Hindawi
Journal of Food Quality
Volume 2022, Article ID 2772362, 13 pages
https://doi.org/10.1155/2022/2772362

Research Article

Variations of Nutrient and Antinutrient Components of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.) Seeds

Oluwaseyi Samuel Olanrewaju,[1,2] Olaniyi Oyatomi,[2] Michael Abberton,[2] and Olubukola Oluranti Babalola[1]

[1]*Food Security and Safety Focus Area, Faculty of Natural and Agricultural Sciences, North-West University, Private Bag X2046 Mmabatho 2735, South Africa*
[2]*Genetic Resources Center, International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan 200001, Oyo State, Nigeria*

Correspondence should be addressed to Olubukola Oluranti Babalola; olubukola.babalola@nwu.ac.za

Received 19 May 2022; Accepted 9 September 2022; Published 21 October 2022

Academic Editor: Amjad Iqbal

Bambara groundnut (BGN) fits the bill when it comes to an acceptable level of nutrient and mineral composition. BGN is a balanced food that can help eradicate food and nutritional insecurity if it is incorporated into the major food system. However, there is a large degree of variation in nutrient composition and antinutritional factors among BGN accessions. Here, we show the degree of variability of nutrient and antinutrient components such as percentage ash, moisture, protein, fat, tryptophan, tannin, and phytate contents in seeds of 95 accessions of BGN. Data were subjected to analysis of variance (ANOVA), followed by correlation and principal component analysis. Clustering was done to show the relatedness between the accessions in response to the various traits. A high level of heterogeneity was observed among the accessions for the various traits studied. PC1 and PC2 show 41.2% of the total observed variations. Cluster analysis grouped accessions into four main clusters. This study was able to confirm the high level of diversity in the components of nutrients and antinutrients previously reported in BGN. The results of this study are expected to aid in identifying parent lines for improved breeding programs.

1. Introduction

The world's population is predicted to exceed 9 billion by 2050 [1]. This, along with the impact of climate change, the unavailability of agricultural land, and the reliance on limited species of crop, has hampered the global achievement of food and nutrition security. In Sub-Saharan Africa and parts of Asia, the effect of climate change is erratic. Flooding, drought, and an increase in temperature are experienced in these areas [2, 3]. Farmlands are affected by environmental impacts from climate change effects such as temperature, humidity, rainfall pattern, and changes in light intensity and duration. Erratic yield and, in some cases, total loss have been the results [4]. Although these cannot be attributed to climate change, biotic factors such as pests, rodents, birds, and other small mammals have their fair share of recorded losses. The food being produced is merely meeting the demands of the ever-increasing population. Food and nutrition insecurity is taking its toll on less-developed nations. According to FAO, we will need to produce 60% more food if we are to sustain the population by 2050 (https://www.fao.org/sustainability/en/).

The nutritional and mineral components are vital to the survival of humans and livestock. Lack of an adequate amount of this can result in various fatal illnesses. The developing world is the most vulnerable to nutrient and mineral deficiencies. Nutrients are necessary for proper development, and an adequate supply is present in most crops, but most of these crops are significantly underutilized in the world food system. Most of these crops are an important part of their immediate local food system. One of these food crops is Bambara groundnut (BGN). Due to its high protein content (9.60–40.0%) [5, 6] and a good balance of essential amino acids [7], it is regarded as a complete food

[8, 9]. Hence, it can be a good alternative to meat in terms of protein source [10]. In terms of nutrient components, it competes well with the major food crops, with very few boasting higher nutritional and mineral contents [11]. The high fiber and protein content also makes it an ideal component for animal feed. With all the promising attributes of BGN, it is reported to contain some antinutrient components such as phytates and tannins [12, 13]. These are not good for consumption in large quantities.

Variations in nutrient compositions occupy a unique role in achieving food and nutritional security in the developing world. Diversities in nutrient and mineral composition enhance the reputation of BGN as a complete food. However, the presence of antinutrient factors has a significant effect on the selection and use of some of the accessions. The high level of these factors in these accessions should be taken seriously, as antinutrient factors have been reported to affect the bioavailability of nutrients and minerals by chelating with the required minerals [14], thereby limiting the concentration of nutrients available for use. However, the situation can be taken care of by fermentation of the seeds and other processing methods as reported in some studies [15–17].

In terms of trait improvement, no known varieties of BGN have been developed for improvement. The major hindrance to trait development includes a lack of a complete and well-annotated reference genome for the crop. However, other approaches can be used to improve the crop based on its nutrient and antinutrient composition, such as cooking processes [17]. One such approach is the use of a genome-wide association study (GWAS) approach. GWAS has been used to develop small nucleotide polymorphism (SNP) markers for regions of simple and complex traits in crops [18, 19]. Due to the success of this technology in other crops [19, 20], it would be of great interest if BGN could also benefit from improving its nutrient composition, especially by region mapping the antinutrient components. Locating the region mapping with the antinutrient traits can aid the removal of these traits using advanced technologies like gene editing, thereby producing a safe and nutrient-enriched complete food crop.

How well can BGN improve nutritional security, especially in Sub-Saharan Africa? Most people, especially in the developed world prefer the major crops for their source of nutrients and global acceptability, however, most underutilized crops reportedly contain enough of these nutrients as is found in the major crops. Therefore, in this study, we will the estimate the amount of nutrients and antinutrient components in selected accessions of BGN. Having this information will be key for nutrient-improvement programs in BGN, which will facilitate its incorporation into the food system in ensuring food and nutrition security in Sub-Saharan Africa and the world at large.

2. Materials and Methods

2.1. Source and Preparation of Bambara Groundnut Seed Materials. Ninety-five accessions of BGN seeds obtained from the genetic resource center of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, were selected. The seeds from each accession were milled into powder in the laboratory using a grinder [21]. 20 g of milled seeds were used for the analysis.

2.2. Nutrient Components

2.2.1. Moisture Content. 3 g of the milled sample was weighed in duplicates and placed in moisture canisters. The samples were then placed in an oven (Memmert, GmbH, Model-30-750) for 16 hrs at a temperature of 105°C. The weight was taken every hour until it became constant. The percentage moisture content was calculated according to the formula

$$\%\text{moisture content}\left(\frac{wt}{wt}\right) = \frac{(wt\text{ of wet sample} - wt\text{ of dry sample}) * 100}{wt\text{ of wet sample}}, \quad (1)$$

where wt = weight.

2.2.2. Protein Content. Protein content was estimated from nitrogen content, which was determined by using the micro-Kjeldahl N distillation method followed by multiplication by 6.25. The value of 6.25 is the universally accepted protein content estimation factor. 0.2 g of each powdered sample was weighed into the digestion tubes of a Foss Tecator™ Digestor, and 4 ml of concentrated 98% H_2SO_4 and H_2O_2 were added. The copper tablet was used as the catalyst. The tubes were heated to 420°C in the digestion block until a clear solution was obtained. The resultant was distilled using Kjeltec 2200 distillation apparatus, and automated titer equipment was used for titration. The percentage of protein content displayed on the screen was recorded [22].

2.2.3. Fat Content Determination. The procedure of Official Methods of Analysis (AOAC, 1990) was followed using Foss Soxtec 2055 fat extraction and autoanalyzer equipment. 3.0 g of powdered sample was placed in a tube extracting petroleum ether and heated between 100 and 145°C; the reflux continues until the oil in the samples is leached out of the paper in a cup, leaving the water to evaporate. The oil was now allowed to cool down, and the volume of oil (fat) was obtained by the differential weight after evaporation as compared with the initial weight before evaporation occurred, as shown in the formula:

$$\%\frac{\text{fat}}{\text{oil}} = \frac{((W3 - W2) * 100)}{W1}, \quad (2)$$

where $W3$ = weight of the tube with the extracted oil, $W2$ = weight of the empty tube, and $W1$ = weight of the sample.

2.2.4. Ash Content Determination. The procedure for determining the ash content involves weighing 2 g of the powdered sample in an already known weighed crucible. They were then oven-dried for 4 hours at 105°C, after which they were put in a muffle furnace (Vulcan, Model-3-1750) at 550°C until white ash was obtained [22]. Then, the samples were cooled in a bench-top desiccator and reweighed to estimate the amount of ash. The percentage ash content was calculated:

$$\%\text{ash} = \frac{((\text{weight of crucible} + \text{ash}) - (\text{weight of empty crucible})) * 100}{\text{sample weight}}. \quad (3)$$

2.2.5. Tryptophan Analysis. The determination of the amino acid tryptophan was done as a separate analysis because of its differing hydrolysis conditions. The samples (400 mg) are hydrolyzed under alkaline conditions with saturated barium hydroxide solution heated to 110°C for 20 hours. The hydrolysates were analyzed by reverse-phase liquid chromatography with UV detection at 285 nm using a Waters Breeze HPLC with Empower software (Waters, Millipore Corp., Milford, MA) [23].

2.2.6. Carbohydrate. It was derived from the subtraction of the results obtained from ash, protein, moisture content, and fat from 100, that is, 100 − (ash + protein + moisture content + fat) [24].

2.3. Antinutritional Components

2.3.1. Determination of Phytic Acid. This was analyzed with 1 g of the sample. Extraction and precipitation were done according to the method of Wheeler and Ferrel [25]. The phytic content of the samples was then determined by a 4 : 6 Fe/P atomic ratio.

2.3.2. Determination of Tannins. This was done according to the method of Adegunwa and Alamu [26]. A mixture of 0.5 g samples in 50 ml of distilled water was allowed to stand for 30 mins at 28°C and filtered using Whatman No. 42 filter paper. After dispensing approximately 2 ml of the extract into a 50 ml volumetric flask, standard tannin solution (2 ml) and 2 ml of distilled water were placed in separate volumetric flasks to serve as standards. Folin's reagent and 2.5 ml of saturated NA_2CO_3 solution were added to each flask. The contents of each flask were then made up to 50 ml with distilled water and incubated at 28°C for 90 min. Their absorbance was measured at 260 nm on a spectrophotometer (ThermoFisher Scientific, Model G10 UV-VIS). The blank reagent was used to calibrate the instrument at zero.

2.4. Statistical Analysis. All analysis was done using the R statistical package [27]. Descriptive and summary statistics were computed using the *stat.dev* function in the pastecs package. One-way analysis of variance (ANOVA) was performed using the *lmer* function to determine significant differences between the means of the nutrients and antinutrient components. Fischer's least significant difference (F-LSD) at a probability level of 5% was used to separate the means that were significantly different. The principal component analysis was done with subsequent cluster analysis using the *fviz* function in the FactoMineR package and correlation coefficients to view the groupings and relatedness among these collections of accessions on the different traits.

