit margins of the producer[42]. The drop in coliform count with an increase in lactic acid bacteria count during the germination period could be a result of the reduced pH created by the generation of lactic acid. This low pH probably inhibited the growth of the coliforms[43]. Also, the increase in fungi count relative to coliforms could be a result of the competitive advantage gained by the fungi which inhibited the proliferation of the coliforms[42].

It was observed that the processing regimes caused a lowering the microbial counts in the raw sorghum to significantly lower values that fall within the recommended safe and acceptable limits for grains that could be used as potential substitutes for barley for brewing and other food uses[44] . The coliform count of the malt showed that it is safe for consumption and utilization for food purposes.

The values for aerobic plate count in the finished sorghum are comparable to those reported by Kazimierska et al.[45]. The values for lactic acid bacteria in the malt are similar to those reported by Byakika et al.[39] while the values for fungal and coliforms aligned with those reported by Babič et al. [46] and Adebayo-Oyetoro et al.[47] respectively. The microbial counts for bacteria and lactic acid bacteria were within recommended limits as spelled out by Mgomi et al.[48]. The increase in the microbial count during germination the period is supported by Hwabejire et al.[49].

The relatively high microbial load of the fresh cassava varieties could have been a result of the poor post-harvest handling activities[50]. The reduction in microbial counts after processing into flours could be due to the lower moisture content created by drying during processing[51]. No coliforms were detected in the flour even though there were substantial amounts in the fresh cassava roots[52]. This is evident that there was the absence of contamination from external sources during the processing regime and a clear pointer to the fact that the cassava flour varieties are safe for consumption and can be utilized for alcoholic beverage production and other food purposes[53]. Also, the aerobic bacteria, lactic acid bacterial and fungal counts of the cassava flours were within the recommended safe and accepted limits. The values for the fresh cassava roots were comparable to the values quoted by Bantadjan et al.[54]. Also, the values for the cassava flours were in agreement with the findings of Zhang et al.[55].

Proximate analyses of sorghum and yellow cassava varieties

Proximate analyses of the sorghum and yellow cassava varieties are presented in Tables 3 & 4. The parameters determined include moisture content, crude protein, fat content, and ash content. The processed yellow cassava flours had lower moisture content than the fresh roots. When compared to variety IBA 070539, the yellow cassava variety IBA 070593 had higher values for all proximal characteristics examined. The statistical analysis's findings showed that there was a highly significant difference in all parameters between the types.

Steeping increased the moisture content of the sorghum samples. Germination for 5 d had little or no effect on the moisture levels of the sorghum samples as the values changed from 41.60% ± 0.20% and 38.08 ± 0.39% after day 1 of germination to values of 41.57% ± 1.03% and 41.42% ± 0.72% respectively after day 5 of germination. However, lower values of 6.84% ± 0.07% and 5.57% ± 0.15% respectively were recorded for the finished malt of the sorghum samples. The yellow cassava varieties had higher moisture content than the sorghum

Table 3. Proximate analysis of processed sorghum varieties.