3. Results

3.1. Descriptive Statistics and ANOVA Analysis. Descriptive statistics showed a significant coefficient of variation (CV > 20) in ash content, moisture content, tryptophan, and tannin contents (Table 1, Figure S1). The ranges of 50.6–69.3, 0.76–6.39, 2.88–13.55, 12.51–26.72, 3.19–9.88, 0.09–0.47, 0.08–0.42, and 3.17–7.42 were recorded for carbohydrate, ash, moisture, protein, fat, tryptophan, tannin, and phytate content, respectively. Among the nutrient components, carbohydrate has the highest range but lowest variation, while phytate has the highest range between the two antinutrient components and the lowest variation. In the ANOVA result (Table 2), all components were highly significant ($p < 0.0001$). The resulting means separation showed a high level of heterogeneity among the accessions for the traits, especially for ash, moisture, phytate, and tryptophan contents (Table 3).

3.2. Principal Component Analysis. When we looked at the variation in nutrient and antinutrient content among the 95 BGN accessions, the first three principal components (PC) with eigenvalues ≥1 described around 62% of the variation (Tables 4, and . The first, second, and third PCs accounted for 29.74%, 17.55%, and 14.45% of the variations, respectively, in the dataset under consideration. The principal components (PC) are represented as dimensions (dim.). PC1 (Dim.1) was mostly influenced by the following characteristics: CHO (40.97%), moisture content (18.58%), protein (16.87%), ash (10.51%), and fat (9.67%). In the second PC (Dim.2), the variables ash, moisture content, tannin, and protein each accounted for 21.33% of the variations, 16.91% of the variations, 42.66% of the

Table 1: Descriptive statistics of the nutrient and antinutrient compositions.

Traits	Mean	Std. error	Std. dev	C.V.	Min	Max	Range
Carbohydrate (%)	58.34	0.30	4.12	0.07	50.6	69.3	18.7
Ash (%)	3.82	0.07	0.91	23.78	0.76	6.39	5.63
MC (%)	8.86	0.19	2.62	29.50	2.88	13.55	10.67
Protein (%)	22.43	0.16	2.12	9.45	12.51	26.72	14.21
Fat (%)	6.49	0.09	1.20	18.51	3.19	9.88	6.69
Tryptophan	0.21	0.00	0.06	30.34	0.09	0.47	0.38
Tannin (%)	0.20	0.01	0.08	40.45	0.08	0.42	0.34
Phytate (mg/100 g)	5.61	0.07	0.95	16.94	3.24	8.32	5.08

†Std. error: standard error; Std. dev: standard deviation; C.V: coefficient of variation in %; Min: minimum; Max: maximum.

Table 2: ANOVA table for each accession's response to the traits measured.

Traits	Sum sq.	Mean sq.	F-value	Pr (>F)	LSD
Carbohydrate	3198.7	34.029	244.19	<2.2e-16***	0.74
Ash	150.538	1.60146	60.483	<2.2e-16***	0.32
Fat	266.28	2.83279	145.43	<2.2e-16***	0.28
Moisture content	1260.6	13.4107	247.2	<2.2e-16***	0.46
Phytate	185.56	1.97404	72.88	<2.2e-16***	0.33
Protein	831.91	8.8501	199.33	<2.2e-16***	0.42
Tannin	1.21367	0.0129	72.365	<2.2e-16***	0.03
Tryptophan	1.376	0.01463	8.454	<2.2e-16***	0.08

†LSD: least significant difference; ***highly significant at $p < 0.0001$.

variations, and 11.56% of the variations. Tryptophan (48.70%) and phytate (40.95%) were the most important contributors to the variation described by PC3 (Dim.3).

The various links between accessions and attributes are depicted in Figure 1. These accessions whose vectors are plotted close to the vector for a specific nutrient or antinutrient component are highly correlated to that nutrient or antinutrient component, whereas the length of a vector for an accession will estimate its mean for that specific nutrient or antinutrient component. An accession that is drawn along with a lengthy vector implies that it has a high mean value for the nutrient or antinutrient that it relates to. In the study of CHO, three accessions were among those identified as being strongly connected with the vector: TVSu-2065, TVSu-2071, and TVSu-2086. A few accessions associated with ash were identified, including TVSu-1859, TVSu-1823, and TVSu-2046, among others. In addition, TVSu-1943, TVSu-1930, and TVSu-1979 were among those identified as being near the vector for moisture content, and the accessions associated with protein were identified as being TVSu-2048, TVSu-2021, and TVSu-1923, among others. There were other accessions in close proximity to the fat vector, including TVSu-1905, TVSu-1952, and TVSu-1899, all of which were identified as such. In terms of tryptophan content, accessions TVSu-2031 and TVSu-1764 were among those found to be associated, whereas accessions TVSu-1918, TVSu-1892, and TVSu-2025 were among those found to relate to tannin content. Phytate is associated with the accession TVSu-1863, which is one of the accessions associated with it.

3.3. Clustering Based on Analyzed Traits. The 95 accessions may be divided into four distinct clusters based on their nutritional and antinutritional features, according to hierarchical clustering (Figure 2). Three clusters with a similar number of accessions were identified. The first cluster had thirteen accessions, whereas the second cluster, with thirty accessions, was the largest. With twenty-five and twenty-seven accessions, the third and fourth clusters followed closely behind the second cluster. The first cluster was defined by accessions with high CHO mean values but low MC mean values. Accessions in the second cluster had high mean values for ash, fat, and phytate content, whereas accessions in the third cluster had low mean values for phytate and fat but a high mean value for MC, and accessions in the fourth cluster had high mean values for tryptophan and tannin (Figure 2).

3.4. Correlation among Nutritional and Antinutritional Components. In the bivariate correlations, it was discovered that the nutrients had varying degrees of association with one another (Figure 3). Asterisks indicate that the correlations are statistically significant at a p value of less than 0.05. Positive correlations are represented by the blue hues, whilst negative correlations are represented by the red colors. The deeper the hue, the greater the degree of negativity or positivity represented by the matrix. Phytate was strongly linked with protein ($r = 0.58$, $p < 0.05$), fat ($r = 0.28$, $p < 0.05$), and ash ($r = 0.58$, $p < 0.05$) in the correlation matrix (Figure 3). Tryptophan correlated negatively with protein content ($r = -0.17$, $p < 0.05$), tannin ($r = -0.10$, $p < 0.05$), and moisture content ($r = 0.43$, $p < 0.5$). Fat correlated positively with moisture content ($r = 0.43$, $p < 0.5$) and tannin ($r = 0.16$, $p < 0.5$). The moisture content and CHO ($r = -0.83$) had the largest negative connection, followed

Table 3: Mean ± standard deviation of nutrient and antinutrient components in each accession.

Accessions	Nutrient components						Antinutrient components	
	CHO	Ash	MC	Protein	Fat	Tryptophan	Tannin	Phytate
TVSu-1470	59.32 ± 0.56^{t-w}	4.16 ± 0.00^{k-t}	7.73 ± 0.35^{BCD}	23.22 ± 0.01^{q-u}	5.59 ± 0.90^{xyz}	0.14 ± 0.00^{n-s}	0.13 ± 0.00^{G-L}	8.32 ± 0.00^{a}
TVSu-1538	59.72 ± 0.03^{r-u}	3.36 ± 0.12^{E-I}	7.55 ± 0.07^{CD}	22.21 ± 0.02^{BCD}	7.16 ± 0.01^{lm}	0.20 ± 0.00^{i-p}	0.09 ± 0.00^{OP}	5.41 ± 0.03^{y-D}
TVSu-1547	59.51 ± 0.06^{s-v}	2.17 ± 0.00^{Q}	7.96 ± 0.01^{A-D}	23.22 ± 0.00^{q-u}	7.16 ± 0.02^{lm}	0.18 ± 0.00^{j-r}	0.12 ± 0.00^{I-N}	5.12 ± 0.00^{D-H}
TVSu-1557	60.32 ± 0.04^{qr}	2.13 ± 0.06^{QR}	8.24 ± 0.08^{w-A}	23.11 ± 0.03^{r-v}	6.21 ± 0.01^{s-v}	0.18 ± 0.00^{j-r}	0.13 ± 0.00^{G-L}	5.65 ± 0.07^{v-A}
TVSu-1574	57.70 ± 0.03^{CDE}	6.16 ± 0.00^{ab}	8.13 ± 0.00^{y-B}	23.06 ± 0.02^{r-v}	4.96 ± 0.00^{BC}	0.14 ± 0.00^{n-s}	0.12 ± 0.01^{J-O}	4.49 ± 0.03^{JK}
TVSu-1589	62.80 ± 0.02^{g}	3.18 ± 0.03^{G-L}	8.48 ± 0.16^{u-y}	19.92 ± 0.12^{MN}	5.63 ± 0.03^{xy}	0.13 ± 0.01^{p-s}	0.13 ± 0.01^{H-M}	5.38 ± 0.07^{z-E}
TVSu-1649	60.33 ± 0.18^{qr}	4.20 ± 0.22^{j-s}	8.17 ± 0.03^{y-B}	22.49 ± 0.04^{y-B}	4.83 ± 0.02^{C}	0.16 ± 0.01^{l-s}	0.11 ± 0.00^{K-P}	4.35 ± 0.10^{JKL}
TVSu-1663	61.90 ± 0.37^{ijk}	4.12 ± 0.30^{l-t}	8.10 ± 0.04^{y-B}	21.10 ± 0.01^{GHI}	4.80 ± 0.00^{C}	0.16 ± 0.01^{l-s}	0.19 ± 0.01^{w-A}	4.05 ± 0.07^{L-O}
TVSu-1664	58.71 ± 0.12^{w-A}	3.99 ± 0.05^{p-w}	8.15 ± 0.06^{y-B}	22.96 ± 0.01^{t-w}	6.20 ± 0.02^{s-v}	0.18 ± 0.01^{j-r}	0.17 ± 0.01^{z-E}	3.78 ± 0.07^{NO}
TVSu-1680	66.35 ± 0.49^{c}	3.86 ± 0.19^{t-A}	8.16 ± 0.10^{y-B}	16.28 ± 0.06^{Q}	5.36 ± 0.00^{yzA}	0.17 ± 0.01^{k-s}	0.17 ± 0.00^{y-D}	4.18 ± 0.06^{KLM}
TVSu-1701	62.58 ± 0.12^{ghi}	3.55 ± 0.13^{A-F}	8.27 ± 0.01^{w-A}	22.40 ± 0.01^{z-C}	3.21 ± 0.02^{D}	0.19 ± 0.01^{j-q}	0.16 ± 0.00^{A-F}	5.96 ± 0.04^{p-v}
TVSu-1706	62.94 ± 0.08^{g}	3.45 ± 0.02^{B-G}	8.32 ± 0.05^{w-A}	19.68 ± 0.00^{NO}	5.61 ± 0.02^{xyz}	0.17 ± 0.01^{k-s}	0.19 ± 0.01^{w-A}	4.62 ± 0.04^{IJ}
TVSu-1724	68.76 ± 0.00^{a}	3.05 ± 0.05^{H-N}	8.49 ± 0.03^{u-y}	12.52 ± 0.00$_{R}$	7.19 ± 0.02^{im}	0.24 ± 0.01^{f-l}	0.19 ± 0.00^{v-z}	5.19 ± 0.00^{C-G}
TVSu-1733	61.90 ± 0.07^{ijk}	3.74 ± 0.20^{v-B}	8.44 ± 0.05^{v-z}	19.70 ± 0.36^{NO}	6.23 ± 0.02^{r-u}	0.20 ± 0.01^{i-p}	0.27 ± 0.01^{l-o}	3.74 ± 0.03^{O}
TVSu-1739	62.02 ± 0.02^{hij}	2.95 ± 0.03^{L-O}	8.63 ± 0.06^{u-x}	19.88 ± 0.00^{MN}	6.53 ± 0.01^{opq}	0.13 ± 0.00^{p-s}	0.38 ± 0.01^{bcd}	4.35 ± 0.03^{JKL}
TVSu-1740	67.77 ± 0.01^{b}	0.85 ± 0.09^{S}	8.69 ± 0.16^{t-w}	17.50 ± 0.06^{P}	5.21 ± 0.01^{AB}	0.35 ± 0.00^{cde}	0.41 ± 0.01^{a}	3.81 ± 0.10^{NO}
TVSu-1742	61.12 ± 0.60^{l-p}	4.12 ± 0.30^{l-t}	8.01 ± 0.10^{z-C}	20.74 ± 0.00^{IJK}	6.02 ± 0.02^{uvw}	0.41 ± 0.01^{abc}	0.18 ± 0.00^{x-C}	4.17 ± 0.07^{KLM}
TVSu-1745	61.21 ± 0.06^{k-o}	3.01 ± 0.18^{K-O}	9.46 ± 0.27^{opq}	20.94 ± 0.48^{HIJ}	5.39 ± 0.01^{yzA}	0.22 ± 0.02^{g-o}	0.14 ± 0.01^{F-K}	6.13 ± 0.07^{n-s}
TVSu-1758	58.67 ± 0.00^{w-A}	3.60 ± 0.11^{y-F}	8.94 ± 0.08^{r-u}	22.23 ± 0.03^{A-D}	6.57 ± 0.01^{opq}	0.23 ± 0.01^{f-l}	0.12 ± 0.01^{J-O}	5.41 ± 0.04^{y-D}
TVSu-1763	61.64 ± 1.04^{jkl}	1.84 ± 0.10^{R}	7.57 ± 0.80^{CD}	23.38 ± 0.02^{o-s}	5.58 ± 0.02^{xyz}	0.22 ± 0.01^{g-o}	0.30 ± 0.01^{h-k}	6.93 ± 0.06^{d-g}
TVSu-1764	59.07 ± 0.21^{u-y}	3.37 ± 0.15^{E-H}	8.53 ± 0.04^{u-y}	22.85 ± 0.03^{u-y}	6.19 ± 0.01^{s-v}	0.23 ± 0.00^{f-l}	0.21 ± 0.00^{t-w}	6.68 ± 0.03^{g-j}
TVSu-1765	59.93 ± 0.99^{rst}	3.19 ± 0.16^{G-L}	9.45 ± 0.16^{opq}	21.83 ± 0.02^{DEF}	5.61 ± 0.05^{xyz}	0.22 ± 0.00^{g-n}	0.27 ± 0.01^{m-p}	5.49 ± 0.03^{y-C}
TVSu-1785	60.89 ± 0.14^{m-q}	3.19 ± 0.02^{G-L}	9.27 ± 0.10^{p-s}	21.83 ± 0.05^{DEF}	4.83 ± 0.02^{C}	0.21 ± 0.01^{h-p}	0.38 ± 0.01^{abc}	6.26 ± 0.07^{l-p}
TVSu-1787	61.48 ± 0.02^{j-n}	3.04 ± 0.10^{J-N}	9.44 ± 0.00^{opq}	19.85 ± 0.24^{N}	6.21 ± 0.01^{s-v}	0.14 ± 0.00^{n-s}	0.40 ± 0.01^{ab}	5.85 ± 0.00^{s-x}
TVSu-1823	57.73 ± 0.02^{CDE}	3.90 ± 0.15^{s-y}	9.13 ± 0.03^{q-t}	23.46 ± 0.02^{n-r}	5.79 ± 0.00^{wx}	0.19 ± 0.01^{j-q}	0.18 ± 0.00^{x-C}	6.37 ± 0.05^{j-n}
TVSu-1836	60.68 ± 0.05^{opq}	3.42 ± 0.04^{C-G}	9.57 ± 0.22^{opq}	19.94 ± 0.11^{MN}	6.40 ± 0.03^{qrs}	0.20 ± 0.01^{i-p}	0.35 ± 0.01^{def}	5.11 ± 0.06^{D-H}
TVSu-1839	57.00 ± 0.02^{EFG}	4.25 ± 0.01^{i-q}	9.34 ± 0.11^{o-r}	23.19 ± 0.01^{r-u}	6.23 ± 0.02^{r-u}	0.19 ± 0.01^{j-q}	0.33 ± 0.00^{efg}	6.15 ± 0.03^{n-s}
TVSu-1843	59.15 ± 0.04^{u-x}	3.68 ± 0.08^{w-E}	8.37 ± 0.02^{w-A}	22.04 ± 0.02^{CDE}	6.77 ± 0.01^{no}	0.23 ± 0.00^{f-l}	0.35 ± 0.00^{ef}	5.48 ± 0.02^{y-C}
TVSu-1850	57.34 ± 0.01^{DEF}	2.50 ± 0.02^{P}	9.13 ± 0.08^{q-t}	24.64 ± 0.04^{d-g}	6.40 ± 0.02^{qrs}	0.21 ± 0.01^{h-p}	0.15 ± 0.00^{D-I}	4.58 ± 0.06^{IJ}
TVSu-1851	55.33 ± 0.27^{M-R}	3.36 ± 0.20^{E-I}	9.64 ± 0.02^{op}	24.92 ± 0.04^{cd}	6.76 ± 0.01^{nop}	0.25 ± 0.01^{f-k}	0.12 ± 0.01^{J-O}	3.90 ± 0.06^{MNO}
TVSu-1859	56.48 ± 0.43^{G-J}	3.99 ± 0.09^{p-w}	9.33 ± 0.21^{o-r}	24.22 ± 0.02^{h-k}	5.99 ± 0.01^{uvw}	0.24 ± 0.01^{f-l}	0.12 ± 0.01^{J-O}	4.16 ± 0.07^{KLM}
TVSu-1863	56.08 ± 0.51^{I-L}	3.44 ± 0.03^{B-G}	10.73 ± 0.08^{c-k}	24.75 ± 0.03^{def}	5.01 ± 0.44^{BC}	0.18 ± 0.00^{j-r}	0.14 ± 0.01^{E-J}	5.24 ± 0.06^{B-F}

Table 3: Continued.