Sample code	Moisture (%)	Crude protein (%)	Fat (%)	Ash (%)	HCN content (mg/100 g)
RSA	17.75 ± 0.12c	11.39 ± 0.25abc	9.20 ± 0.29i	1.55 ± 0.24cd	2.83 ± 0.12a
RSB	15.46 ± 0.1b	14.85 ± 0.42g	6.50 ± 0.25h	2.57 ± 0.29e	3.08 ± 0.27ab
SSA	40.71 ± 0.16fgh	11.35 ± 0.23abc	3.62 ± 0.25g	1.20 ± 0.16abc	3.28 ± 0.14bc
SSB	34.30 ± 0.20d	14 ± 0.32f	2.45 ± 0.29bc	1.77 ± 0.20d	3.52 ± 0.28c
SG1A	41.60 ± 0.20fgh	11.23 ± 0.29ab	3.55 ± 0.30fg	0.99 ± 0.12a	3.72 ± 0.19cd
SG1B	38.08 ± 0.39e	12.72 ± 0.55e	2.19 ± 0.31a	1.08 ± 0.21ab	4.12 ± 0.36d
SG2A	42.24 ± 1.61ghi	11.27 ± 0.25abc	3.35 ± 0.21efg	0.99 ± 0.25a	4.83 ± 0.33e
SG2B	40.32 ± 1.62fgh	12.12 ± 0.25d	1.69 ± 0.19a	1.01 ± 0.35a	4.61 ± 0.25e
SG3A	43.33 ± 1.68i	11.15 ± 0.30a	3.19 ± 0.23defg	0.93 ± 0.26a	5.82 ± 0.16g
SG3B	42.60 ± 0.90hi	11.88 ± 0.38cd	2.75 ± 0.30cd	1.35 ± 0.22abc	5.34 ± 0.21f
SG4A	42.58 ± 0.70hi	11.07 ± 0.32a	3.16 ± 0.30defg	1.02 ± 0.18ab	5.80 ± 0.17g
SG4B	40.59 ± 0.93fg	11.85 ± 0.46bcd	3.12 ± 0.35defg	1.50 ± 0.15cd	6.55 ± 0.29h
SG5A	41.57 ± 1.03	11.1 ± 0.25a	3.20 ± 0.37defg	0.95 ± 0.19a	6.74 ± 0.32hi
SG5B	41.42 ± 0.72	11.17 ± 0.31a	3.07 ± 0.4def	1.43 ± 0.23bcd	7.15 ± 0.30i
FMA	6.84 ± 0.07a	13.51 ± 0.25f	2.35 ± 0.2bc	1.03 ± 0.19ab	10.32 ± 0.21j
FMB	5.57 ± 0.15a	14.84 ± 0.42g	2.82 ± 0.25cde	1.52 ± 0.15cd	11.46 ± 0.29k

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where RSA = Raw sorghum variety 1, RSB = Raw sorghum variety 2, SSA = Steeped sorghum variety 1, SSB = Steeped sorghum variety 2, SG1A = Germinated sorghum variety 1 after day 1, SG1B = Germinated sorghum variety 2 after day 1, SG2A = Germinated sorghum variety 1 after day 2, SG2B = Germinated sorghum variety 2 after day 2, SG3A = Germinated sorghum variety 1 after day 3, SG3B = Germinated sorghum variety 2 after day 3, SG4A = Germinated sorghum variety 1 after day 4, SG4B = Germinated sorghum variety 2 after day 4, SG5A = Germinated sorghum variety 1 after day 5, SG5B = Germinated sorghum after day 5, FMA = Finished malt of sorghum variety 1, FMB = Finished malt of sorghum variety 2.

Table 4. Proximate analysis of Raw/fresh roots of yellow cassava varieties

Sample code	Moisture (%)	Crude protein (%)	Fat (%)	Ash (%)	HCN content (mg/100 g)
RY53	67.52 ± 0.96b	3.12 ± 0.33b	2.23 ± 0.12c	5.73 ± 0.10c	4.12 ± 0.09c
RY59	73.47 ± 0.86c	3.36 ± 0.15b	1.85 ± 0.11b	6.07 ± 0.13d	3.83 ± 0.08b
FY53	11.33 ± 0.28a	2.20 ± 0.18a	1.27 ± 0.15a	3.32 ± 0.14a	0.27 ± 0.03a
FY59	10.83 ± 0.20a	2.44 ± 0.13a	1.32 ± 0.09a	3.56 ± 0.08b	0.23 ± 0.03a

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where RY53 = Raw/fresh roots of yellow cassava variety *IBA070539*, RY59 = Raw/fresh roots of yellow cassava variety *IBA070539*, FY59 = Flour of Yellow cassava variety *IBA070593*, FY53 = Flour of Yellow cassava variety *IBA070539*.

samples both in the raw and processed form. The increase in the moisture content of the sorghum grains due to steeping could be as a result of the absorption of water by the aleurone layer of the seeds for possible enzyme generation[56]. The lower moisture levels of the sorghum malt could have been a result of the kilning carried out during the process of malting[18]. The moisture content of the fresh cassava roots decreased by 83.22% and 85.26% respectively in the cassava varieties. Significant differences were observed for the values.