Accessions	Nutrient components						Antinutrient components	
	CHO	Ash	MC	Protein	Fat	Tryptophan	Tannin	Phytate
TVSu-1866	$58.80 \pm 0.50^{v-z}$	$3.40 \pm 0.20^{D-G}$	9.75 ± 0.08^{no}	21.46 ± 0.01^{FG}	6.60 ± 0.24^{opq}	$0.20 \pm 0.01^{i-p}$	$0.17 \pm 0.01^{z-E}$	$5.37 \pm 0.06^{A-E}$
TVSu-1868	$55.71 \pm 0.56^{K-P}$	$3.31 \pm 0.07^{F-K}$	9.43 ± 0.08^{opq}	25.42 ± 0.21^{b}	$6.14 \pm 0.18^{s-v}$	$0.22 \pm 0.01^{g-o}$	$0.28 \pm 0.01^{k-n}$	4.63 ± 0.00^{IJ}
TVSu-1874	$56.38 \pm 0.70^{G-K}$	$3.15 \pm 0.18^{G-M}$	$8.20 \pm 0.08^{x-A}$	$23.68 \pm 0.23^{m-p}$	8.60 ± 0.17^{c}	$0.24 \pm 0.01^{f-l}$	$0.24 \pm 0.01^{p-s}$	$5.06 \pm 0.14^{E-H}$
TVSu-1879	$55.10 \pm 0.13^{O-T}$	$3.04 \pm 0.14^{I-N}$	$10.33 \pm 0.01^{i-m}$	25.60 ± 0.01^{b}	5.94 ± 0.06^{vw}	$0.20 \pm 0.01^{i-p}$	$0.25 \pm 0.01^{o-r}$	$6.24 \pm 0.07^{l-q}$
TVSu-1892	$57.64 \pm 0.06^{C-E}$	$3.37 \pm 0.16^{E-H}$	$10.85 \pm 0.03^{c-h}$	20.79 ± 0.24^{IJK}	7.36 ± 0.01^{kl}	$0.16 \pm 0.01^{l-s}$	$0.29 \pm 0.00^{i-m}$	$6.32 \pm 0.07^{k-o}$
TVSu-1895	$60.44 \pm 0.51^{p-r}$	$2.78 \pm 0.13^{N-P}$	$10.63 \pm 0.03^{d-l}$	20.96 ± 0.47^{HI}	5.20 ± 0.02^{AB}	$0.14 \pm 0.01^{o-s}$	$0.14 \pm 0.00^{E-J}$	$5.09 \pm 0.10^{D-H}$
TVSu-1898	52.59 ± 0.30^{Y}	$4.51 \pm 0.13^{f-j}$	$10.93 \pm 0.00^{c-f}$	$22.59 \pm 0.05^{w-B}$	9.40 ± 0.04^{b}	0.11 ± 0.01^{qrs}	$0.16 \pm 0.01^{B-G}$	$6.19 \pm 0.07^{m-r}$
TVSu-1899	$54.41 \pm 0.25^{T-W}$	$3.75 \pm 0.12^{v-B}$	$10.87 \pm 0.10^{c-h}$	$22.42 \pm 0.03^{z-C}$	8.55 ± 0.02^{c}	$0.14 \pm 0.01^{o-s}$	$0.18 \pm 0.00^{x-C}$	$5.46 \pm 0.07^{y-C}$
TVSu-1905	$54.53 \pm 0.80^{S-W}$	$4.56 \pm 0.11^{e-i}$	$10.80 \pm 0.10^{c-h}$	20.29 ± 0.50^{LM}	9.83 ± 0.05^{a}	$0.16 \pm 0.01^{l-s}$	0.23 ± 0.01^{rst}	$7.03 \pm 0.03^{c-f}$
TVSu-1912	50.85 ± 0.33^{1}	$4.75 \pm 0.06^{d-g}$	$10.74 \pm 0.13^{c-k}$	$24.30 \pm 0.01^{g-j}$	9.37 ± 0.03^{b}	$0.18 \pm 0.01^{j-r}$	$0.28 \pm 0.00^{j-n}$	$6.79 \pm 0.07^{e-i}$
TVSu-1915	51.23 ± 0.03^{Z1}	$4.37 \pm 0.02^{h-n}$	$10.62 \pm 0.04^{e-m}$	$24.20 \pm 0.00^{h-k}$	9.60 ± 0.04^{ab}	$0.20 \pm 0.01^{i-p}$	$0.30 \pm 0.01^{i-l}$	$6.06 \pm 0.06^{n-s}$
TVSu-1918	57.77 ± 0.23^{BCD}	$3.60 \pm 0.11^{y-F}$	$10.63 \pm 0.08^{d-l}$	21.78 ± 0.01^{EF}	$6.23 \pm 0.02^{r-u}$	$0.21 \pm 0.01^{h-p}$	0.35 ± 0.00^{ef}	$5.12 \pm 0.07^{D-H}$
TVSu-1920	53.29 ± 0.35^{XY}	4.94 ± 0.21^{d}	$10.86 \pm 0.00^{c-h}$	$22.53 \pm 0.03^{x-B}$	8.39 ± 0.01^{cd}	$0.23 \pm 0.01^{g-m}$	$0.17 \pm 0.01^{z-E}$	$6.73 \pm 0.07^{f-i}$
TVSu-1921	$54.65 \pm 0.01^{R-W}$	$4.44 \pm 0.14^{g-l}$	$10.63 \pm 0.20^{d-l}$	$24.30 \pm 0.05^{g-j}$	5.99 ± 0.01^{uvw}	$0.17 \pm 0.00^{k-s}$	$0.27 \pm 0.01^{m-p}$	$5.52 \pm 0.07^{y-B}$
TVSu-1923	$55.33 \pm 0.13^{M-R}$	5.99 ± 0.02^{b}	$10.61 \pm 0.06^{e-m}$	$24.68 \pm 0.00^{d-g}$	3.40 ± 0.00^{D}	0.47 ± 0.00^{a}	0.31 ± 0.01^{ghi}	$6.59 \pm 0.07^{h-k}$
TVSu-1930	$55.22 \pm 0.12^{N-S}$	$4.29 \pm 0.11^{h-p}$	$10.88 \pm 0.08^{c-g}$	$23.41 \pm 0.04^{o-s}$	$6.21 \pm 0.01^{s-v}$	$0.23 \pm 0.01^{f-l}$	0.36 ± 0.01^{cde}	$5.99 \pm 0.07^{p-u}$
TVSu-1937	56.87 ± 0.08^{FGH}	$4.24 \pm 0.02^{j-r}$	$10.79 \pm 0.06^{c-j}$	21.32 ± 0.01^{GH}	6.80 ± 0.00^{no}	$0.25 \pm 0.01^{f-k}$	$0.25 \pm 0.01^{o-r}$	$5.52 \pm 0.07^{y-C}$
TVSu-1939	$54.95 \pm 0.04^{Q-U}$	$4.49 \pm 0.25^{g-j}$	10.32 ± 0.28^{klm}	$22.24 \pm 0.01^{A-D}$	8.01 ± 0.04^{efg}	$0.28 \pm 0.01^{e-i}$	$0.31 \pm 0.01^{g-j}$	$6.22 \pm 0.03^{m-q}$
TVSu-1941	51.24 ± 0.22^{Z1}	6.33 ± 0.06^{a}	$10.33 \pm 0.00^{j-m}$	$24.46 \pm 0.10^{e-i}$	7.66 ± 0.01^{hij}	0.10 ± 0.00^{s}	$0.22 \pm 0.01^{s-v}$	$5.25 \pm 0.07^{B-F}$
TVSu-1943	53.29 ± 0.04^{XY}	$4.12 \pm 0.02^{l-t}$	$10.74 \pm 0.05^{c-k}$	$23.77 \pm 0.01^{l-o}$	8.09 ± 0.11^{ef}	0.39 ± 0.04^{bcd}	0.33 ± 0.01^{efg}	4.18 ± 0.06^{KLM}
TVSu-1945	51.69 ± 0.21^{Z}	$4.14 \pm 0.10^{l-t}$	$10.73 \pm 0.03^{c-k}$	25.21 ± 0.01^{bc}	8.24 ± 0.26^{de}	0.29 ± 0.00^{efg}	$0.17 \pm 0.01^{z-E}$	$6.72 \pm 0.07^{f-i}$
TVSu-1951	$55.27 \pm 0.25^{N-R}$	$4.13 \pm 0.13^{l-t}$	$10.79 \pm 0.02^{c-i}$	$22.23 \pm 0.02^{A-D}$	7.59 ± 0.01^{ijk}	$0.28 \pm 0.01^{e-i}$	$0.19 \pm 0.01^{w-A}$	7.32 ± 0.07^{bc}
TVSu-1952	53.22 ± 0.30^{XY}	$3.33 \pm 0.26^{F-J}$	$10.72 \pm 0.00^{c-k}$	$24.37 \pm 0.01^{f-j}$	8.38 ± 0.03^{cd}	0.31 ± 0.00^{def}	$0.25 \pm 0.01^{o-r}$	$6.56 \pm 0.02^{h-l}$
TVSu-1956	53.91 ± 0.10^{WX}	$4.30 \pm 0.20^{h-p}$	$10.52 \pm 0.17^{f-m}$	$23.88 \pm 0.02^{k-n}$	7.40 ± 0.02^{jkl}	0.29 ± 0.01^{efg}	$0.16 \pm 0.01^{B-G}$	$6.75 \pm 0.02^{f-i}$
TVSu-1957	$54.43 \pm 0.05^{T-W}$	$4.09 \pm 0.05^{m-t}$	$10.58 \pm 0.00^{e-m}$	$23.33 \pm 0.01^{p-t}$	7.58 ± 0.01^{ijk}	0.46 ± 0.01^{ab}	0.24 ± 0.00^{qrs}	$6.48 \pm 0.02^{i-m}$
TVSu-1959	52.97 ± 0.39^{Y}	$4.40 \pm 0.05^{h-n}$	13.43 ± 0.13^{a}	22.21 ± 0.07^{BCD}	7.01 ± 0.04^{mn}	$0.13 \pm 0.01^{p-s}$	$0.19 \pm 0.01^{w-A}$	$6.26 \pm 0.06^{l-p}$
TVSu-1962	$55.82 \pm 0.23^{J-O}$	$3.93 \pm 0.17^{r-x}$	$10.72 \pm 0.04^{c-k}$	$22.77 \pm 0.04^{v-z}$	6.78 ± 0.01^{no}	$0.15 \pm 0.01^{m-s}$	$0.21 \pm 0.00^{t-w}$	3.98 ± 0.00^{MNO}
TVSu-1964	57.93 ± 0.16^{BCD}	0.85 ± 0.09^{S}	$10.85 \pm 0.01^{c-h}$	$22.96 \pm 0.02^{t-w}$	7.43 ± 0.02^{jkl}	$0.17 \pm 0.01^{k-s}$	0.33 ± 0.01^{fgh}	$6.12 \pm 0.02^{n-s}$
TVSu-1972	$54.74 \pm 0.16^{R-V}$	$4.38 \pm 0.13^{h-n}$	11.08 ± 0.04^{cd}	$23.41 \pm 0.02^{o-s}$	6.40 ± 0.01^{qrs}	$0.19 \pm 0.01^{j-q}$	$0.11 \pm 0.00^{K-P}$	$5.72 \pm 0.08^{t-y}$
TVSu-1979	54.23 ± 0.04^{UVW}	2.85 ± 0.03^{MNO}	$10.81 \pm 0.03^{c-h}$	25.56 ± 0.00^{b}	6.56 ± 0.02^{opq}	$0.22 \pm 0.01^{g-o}$	$0.30 \pm 0.00^{h-k}$	$5.58 \pm 0.01^{x-A}$
TVSu-2000	$55.06 \pm 0.11^{P-T}$	4.85 ± 0.06^{de}	11.13 ± 0.03^{c}	$24.02 \pm 0.04^{j-m}$	4.95 ± 0.06^{BC}	0.10 ± 0.01^{rs}	$0.14 \pm 0.01^{F-K}$	$6.36 \pm 0.23^{j-n}$
TVSu-2003	$56.06 \pm 1.46^{I-M}$	2.69 ± 0.00^{OP}	12.33 ± 1.03^{b}	$22.43 \pm 0.00^{z-C}$	6.49 ± 0.00^{pqr}	0.29 ± 0.03^{efg}	$0.20 \pm 0.00^{t-x}$	$5.61 \pm 0.00^{w-A}$

Table 3: Continued.

Accessions	Nutrient components						Antinutrient components	
	CHO	Ash	MC	Protein	Fat	Tryptophan	Tannin	Phytate
TVSu-2017	55.91 ± 0.00^{I-N}	4.23 ± 0.02^{j-r}	10.94 ± 0.02^{c-f}	22.43 ± 0.00^{z-C}	6.49 ± 0.00^{pqr}	0.30 ± 0.02^{efg}	0.20 ± 0.00^{t-x}	4.85 ± 0.07^{HI}
TVSu-2018	60.76 ± 0.01^{n-q}	2.92 ± 0.02^{L-O}	8.86 ± 0.00^{s-v}	21.08 ± 0.01^{GHI}	6.39 ± 0.02^{qrs}	0.39 ± 0.12^{bcd}	0.09 ± 0.01^{P}	5.06 ± 0.06^{E-H}
TVSu-2019	54.40 ± 0.08^{T-W}	4.34 ± 0.03^{h-o}	4.34 ± 0.03^{c-i}	24.84 ± 0.03^{cde}	5.64 ± 0.06^{xy}	0.26 ± 0.05^{f-j}	0.23 ± 0.01^{rst}	7.44 ± 0.38^{b}
TVSu-2020	54.13 ± 1.02^{VW}	4.51 ± 0.13^{f-j}	10.85 ± 0.04^{c-h}	22.61 ± 0.44^{w-B}	7.91 ± 0.11^{fgh}	0.29 ± 0.23^{e-h}	0.23 ± 0.01^{rst}	6.00 ± 0.02^{o-t}
TVSu-2021	52.77 ± 0.04^{Y}	5.46 ± 0.10^{c}	10.53 ± 0.16^{f-m}	24.84 ± 0.02^{cde}	6.40 ± 0.01^{qrs}	0.14 ± 0.01^{n-s}	0.15 ± 0.00^{D-I}	3.24 ± 0.06^{P}
TVSu-2022	58.06 ± 0.28^{z-D}	4.40 ± 0.10^{h-m}	10.49 ± 0.06^{f-m}	21.04 ± 0.02^{HI}	6.02 ± 0.02^{uvw}	0.16 ± 0.02^{l-s}	0.24 ± 0.00^{qrs}	5.92 ± 0.06^{q-w}
TVSu-2025	58.51 ± 0.35^{x-B}	3.94 ± 0.14^{q-x}	11.00 ± 0.04^{cde}	20.93 ± 0.02^{HIJ}	5.64 ± 0.04^{wy}	0.17 ± 0.01^{k-s}	0.26 ± 0.01^{n-q}	7.11 ± 0.06^{cde}
TVSu-2030	54.68 ± 0.37^{R-V}	5.50 ± 0.12^{c}	10.19 ± 0.15^{lmn}	23.42 ± 0.03^{o-r}	6.22 ± 0.02^{r-u}	0.21 ± 0.02^{h-p}	0.10 ± 0.01^{NOP}	4.90 ± 0.07^{GHI}
TVSu-2031	58.95 ± 0.09^{v-y}	4.20 ± 0.13^{j-s}	7.51 ± 0.05^{D}	23.00 ± 0.00^{s-w}	6.35 ± 0.01^{q-t}	0.17 ± 0.00^{k-s}	0.23 ± 0.01^{rst}	4.10 ± 0.06^{LMN}
TVSu-2032	58.37 ± 0.17^{y-C}	3.66 ± 0.10^{x-E}	10.42 ± 0.03^{h-m}	20.41 ± 0.01^{KL}	7.15 ± 0.02^{lm}	0.47 ± 0.00^{a}	0.18 ± 0.00^{x-C}	7.30 ± 0.13^{bc}
TVSu-2034	56.15 ± 0.74^{H-L}	4.48 ± 0.08^{e-h}	10.43 ± 0.10^{klm}	23.12 ± 0.02^{u-y}	6.35 ± 0.02^{tuv}	0.15 ± 0.08^{m-s}	0.20 ± 0.01^{u-y}	4.97 ± 0.06^{r-x}
TVSu-2038	58.83 ± 0.84^{v-y}	3.88 ± 0.04^{s-z}	10.68 ± 0.04^{c-k}	21.23 ± 0.51^{GH}	5.39 ± 0.01^{yzA}	0.25 ± 0.01^{f-k}	0.10 ± 0.00^{M-P}	5.70 ± 0.07^{t-z}
TVSu-2042	55.87 ± 0.30^{I-N}	4.22 ± 0.11^{j-r}	10.46 ± 0.04^{g-m}	24.12 ± 0.01^{i-l}	5.35 ± 0.04^{zA}	0.28 ± 0.01^{e-i}	0.14 ± 0.01^{F-K}	7.21 ± 0.02^{bcd}
TVSu-2043	55.63 ± 0.20^{L-Q}	4.48 ± 0.11^{g-k}	10.43 ± 0.1^{g-m}	23.12 ± 0.03^{r-v}	6.35 ± 0.04^{q-t}	0.23 ± 0.01^{f-l}	0.20 ± 0.01^{u-y}	4.97 ± 0.09^{FGH}
TVSu-2045	55.63 ± 0.20^{GHI}	4.82 ± 0.15^{def}	10.20 ± 0.00^{lmn}	22.63 ± 0.03^{w-A}	5.80 ± 0.00^{wx}	0.09 ± 0.00^{s}	0.18 ± 0.01^{w-B}	6.79 ± 0.00^{e-i}
TVSu-2046	56.56 ± 0.16^{A-D}	4.38 ± 0.01^{h-n}	10.16 ± 0.12^{mn}	20.95 ± 0.02^{HIJ}	6.55 ± 0.02^{opq}	0.39 ± 0.04^{bcd}	0.09 ± 0.01^{P}	6.63 ± 0.04^{g-k}
TVSu-2048	57.98 ± 0.25^{XY}	4.11 ± 0.11^{m-t}	10.31 ± 0.00^{klm}	26.71 ± 0.01^{a}	5.58 ± 0.00^{xyz}	0.22 ± 0.10^{g-n}	0.16 ± 0.01^{B-G}	5.39 ± 0.06^{z-D}
TVSu-2051	53.30 ± 0.13^{v-y}	4.04 ± 0.12^{o-v}	10.47 ± 0.02^{g-m}	20.54 ± 0.00^{JKL}	6.16 ± 0.02^{s-v}	0.16 ± 0.02^{l-s}	0.17 ± 0.01^{z-E}	5.66 ± 0.07^{u-A}
TVSu-2055	58.81 ± 0.15^{gh}	4.41 ± 0.11^{h-m}	3.04 ± 0.04^{EF}	23.63 ± 0.03^{m-q}	6.18 ± 0.02^{s-v}	0.17 ± 0.01^{k-s}	0.14 ± 0.01^{E-J}	6.36 ± 0.03^{j-n}
TVSu-2056	62.75 ± 0.16^{ij}	4.59 ± 0.04^{e-h}	3.48 ± 0.30^{E}	24.60 ± 0.01^{d-h}	5.38 ± 0.01^{yzA}	0.21 ± 0.02^{h-p}	0.15 ± 0.00^{D-I}	6.63 ± 0.11^{g-k}
TVSu-2060	61.96 ± 0.35^{ef}	3.72 ± 0.01^{v-D}	3.03 ± 0.03^{EF}	22.94 ± 0.05^{t-x}	5.57 ± 0.02^{xyz}	0.17 ± 0.00^{k-s}	0.13 ± 0.01^{H-M}	6.59 ± 0.07^{h-k}
TVSu-2065	64.75 ± 0.13^{a}	3.60 ± 0.02^{y-F}	3.00 ± 0.02^{F}	19.36 ± 0.02^{O}	4.77 ± 0.02^{C}	0.47 ± 0.00^{a}	0.09 ± 0.00^{OP}	6.86 ± 0.07^{e-h}
TVSu-2067	69.29 ± 0.05^{qrs}	4.08 ± 0.02^{n-u}	3.01 ± 0.01^{F}	24.95 ± 0.36^{cd}	7.78 ± 0.02^{ghi}	0.23 ± 0.01^{f-l}	0.11 ± 0.01^{L-P}	5.93 ± 0.06^{q-w}
TVSu-2068	60.19 ± 0.50^{de}	3.73 ± 0.01^{v-C}	3.12 ± 0.07^{EF}	21.24 ± 0.03^{GH}	6.56 ± 0.03^{opq}	0.17 ± 0.11^{k-s}	0.13 ± 0.03^{G-L}	5.39 ± 0.07^{y-D}
TVSu-2071	65.36 ± 0.11^{d}	3.73 ± 0.04^{v-C}	3.05 ± 0.01^{EF}	21.16 ± 0.27^{GHI}	6.58 ± 0.02^{opq}	0.39 ± 0.04^{bcd}	0.17 ± 0.02^{y-D}	6.13 ± 0.00^{n-s}
TVSu-2074	65.49 ± 0.45^{l-p}	4.31 ± 0.02^{h-p}	2.98 ± 0.04^{F}	25.23 ± 0.04^{bc}	6.38 ± 0.02^{qrs}	0.22 ± 0.10^{g-n}	0.18 ± 0.02^{w-B}	6.07 ± 0.07^{n-s}
TVSu-2075	61.12 ± 0.12^{cd}	3.62 ± 0.02^{x-F}	2.97 ± 0.00^{F}	20.95 ± 0.01^{HIJ}	6.71 ± 0.06^{op}	0.16 ± 0.02^{l-s}	0.20 ± 0.03^{u-y}	5.39 ± 0.07^{y-D}
TVSu-2076	65.76 ± 0.08^{f}	4.13 ± 0.03^{l-t}	3.13 ± 0.11^{EF}	21.49 ± 0.13^{FG}	7.19 ± 0.01^{lm}	0.17 ± 0.01^{k-s}	0.23 ± 0.02^{rst}	6.49 ± 0.03^{i-m}
TVSu-2083	64.07 ± 0.08^{j-m}	3.89 ± 0.01^{s-y}	2.99 ± 0.01^{F}	25.21 ± 0.01^{bc}	6.35 ± 0.01^{q-t}	0.02 ± 0.19^{g-m}	0.22 ± 0.04^{r-u}	5.38 ± 0.07^{z-E}
TVSu-2085	61.57 ± 0.01^{g}	3.76 ± 0.05^{u-B}	2.92 ± 0.04^{F}	23.66 ± 0.03^{m-p}	6.77 ± 0.00^{nop}	0.35 ± 0.08^{cde}	0.15 ± 0.04^{C-H}	5.66 ± 0.06^{v-A}
TVSu-2086	62.91 ± 0.08^{d}	3.57 ± 0.04^{z-F}	3.07 ± 0.09^{EF}	21.01 ± 0.50^{HI}	6.79 ± 0.01^{no}	0.15 ± 0.01^{m-s}	0.10 ± 0.01^{NOP}	5.89 ± 0.04^{r-x}

Numbers representing means ± standard deviation in a column followed by the same letter are not significantly different according to Fischer's least significant difference (LSD) test ($p < 0.05$). MC: moisture content; phytate (mg/100 g); % tannin. MC = CHO = protein = ash = fat (%).