The percentage moisture content of cassava flour is an index of its keeping qualities and storage time. Cassava flour with lower moisture has a longer shelf life compared to one with higher moisture content. The result for moisture reveals that yellow cassava variety *IBA 070593* has a relatively longer shelf life than variety *IBA 070539*. The moisture contents of the flour of the two yellow cassava varieties used in this research work were very similar to the literature findings. The values obtained were similar to those reported for cassava varieties *TME 419*, *TME 326*, *TMS 01/1368* and *TMS 3000*[57]. However, the result for moisture content of the yellow cassava varieties was found to be slightly lower than that reported for the variety *TMS98/0505* by Nwokoro et al.[58]. The finished sorghum malt and the flour of the two yellow cassava varieties were lower in moisture, crude protein, and fat content than the raw sorghum variety.

Steeping and germination of the sorghum grains marginally reduced the crude protein content from initial values of 11.39% ± 0.25% and 14.85% ± 0.42% in the raw sorghum samples to values of 11.10% ± 0.25% and 11.17% ± 0.31% respectively in the sorghum samples after five days of germination. However, malting increased the crude protein to values of 13.51% ± 0.25% and 14.84% ± 0.42% respectively. The increase in the crude protein of the sorghum grains on malting could be a result of the hydrolysis of the proteins thereby making them water soluble and readily available[59]. Also, it could have been a result of the mobilization of accessible nitrogen during germination after water uptake *via* steeping by protein-digesting enzymes to cause the formation of easy-to-use amino acids.

The raw sorghum samples had higher crude protein content than the fresh cassava roots. The fresh cassava roots had crude protein values ranging between 3.12% ± 0.33% and 3.36% ± 0.15% compared to the processed cassava flours which had values ranging between 2.20% ± 0.18% and 2.44% ± 0.13% respectively. Significant differences were observed for the values. Processing of the cassava roots into flour which caused a reduction of the protein content could be attributed to the loss of volatile nutrients during the processing regime[60]. This trend is similar to the work of Adebo & Kesa[61].

The crude protein content of the two yellow cassava varieties used in this research work was found to be higher than the values reported for local cassava varieties '*Iboko*' and '*Ohaukwu*', *TMS30572*, *TMS 419* and *TMS 326*[62].

Also, steeping, germination, and malting lowered the fat content of the sorghum grains from starting values of 9.20% ± 0.29% and 6.50% ± 0.25% in the raw sorghum samples to values of 2.35% ± 0.20% and 2.85% ± 0.25% respectively in the sorghum malt. Lowering of the fat content of the sorghum grains during steeping could be as a result of the biochemical and physiological changes occurring during the process as such changes require energy which requires utilization of the fat for such purpose[63]. This finding aligns with the report by Khoddami et al.[64]. Also, it may be that the breakdown of the fats by lipases into glycerin and fatty acids which are easily soluble in water could have led to their diffusion into the endogenous tissues of the grain thereby causing their decrease[65].

The sorghum malt had a higher fat content than the yellow cassava flours. The same applies to the raw sorghum samples and the fresh cassava roots. Conversion of the fresh cassava roots into flour decreased the fat content by 46.19% and 28.65% respectively for the cassava varieties. Significant differences were observed for the values. Fats are important in the building up of the structure of cells and provide alternative energy routes to cells when the need arises. Compared to yellow cassava types UMUCASS 37, UMUCASS 38, and TMS 326, the fat content of the yellow cassava cultivars was much lower. On the other hand, the yellow cassava varieties had a somewhat greater fat content than the TMS05/1636 and TME 419 values[66]. Overall, the fat content values of the yellow cassava varieties included in this study were comparable to those found in other previously released varieties.

The same trend was observed for the ash content of the sorghum varieties as the values decreased from values of 1.55% ± 0.24% and 2.57% ± 0.29% in the raw sorghum samples to values ranging between 1.03% ± 0.19% and 1.52% ± 0.15% in the finished malt. Processing of the fresh cassava roots into flour reduced the ash content by 42.06% and 41.35% respectively in the varieties. The fresh cassava roots had higher ash content than the raw sorghum samples. Also, the flour of the cassava varieties had higher ash content than the finished malt. Significant differences were observed for the values. The ash content of a sample gives a reasonable insight into the amount of inorganic mineral elements that the sample contains. The result of proximate analysis for ash content of the two yellow cassava varieties were found to be higher than that of all six yellow cassava varieties reported by Boakye Peprah et al.[62], as well as varieties *TME 419*, *TMS 326*, '*Iboko*', '*Ohaukwu*', '*Qulle*', '*Kello*' and *TMS30572*[67]. The result obtained for the ash content shows the supremacy of the two yellow cassava varieties used in this research work over all other known varieties so far reported in the literature. It shows that the two yellow cassava varieties possess higher nutritive value than other previously released varieties as reported in the literature.

The cyanide content of the sorghum samples increased as a result of steeping and further increased on germination and malting of the grains. The raw sorghum had values of 2.83 ± 0.12 mg/100 g and 3.08 ± 0.27 mg/100 g which increased on steeping to values of 3.28 ± 0.14 mg/100 g and 3.52 ± 0.28 mg/100 g respectively. These values increased on germination for 5 d to 6.74 ± 0.32 mg/100 g and 7.15 ± 0.30 mg/100 g respectively and further increased on malting to values of 10.32 ± 0.21 mg/100 g and 11.46 ± 0.29 mg/100 g respectively. The cyanide content of the yellow cassava varieties was reduced by processing a into flours. The fresh cassava roots had values of 4.12 ± 0.09 mg/100 g and 3.83 ± 0.08 mg/100 g while the cassava flours had values of 0.27 ± 0.03 mg/100 g and 0.23 ± 0.03 mg/100 g respectively. This indicated a reduction by 93.44% and 94.00% respectively. The yellow cassava roots had higher cyanide content than the raw sorghum varieties. The same cannot be said of the cassava flours and the sorghum malt. Significant differences were observed for the values. The HCN (cyanide) content of the fresh roots of the yellow cassava varieties was lower compared to the values of 4.50 mg/100 g for TMS 81/00110 reported by Boakye Peprah et al.[62]; 16.05 mg/100 g for UM 8082 reported by Odoemelam et al.[66]; and 9.24 mg/100 g for yellow cassava reported by Ramírez et al.[68]. The reduction in the HCN content in the processing of the cassava roots into flour could be attributed to the effect of the processing regime employed which involved milling, pressing and drying[69]. This submission is supported by Baguma et al.[70]. The level of cyanide in the flour of the yellow cassava varieties is lower than the recommended safe limit of 1.00 mg/100 g for cassava flour[66].

Antinutritional analyses of processed sorghum varieties

The results of antinutritional analyses of the sorghum and yellow cassava varieties are depicted in Tables 5 & 6. All three processes of steeping, germination and malting had significant effects on reducing the phytate content of the sorghum samples. Processing of the sorghum samples from steeping to malting decreased the phytate by 83.00% and 80.63% respectively. Also, processing of the fresh cassava roots into flour had a considerable impact on the reduction of phytate in the sample from values of 151.43 ± 0.95 mg/100 g and 128.81 ± 2.17 mg/100 g to values of 109.26 ± 3.15 mg/100 g and 84.85 ± 0.60 mg/100 g respectively. Significant differences were observed for the values. The same trend applies to the oxalate and tannin content of the sorghum samples as well as the cassava roots processed into flour. The oxalate content of the raw sorghum decreased by 64.35% and 61.61% respectively in the finished malt while the tannin content dropped from values of 2.85 ± 0.02 mg/100 g and 1.82 ± 0.03 mg/100 g in the raw sorghum to 0.52 ± 0.03 mg/100 g and 0.40 ± 0.02 mg/100 g respectively in the finished malt. For the processed cassava roots, the oxalate decreased by 48.34% and 56.70% respectively in the cassava flour while the tannin content showed a reduction from values of 72.35 ± 1.89 mg/100 g and 85.50 ± 0.83 mg/100 g to values of 36.40 ± 1.15 mg/100 g and 21.28 ± 1.13 mg/100 g respectively in the cassava flour. Significant differences were observed for the values. The decrease in antinutritional factors during steeping and malting may be a result of modification during the malting process as well as leaching of the antinutrients during steeping, especially tannins. Phytate reduction could have been due to the activities of the enzyme phytase which are inherently present in the grains and which were activated during the germination process. Milling has been reported to reduce the amount of phytate in dehulled grains[71]. The result conforms with the findings of Zhang et al.[72]. For the processed cassava roots, the effect of milling and drying could have caused the leaching of the tannins as well solubilization of enzymes for them to carry out their activities, especially phytase.