Table 4: Contribution of principal components to the variations of the nutrient and antinutrient components among the BGN accessions.

Traits	Dim.1	Dim.2	Dim.3
CHO	40.97	0.18	0.40
Ash	10.51	21.33	1.65
Fat	9.67	3.99	5.09
Moisture content	18.58	16.91	2.30
Phytate	2.57	3.34	40.95
Protein	16.87	11.56	0.01
Tannin	0.66	42.66	0.91
Tryptophan	0.18	0.03	48.70
Eigenvalue	2.38	1.40	1.16
Proportion of variance (%)	29.74	17.55	14.45
Cumulative variance (%)	29.74	47.29	61.74

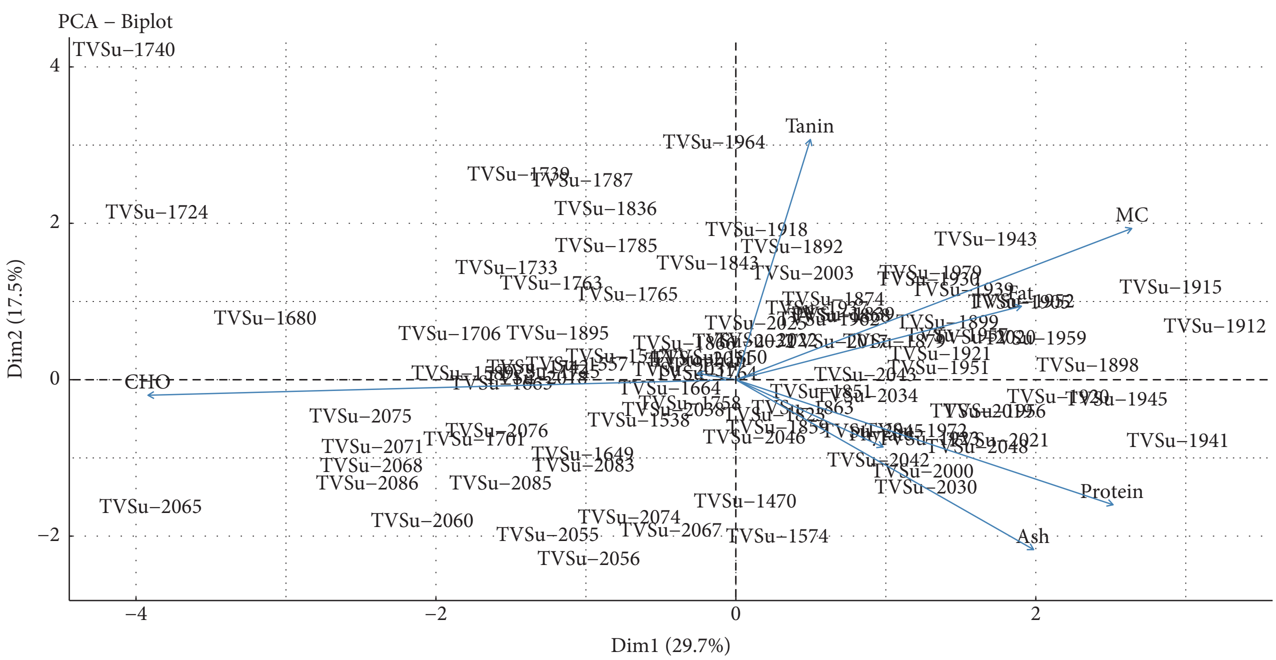

Figure 1: Biplot shows the relationship between the different accessions with the nutrient and antinutrient compositions.

by protein and CHO ($r = -0.77$), which had the second highest negative correlation. A positive correlation was found between phytate and protein ($r = 0.23$, $p < 0.5$) as well as tryptophan ($r = 0.08$, $p < 0.5$), while a negative correlation was found between phytate and tannin ($r = 0.21$, $p < 0.5$). This means that the amount of phytate is not affected by the amount of tannin present.

4. Discussion

Food insecurity in the developing world often results from the low nutritional quality of some of the traditional foodstuffs and the high cost of protein foods. Fortified foods are not easily available for most families in the developing world [28] due to the high level of poverty. Legumes have therefore come under immense importance in these regions as they have been proven to be alternative sources to fortified foods for nutrients. Hence, it is of necessity to increase their level of consumpton.

4.1. Genotypic Variability in Nutrient and Antinutrient Contents in BGN. The genetic, physiological, and morphological variations of plants have a direct impact on breeding outcomes. Therefore, the importance of variations in different traits cannot be overemphasized. There are significant variations in nutrient and antinutrient contents among the accessions studied (Tables 2 and 3, Fig S1), therefore, they are excellent resources for developing or selecting parental lines for better nutritional performance.

Carbohydrates are needed for energy and are present in the form of starch and sugars, varying from simple sugars to complex sugars, i.e., the monosaccharides, disaccharides, and polysaccharides. According to Liu, Tang [29], pulse seeds are high in carbohydrate content. Therefore, it is expected that BGN should contain a high amount of carbohydrate. In this study, the carbohydrate content of 58.34% is similar to the result reported in the study of Atoyebi and Osilesi [30] (range of 42.77%–62.76%) and higher than 50.2% reported by Yao and Kouassi [7]. The higher the

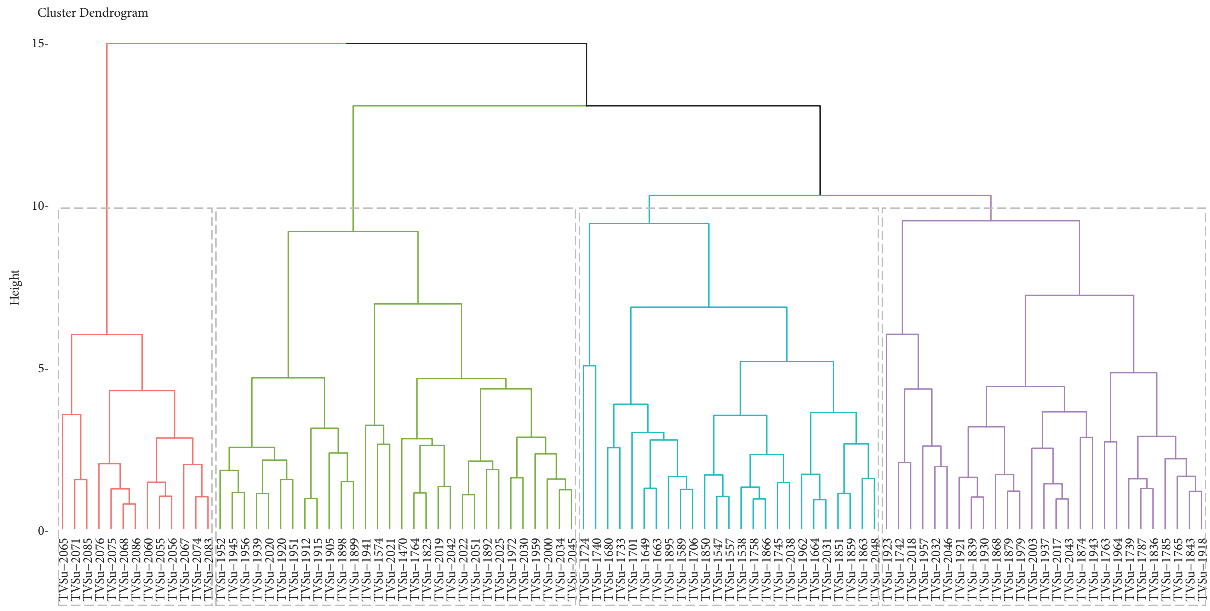

Figure 2: Dendrogram categorizing the accessions according to their similarities with respect to nutrient and antinutrient traits.

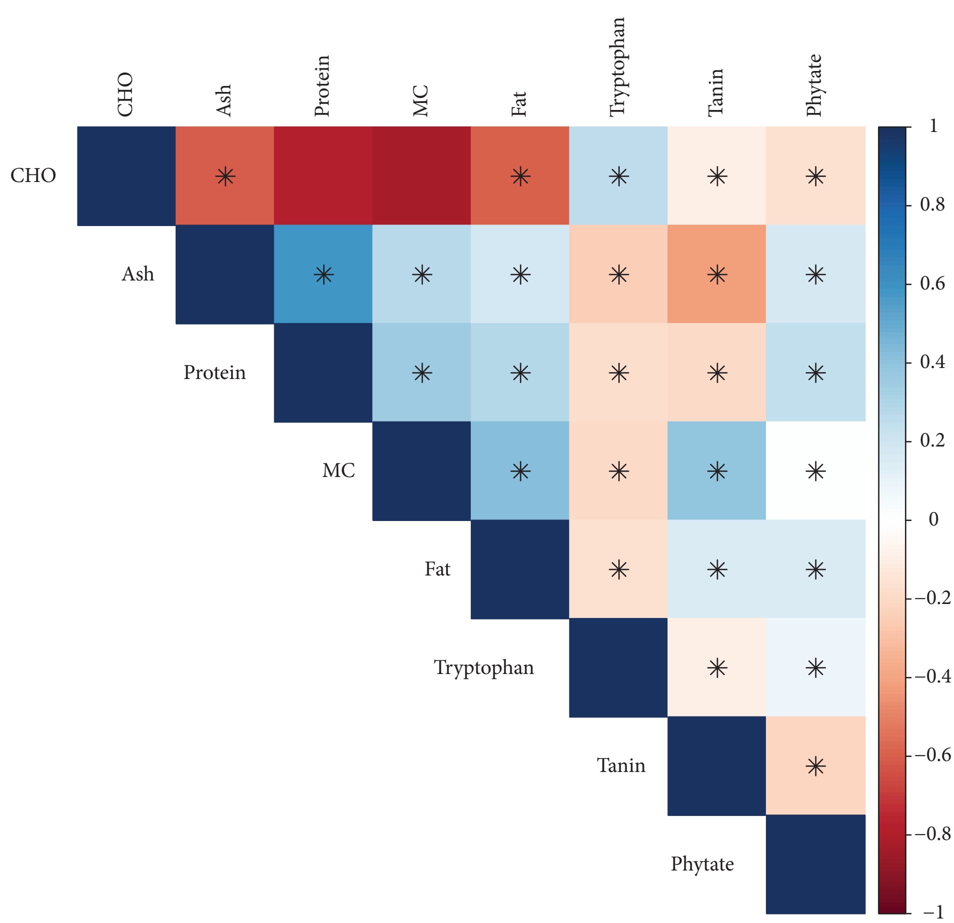

Figure 3: Pearson's linear correlation coefficient of morphological traits studied. * = significant, $p < 0.05$.