Table 5. Antinutritional analyses of processed sorghum varieties.

Sample code	Phytate (mg/100 g)	Oxalate (mg/100 g)	Tannin (mg/100 g)
RSA	42.37 ± 0.89k	76.97 ± 1.63n	2.85 ± 0.02m
RSB	39.55 ± 0.72j	53.5 ± 1.08i	1.82 ± 0.03k
SSA	35.63 ± 1.54i	71.68 ± 0.43m	2.70 ± 0.13l
SSB	34.62 ± 0.93i	51.17 ± 0.69h	1.48 ± 0.03j
SG1A	30.33 ± 0.99h	68.54 ± 1.46l	1.45 ± 0.01ij
SG1B	27.68 ± 1.03g	49.46 ± 0.97gh	1.21 ± 0.02h
SG2A	26.64 ± 0.54g	63.33 ± 0.89k	1.40 ± 0.03i
SG2B	24.33 ± 1.13f	41.57 ± 1.07f	0.84 ± 0.01ef
SG3A	20.55 ± 1.05e	56.84 ± 1.25j	0.95 ± 0.02g
SG3B	19.64 ± 0.84e	39.72 ± 1.07e	0.81 ± 0.01e
SG4A	16.91 ± 0.39d	48.35 ± 0.95g	0.88 ± 0.02f
SG4B	14.26 ± 0.48c	35.47 ± 1.09d	0.72 ± 0.01d
SG5A	13.26 ± 0.52bc	41.77 ± 1.59f	0.81 ± 0.02e
SG5B	12.36 ± 0.28bc	29.33 ± 0.99c	0.63 ± 0.03c
FMA	7.20 ± 0.28a	27.44 ± 0.94b	0.52 ± 0.03b
FMB	7.66 ± 0.22a	20.54 ± 0.92a	0.40 ± 0.02a

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where RSA = Raw sorghum variety 1, RSB = Raw sorghum variety 2, SSA = Steeped sorghum variety 1, SSB = Steeped sorghum variety 2, SG1A= Germinated sorghum variety 1 after day 1, SG1B= Germinated sorghum variety 2 after day 1, SG2A = Germinated sorghum variety 1 after day 2, SG2B = Germinated sorghum variety 2 after day 2, SG3A = Germinated sorghum variety 1 after day 3, SG3B = Germinated sorghum variety 2 after day 3, SG4A = Germinated sorghum variety 1 after day 4, SG4B = Germinated sorghum variety 2 after day 4, SG5A = Germinated sorghum variety 1 after day 5, SG5B = Germinated sorghum after day 5, FMA = Finished malt of sorghum variety 1, FMB = Finished malt of sorghum variety 2.

Table 6. Antinutritional analyses of raw/fresh roots of yellow cassava varieties

Sample code	Phytate (mg/100 g)	Oxalate (mg/100 g)	Tannin (mg/100 g)
RY53	151.43±0.95d	35.58±1.04c	72.35±1.89c
RY59	128.81±2.17c	49.14±2.20d	85.50±0.83d
FY53	109.26±3.15b	18.38±0.88a	36.4±1.15b
FY59	84.85±0.60a	21.28±1.65b	21.28±1.13a

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where RY53 = Raw/fresh roots of yellow cassava variety *IBA070539*, RY59 = Raw/fresh roots of yellow cassava variety *IBA070539*, FY59 = Flour of Yellow cassava variety *IBA070593*, FY53 = Flour of Yellow cassava variety *IBA070539*.

Mineral analyses of sorghum and yellow cassava varieties

The results of mineral analyses of sorghum and yellow cassava varieties are shown in Tables 7 & 8. Steeping of the sorghum grains increased the mineral content and significant differences were observed for all the minerals. The highest increase for the minerals as a result of steeping of the grains was observed for sodium with an increase of 43.79% while the

Table 7. Mineral analyses of processed sorghum varieties.