moisture content, the higher the susceptibility of the seeds to attacks from microorganisms [28]. Therefore, those seeds with low moisture content will have a longer shelf life than those with high moisture content. Pulse seeds contain 20%–40% protein [31, 32], a value twice as much as that present in cereals. The value for protein content in this study, which is below 25%, is similar to that obtained by Nti [33], who reported a range of 19.3% to 27.1%, and Sirivongpaisal [34], who reported 15.48% protein content. Compared with soybean, BGN is lower in protein content, as reported in the study of Wijewardana and Reddy [35] on soybean seeds under well-watered conditions. However, these values fall in the range obtained for protein content in other pulses such as peas, chickpeas, beans, lupin, and cowpea [32, 36]. Within the *Vigna* genus, BGN mean concentrations of the nutrient components are similar to those reported in cowpea and mungbean [13, 37, 38]. Tryptophan is a precursor of auxin, which is an essential growth hormone in plants [39–41], and bioactive compounds such as nicotinamide, melatonin, and kynurenine in humans [42, 43]. The tryptophan levels recorded in this study show that BGN can help get the required amount of tryptophan in the quantity recommended by WHO, which is 1.70, 0.85, and 0.66 for infants, children, and adolescents, respectively [44]. The tannin content reported in this study (0.09%–0.41%) is lower than 0.25%–2.27% reported by Ofori and Kumaga [45]. However, the mean value of 0.20 is greater than 0.046 reported by Mazahib and Nuha [46] in Sudan and 0.039 reported by Ijarotimi and Esho [47] in Nigeria. However, it is lower than the tannin content in faba beans, which is between 8 and 9% [14]. Tannins are known to be present in food products and to inhibit the activities of trypsin, chymotrypsin, amylase, and lipase, as well as lower protein quality and interfere with iron absorption [48]. Tanning can be detrimental to microbial enzyme activities, including cellulose digestion and intestinal digestion, if the tannin concentration in the diet becomes too high [49]. The utilization efficiency and ease of digestion of nutrients are affected by the tannin content present [50]. The strong antinutritional compound phytate is present in nearly all legumes and seeds [48]. Phytic acid inhibits dietary tyrosinase, trypsin, pepsin, and lipases [51]. The average phytic acid level reported by Mazahib and Nuha [46] in Egyptian landraces was 14.78 mg/100 g, which is higher than that reported in this study. The mean phytic acid content reported in this study is higher than that reported in the study of Yao and Kouassi [7], who reported a mean value of 1.1 mg/100 g. Phytic acid binds to ion complexes, resulting in a decrease in the concentrations of these ions [52]. Most of the phosphorus in phytic acid is unavailable to monogastric animals because they do not have the enzyme phytase [53]. Furthermore, dehulling in some pulses increases their phytic acid content but decreases their tannin content because tannins are mainly found in the seed coats [54].

4.2. Association among Accession, Nutrient, and Antinutrient Components. In addition, the PCA biplot showed four clear separations in the biplot according to the nutrient components (Figure 1). Accessions high in carbohydrates are also high in tryptophan, while those high in tannin content are also high in moisture and fat content, but they are low in carbohydrate, tryptophan, protein, ash, and phytate content. Likewise, those high in protein content are also high in ash and phytate content but low in the other components. Considering the antinutrients, those high in phytates are low in tannins and *vice versa*. Tryptophan is an amino acid constituting total proteins. They are therefore part of the total protein; hence, accessions high in tryptophan are expected to be high in protein and correlate positively with total protein. In this study, however, accessions high in tryptophan were low in total protein and *vice versa*.

The hierarchical clustering (Figure 2) agreed with the biplot result (Figure 1), which showed that accessions with comparable nutritional and antinutrient contents were clustered together. Divergence among BGN accessions has been successfully identified using clustering based on nutritional and antinutrient components [7, 45–47, 55–58]. To avoid inbreeding depression, the selection of accessions for crossing should focus on divergent accessions, while proposing a few accessions for production might reduce the risk posed by biotic and abiotic pressures, particularly in stress-prone areas such as Sub-Saharan Africa.

4.3. Association between Nutrient and Antinutrient Components. Finally, the correlation between the nutrient and antinutrient components showed that breeding for nutritional components in these accessions will require careful selection processes. Although there are many significant correlations, the numbers of positive correlations are however similar to those of negative correlations. The negative relationship between carbohydrates and protein aligns with the result reported in the study of Ndidi and Ndidi [59]. However, the opposite was reported for the relationship between ash and phytate. The correlation between tannin and phytate reported in this study is supported in the study of Unigwe and Doria [60].

The environment interacts with different plants to give different responses, which are observed in the nutrient, antinutrient components, and other traits, such as reported in the studies of Ribeiro and Kläsener [61], Fauziah and Mas'udah [62], Vogelsang-O'Dwyer and Petersen [63], Olanrewaju and Oyatomi [64], and Olanrewaju and Oyatomi [65]. Because these traits are regulated by specific genes. The impact of the environment on these genes to affect the nutrient components was not considered in this study. Therefore, nutrient and antinutrient components from plants grown in various environments should be studied to ascertain the extent of the environmental influence on the nutrient and antinutrient components. Secondly, the emergence of NGS has revolutionized molecular studies in various areas; therefore, gene locus regulating these traits can be identified using technologies such as GWAS for improvement breeding programs.

5. Conclusion

In this study, two of the traits studied, *viz.* carbohydrate and tryptophan, are high in more than half of the accessions, while the others have high amounts of the remaining traits, including the antinutrient factors. Therefore, the selection of accessions having low or minimal amounts of antinutrient components can be made possible for future improvement. The variation in nutrient and antinutrient components in

BGN observed here agrees with previous findings. The results of this study offer opportunities for the selection and breeding of the crop for beneficial nutrient compositions and, at the same time, those with low amounts of antinutrient factors. Therefore, BGN can successfully improve nutritional security even more than some major crops.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The first author is gratefully acknowledged for school bursaries and research fellowships, respectively, from North-West University and IITA. The assistance rendered by the staff of the Genetic Resource Center, IITA, is greatly appreciated. The work of GRC was funded by the Global Crop Diversity Trust and CGIAR.

Supplementary Materials

Figure S1: nutrient and antinutrient compositions of each accession. Table S1: contribution of the traits to each PCA component. (*Supplementary Materials*)

References

[1] F. C. McKenzie and J. Williams, "Sustainable food production: constraints, challenges and choices by 2050," *Food Security*, vol. 7, no. 2, pp. 221–233, 2015.

[2] K. Tesfaye, G. Kruseman, J. E. Cairns et al., "Potential benefits of drought and heat tolerance for adapting maize to climate change in tropical environments," *Climate Risk Management*, vol. 19, pp. 106–119, 2018.

[3] E. Plänitz, "Neglecting the urban? Exploring rural-urban disparities in the climate change–conflict literature on Sub-Sahara Africa," *Urban Climate*, vol. 30, Article ID 100533, 2019.

[4] K. van der Geest, S. Alex de, K. Stefan et al., "The impacts of climate change on ecosystem services and resulting losses and damages to people and society," in *Loss and Damage from Climate Change*, pp. 221–236, Springer, Berlin, Germany, 2019.

[5] S. A. Oyeyinka, E. Umaru, S. J. Olatunde, and J. K. Joseph, "Effect of short microwave heating time on physicochemical and functional properties of Bambara groundnut starch," *Food Bioscience*, vol. 28, pp. 36–41, 2019.

[6] S. M. Mohammed, "Pre-breeding of Bambara groundnut (*Vigna subterranea* [L.] verdc.)," in *Plant Science*p. 202, University of KwaZulu-Natal, Piertamaritzburg, South Africa, 2014.

[7] D. N. Yao, K. Kouassi, D. Erba, F. Scazzina, N. Pellegrini, and M Casiraghi, "Nutritive evaluation of the Bambara groundnut Ci12 landrace [*Vigna subterranea* (L.) verdc. (Fabaceae)] produced in côte d'Ivoire," *International Journal of Molecular Sciences*, vol. 16, no. 9, pp. 21428–21441, 2015.

[8] A. O. Abiodun O and S. Ab, "Quality evaluation of millet-based fura powder supplemented with Bambara groundnut," *International Journal of Food Science, Nutrition and Dietetics*, vol. 6, no. 3, pp. 358–362, 2017.

[9] S. A. Oyeyinka and A. T. Oyeyinka, "A review on isolation, composition, physicochemical properties and modification of Bambara groundnut starch," *Food Hydrocolloids*, vol. 75, pp. 62–71, 2018.

[10] O. S. Olanrewaju, O. Oyatomi, O. O. Babalola, and M. Abberton, "Breeding potentials of Bambara groundnut for food and nutrition security in the face of climate change," *Frontiers of Plant Science*, vol. 12, no. 3186, Article ID 798993, 2021.

[11] O. O. Babalola, O. S. Olanrewaju, T. Dias, C. F. Ajilogba, F. R. Kutu, and C. Cruz, "Biological nitrogen fixation: the role of underutilized leguminous plants," in *Microorganisms for Green Revolution*, pp. 431–443, Springer, Berlin, Germany, 2017.

[12] A. Popova and D. Mihaylova, "Antinutrients in plant-based foods: a review," *The Open Biotechnology Journal*, vol. 13, no. 1, pp. 68–76, 2019.

[13] R. Azman Halimi, B. J. Barkla, S. Mayes, and G. J. King, "The potential of the underutilized pulse Bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security," *Journal of Food Composition and Analysis*, vol. 77, pp. 47–59, 2019.

[14] R. Akkad, E. Kharraz, J. Han, J. D. House, and J. M. Curtis, "Characterisation of the volatile flavour compounds in low and high tannin faba beans (Vicia faba var. minor) grown in Alberta, Canada," *Food Research International*, vol. 120, pp. 285–294, 2019.

[15] R. H. Belmiro, A. A. L. Tribst, and M. Cristianini, "Effects of high pressure processing on common beans (*Phaseolus vulgaris* L.): cotyledon structure, starch characteristics, and phytates and tannins contents," *Starch-Stärke*, vol. 72, no. 3-4, Article ID 1900212, 2020.