Sample code	Calcium (mg/100 g)	Magnesium (mg/100 g)	Phosphorus (mg/100 g)	Potassium (mg/100 g)	Sodium (mg/100 g)
RSA	39.34 ± 0.93g	141.75 ± 1.54l	312.02 ± 2.18h	508.39 ± 3.09k	30.90 ± 1.45g
RSB	44.77 ± 0.39i	136.61 ± 0.71k	323.01 ± 2.84i	462.47 ± 2.95h	36.63 ± 1.58hi
SSA	48.57 ± 1.83k	152.73 ± 1.64o	328.38 ± 2.38j	532.25 ± 1.77l	44.43 ± 1.03m
SSB	52.67 ± 1.08l	149.45 ± 1.06n	338.21 ± 2.56k	487.57 ± 2.34j	47.04 ± 0.55n
SG1A	42.52 ± 1.06h	146.14 ± 0.96m	312.45 ± 0.98h	510.17 ± 1.16k	38.37 ± 1.03ij
SG1B	46.72 ± 0.96j	141.53 ± 1.11l	329.41 ± 0.9j	464.66 ± 2.17h	41.93 ± 2.91k
SG2A	36.02 ± 1.24f	136.45 ± 1.01j	306.01 ± 1.47g	486.15 ± 3.69j	34.53 ± 0.79h
SG2B	41.54 ± 1.01h	129.37 ± 0.91i	314.85 ± 2.35h	431.58 ± 2.81f	39.13 ± 2.04j
SG3A	31.47 ± 0.95e	124.50 ± 0.85h	280.13 ± 1.79e	476.60 ± 3.72i	27.35 ± 0.80ef
SG3B	34.67 ± 0.70f	112.49 ± 1.22f	285.6 ± 0.63f	409.45 ± 0.61e	28.62 ± 1.17f
SG4A	30.53 ± 1.14e	116.94 ± 1.65g	263.47 ± 0.71d	463.59 ± 0.71h	25.69 ± 0.84e
SG4B	31.78 ± 1.35e	95.36 ± 0.83e	263.73 ± 2.29d	393.49 ± 0.75d	22.51 ± 1.03d
SG5A	25.57 ± 1.43c	91.35 ± 1.25d	243.25 ± 1.03c	447.04 ± 1.88g	20.38 ± 1.06d
SG5B	28.23 ± 0.58d	86.43 ± 0.62c	245.60 ± 1.53c	372.68 ± 0.82c	16.51 ± 0.82c
FMA	8.61 ± 0.84a	31.55 ± 0.95b	86.83 ± 1.55b	141.29 ± 0.76b	9.99 ± 0.62b
FMB	10.82 ± 1.00b	24.36 ± 1.64a	75.45 ± 0.99a	104.41 ± 0.59a	7.80 ± 0.32a

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where RSA = Raw sorghum variety 1, RSB = Raw sorghum variety 2, SSA = Steeped sorghum variety 1, SSB = Steeped sorghum variety 2, SG1A= Germinated sorghum variety 1 after day 1, SG1B= Germinated sorghum variety 2 after day 1, SG2A = Germinated sorghum variety 1 after day 2, SG2B = Germinated sorghum variety 2 after day 2, SG3A = Germinated sorghum variety 1 after day 3, SG3B = Germinated sorghum variety 2 after day 3, SG4A = Germinated sorghum variety 1 after day 4, SG4B = Germinated sorghum variety 2 after day 4, SG5A = Germinated sorghum variety 1 after day 5, SG5B = Germinated sorghum after day 5, FMA = Finished malt of sorghum variety 1, FMB = Finished malt of sorghum variety 2.

Table 8. Mineral analyses of raw/fresh roots of yellow cassava varieties.

Sample code	Calcium (mg/100 g)	Magnesium (mg/100 g)	Phosphorus (mg/100 g)	Potassium (mg/100 g)	Sodium (mg/100 g)
RY53	16.97 ± 1.28c	25.20 ± 1.43b	21.47 ± 1.00d	104.00 ± 1.41c	17.52 ± 1.15d
RY59	14.17 ± 1.63b	25.67 ± 1.89b	19.23 ± 1.11c	211.10 ± 1.63d	12.61 ± 1.08c
FY53	2.49 ± 0.04a	5.41 ± 0.07a	2.11 ± 0.17b	25.57 ± 1.10b	3.92 ± 0.51b
FY59	1.35 ± 0.05a	6.4 ± 0.10a	0.65 ± 0.10a	15.22 ± 0.99a	1.47 ± 0.07a

Values are shown as mean ± standard deviation of triplicates. Note: All similar alphabets within a column represent mean that are not significantly different ($p > 0.05$). KEY: Where RY53 = Raw/fresh roots of yellow cassava variety *IBA070539*, RY59 = Raw/fresh roots of yellow cassava variety *IBA070539*, FY59 = Flour of Yellow cassava variety *IBA070593*, FY53 = Flour of Yellow cassava variety *IBA070539*.

least increase was for potassium with an increase of 4.69%. This could be a result of the activation of the solubilizing enzymes through hydrolysis which causes the release of soluble nutrients. Also, the chemical reaction from antinutritional complexes could have led to the release of minerals causing their increase[73].

However, germination of the grains caused a reduction in the mineral content for the five days of germination. Significant differences were observed for the values. The greatest reduction due to germination was observed for sodium from day 1 to day 5 of germination with a reduction of 64.90% while the least reduction due to germination was observed for potassium with a reduction of 16.01%. This could have been a result of the use of the mineral element for the build-up of cellular components by the endogenous layers of the grains. This finding is supported by Yu et al.[74].

Malting of the grains caused a further reduction in the mineral content of the grains. Significant differences were observed for the values. The greatest reduction as a result of malting was observed for potassium with a reduction of 72.00% while the least was for sodium with a reduction of 50.98%. This could be attributed to the destruction of the minerals which are unstable to heat during the kilning process. This is similar to the finding of Uheh et al.[75]. Processing of the cassava roots into flour led to a rapid depletion of the mineral contents. The highest depletion of nutrients was noticed for phosphorus with a depletion of 96.62% while the least was observed for magnesium with a depletion of 75.07%. Significant differences were observed for the values. This could have been as a result of the leaching of the nutrients during the processing regime. This finding is similar to that reported by Lu et al.[76].

The results from this research could help beverage industries optimize the conditions of the different types of processing regimes that they employ for alcoholic beverage production especially those methods that do not favor heatin-based on the detrimental effect of heat on nutrients. The automation systems could also be redesigned to meet these specifications. The time for grain steeping and germination could be studied upon to determine the most efficacious condition for optimal nutrient delivery by the grains while paying attention to energy and profit requirements. The level of antinutrients decreasing with manipulation of the processing regime conditions could help in the development and better harnessing of grain quality for beverage production. Also, the conditions of malting of grains could be better improved for optimal yields of products from the substrates. The conditions of the post-harvest handling of the substrates could also be improved to limit the level of microbial contamination of the substrates so that in combination with the processing regimes, the potential of microbial spoilage of products could be drastically minimized and shelf-life extended.

Further research on further different varieties of sorghum and cassava still needs to be explored especially the genetically engineered ones to meet the required specifications of the beverage industries. The use of more accurate and modern methods could be used to compare with the results obtained

via traditional methods. Also, the need to further explore other processing regimes like mashing regimes and fermentation is strongly encouraged to improve the yields obtainable from the substrates.

Conclusions

Sorghum and yellow cassava have good microbiological and nutritional properties which along with other important food properties can be employed for alcoholic beverage production. This potential could be limited if the anti-nutritional properties of these raw materials are not manipulated in such a way as to cause their reduction. This research work has revealed that the processes of steeping, germination, and malting could help enhance the nutritional properties of sorghum as well as reduce its antinutritional properties. The conversion of fresh cassava roots into flour is also an important process towards achieving nutrient upgrade and antinutrient reduction. However, more research has to be conducted to study the effects of these processing regimes on the organoleptic and functional properties of these raw materials.

Therefore, sorghum and yellow cassava can be viewed as potential raw materials that can be employed in the production of value-added food products especially alcoholic beverage products.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Akpoghelie PO, Edo GI, Ali SI, Kasar KA, Zainulabdeen K, Mohammed AA, Jikah AN, Yousif E, Oshoma CE, Omonigho SE, Owheruo JO, Ugbune U, John BE, Agbo JJ; data collection: Akpoghelie PO, Edo GI, Jikah AN; data analysis, draft manuscript preparation: Akpoghelie PO, Edo GI, Jikah AN; study supervision, data analysis, interpretation, and critical revision: Oshoma CE, Omonigho SE, Edo GI, Yousif E. All authors approved the final manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflict of interest

The authors declare that they have no conflict of interest.

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