[16] X. W. Qaku, A. Adetunji, and B. C. Dlamini, "Fermentability and nutritional characteristics of sorghum Mahewu supplemented with Bambara groundnut," *Journal of Food Science*, vol. 85, no. 6, pp. 1661–1667, 2020.

[17] O. M. Nwadi, N. Uchegbu, and S. A. Oyeyinka, "Enrichment of food blends with Bambara groundnut flour: past, present, and future trends," *Legume Science*, vol. 2, no. 1, p. e25, 2020.

[18] A. Gyawali, V. Shrestha, K. E. Guill, S. Flint-Garcia, and T. M. Beissinger, "Single-plant GWAS coupled with bulk segregant analysis allows rapid identification and corroboration of plant-height candidate SNPs," *BMC Plant Biology*, vol. 19, no. 1, p. 412, 2019.

[19] D. Kainer, A. Padovan, J. Degenhardt et al., "High marker density GWAS provides novel insights into the genomic architecture of terpene oil yield in Eucalyptus," *New Phytologist*, vol. 223, no. 3, pp. 1489–1504, 2019.

[20] S. Sheoran, S. Jaiswal, D. Kumar et al., "Uncovering genomic regions associated with 36 agro-morphological traits in Indian spring Wheat using GWAS," *Frontiers of Plant Science*, vol. 10, p. 527, 2019.

[21] W. Link, C. Dixkens, M. Singh, M. Schwall, and A. E. Melchinger, "Genetic diversity in European and Mediterranean Faba bean germplasm revealed by RAPD markers," *Theoretical and Applied Genetics*, vol. 90, no. 1, pp. 27–32, 1995.

[22] AOAC, "Official methods of analysis," AOAC, Washington, DC, USA, 2005.

[23] G. Bertacco, O. Boscheche, and G. Lercker, "Gas chromatographic determination of free amino acids in cheese," *Milchwissenschaft*, vol. 47, pp. 348–350, 1992.

[24] K. P. Drapala, M. A. Auty, D. M. Mulvihill, and J. A. O'Mahony, "Performance of whey protein hydrolysate–maltodextrin conjugates as emulsifiers in model infant formula emulsions," *International Dairy Journal*, vol. 62, pp. 76–83, 2016.

[25] E. L. Wheeler and R. E. Ferrel, "A method for phytic acid determination in wheat and wheat fractions," *Cereal Chemistry*, vol. 48, no. 3, pp. 312–320, 1971.

[26] M. Adegunwa, E. Alamu, and L. Omitogun, "Effect of processing on the nutritional contents of yam and cocoyam tubers," *Journal of Applied Bioscience*, vol. 46, pp. 3086–3092, 2011.

[27] R. Core Team, *A Language and Environment for Statistical Computing*, R foundation for statistical computing, Vienna, Austria, 2019.

[28] O. S. Ijarotimi and O. O. Keshinro, "Formulation and nutritional quality of infant formula produced from germinated popcorn, Bambara groundnut and African locust bean flour," *Journal of Microbiology, Biotechnology and Food Sciences*, vol. 9, no. 4, pp. 1358–1388, 2020.

[29] D. Liu, W. Tang, Y. Xin et al., 105784, Comparison on structure and physicochemical properties of starches from Adzuki bean and dolichos bean," *Food Hydrocolloids*, vol. 105, 2020.

[30] J. Olayinka Atoyebi, O. Osilesi, O. Adebawo, and M. Abberton, "Evaluation of Nutrient Parameters of Selected African Accessions of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.)," *American Journal of Food and Nutrition*, vol. 5, no. 3, pp. 83–89, 2017.

[31] M. K. Pandey, M. Roorkiwal, V. K. Singh et al., "Emerging genomic tools for legume breeding: current status and future prospects," *Frontiers of Plant Science*, vol. 7, p. 455, 2016.

[32] S. M. F. Bessada, J. C. M. Barreira, and M. B. P. P. Oliveira, "Pulses and food security: dietary protein, digestibility, bioactive and functional properties," *Trends in Food Science & Technology*, vol. 93, pp. 53–68, 2019.

[33] C. A. Nti, "Effects of Bambara groundnut (Vigna subterranea) variety and processing on the quality and consumer appeal for its products," *International Journal of Food Science and Technology*, vol. 44, no. 11, pp. 2234–2242, 2009.

[34] P. Sirivongpaisal, "Structure and functional properties of starch and flour from Bambara groundnut," *Songklanakarin Journal of Science and Technology*, vol. 30, pp. 51–56, 2008.

[35] C. Wijewardana, K. R. Reddy, and N. Bellaloui, "Soybean seed physiology, quality, and chemical composition under soil moisture stress," *Food Chemistry*, vol. 278, pp. 92–100, 2019.

[36] M. B. Barać, M. Pesic, S. Stanojevic, A. Kostic, and S. Cabrilo, "Techno-functional properties of pea (*Pisum sativum*) protein isolates: a review," *Acta Periodica Technologica*, vol. 46, pp. 1–18, 2015.

[37] O. Boukar, C. A. Fatokun, B. L. Huynh, P. A. Roberts, and T. J. Close, "Genomic tools in cowpea breeding programs: status and perspectives," *Frontiers of Plant Science*, vol. 7, p. 757, 2016.

[38] M. Muñoz-Amatriaín, H. Mirebrahim, P. Xu et al., "Genome resources for climate-resilient cowpea, an essential crop for food security," *The Plant Journal*, vol. 89, no. 5, pp. 1042–1054, 2017.

[39] O. S. Olanrewaju and O. O. Babalola, "Bacterial consortium for improved Maize (*Zea mays* L.) production," *Microorganisms*, vol. 7, no. 11, p. 519, 2019.

[40] O. S. Olanrewaju, B. R. Glick, and O. O. Babalola, "Mechanisms of action of plant growth promoting bacteria," *World Journal of Microbiology and Biotechnology*, vol. 33, no. 11, p. 197, 2017.

[41] O. S. Olanrewaju, "Isolation of bacterial strains for improved maize production," in *Biology*North-West University, Potchefstroom, South Africa, 2016.

[42] M. Friedman, "Analysis, nutrition, and health benefits of tryptophan," *International Journal of Tryptophan Research*, vol. 11, Article ID 117864691880228, 2018.

[43] L. Palego, L. Betti, A. Rossi, and G. Giannaccini, "Tryptophan biochemistry: structural, nutritional, metabolic, and medical aspects in humans," *Journal of Amino Acids*, vol. 2016, Article ID 8952520, 13 pages, 2016.

[44] FAO, *Dietary Protein Quality Evaluation in Human Nutrition*, pp. 1–66, FAO, Rome, Italy, 2011.

[45] K. Ofori, F. Kumaga, and K. Bimi, "Variation in seed size, protein and tannin content of Bambara groundnut (*Vigna subterranea*)," *Tropical Science*, vol. 41, pp. 100–103, 2001.

[46] A. M. Mazahib, N. M. Osman, I. S. Salawa, and E. E. Babiker, "Some nutritional attributes of Bambara groundnut as influenced by domestic processing," *International Food Research Journal*, vol. 20, no. 3, pp. 1165–1171, 2013.

[47] O. Steve Ijarotimi and T. Ruth Esho, "Comparison of nutritional composition and anti-nutrient status of fermented, germinated and roasted Bambara groundnut seeds (Vigna subterranea)," *British Food Journal*, vol. 111, no. 4, pp. 376–386, 2009.

[48] H. Fekadu Gemede and N. Ratta, "Antinutritional factors in plant foods: potential health benefits and adverse effects," *International Journal of Nutrition and Food Sciences*, vol. 3, no. 4, pp. 284–289, 2014.

[49] V. A. Aletor, *Anti-nutritional Factors as Nature's Paradox in Food and Nutrition Securities*, https://196.220.128.81:8080/xmlui/handle/123456789/256, 1999.

[50] M. M. Rahman, X. Feng, H. Zhang, X. Yan, Q. Peng, and P. Yu, "Using vibrational ATR-FTIR spectroscopy with chemometrics to reveal faba CHO molecular spectral profile and CHO nutritional features in ruminant systems," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, vol. 214, pp. 269–276, 2019.

[51] J. Hendricks, "Adventitious toxins," *Fish Nutrition*, vol. 11, pp. 606–651, 1989.

[52] F. Grases, R. M. Prieto, and A. Costa-Bauza, "Dietary phytate and interactions with mineral nutrients," in *Clinical Aspects of Natural and Added Phosphorus in Foods*, pp. 175–183, Springer, Berlin, Germany, 2017.

[53] K. Akande, U. Doma, H. Agu, and H. Adamu, "Major antinutrients found in plant protein sources: their effect on nutrition," *Pakistan Journal of Nutrition*, vol. 9, no. 8, pp. 827–832, 2010.

[54] C. A. Patterson, J. Curran, and T. Der, "Effect of processing on antinutrient compounds in pulses," *Cereal Chemistry Journal*, vol. 94, no. 1, pp. 2–10, 2017.

[55] N. C. Hlanga, A. T. Modi, and I. Mathew, "Evaluating nutritional content among Bambara groundnut lines," *Journal of Food Composition and Analysis*, vol. 102, Article ID 104053, 2021.

[56] A. G. Mahala and A. A. A. Mohammed, "Nutritive evaluation of Bambara groundnut (*Vigna subterranean*) pods, seeds and hull as animal feeds," *Journal of Applied Scientific Research*, vol. 6, no. 5, pp. 383–386, 2010.

[57] M. O. Aremu, O. Olaofe, and E. Akintayo, "Chemical composition and physicochemical characteristics of two varieties

of Bambara groundnut (*Vigna subterrenea*) flours," *Journal of Applied Sciences*, vol. 6, no. 9, pp. 1900–1903, 2006.

[58] I. A. Onimawo, A. H. Momoh, and A. Usman, "Proximate composition and functional properties of four cultivars of Bambara groundnut (*Voandezeia subterranea*)," *Plant Foods for Human Nutrition*, vol. 53, no. 2, pp. 153–158, 1999.

[59] U. S. Ndidi, C. U. Ndidi, I. A. Aimola, O. Y. Bassa, M. Mankilik, and Z. Adamu, "Effects of processing (boiling and roasting) on the nutritional and antinutritional properties of Bambara groundnuts (*Vigna subterranea* [L.] Verdc.) from Southern Kaduna, Nigeria," *Journal of Food Processing*, vol. 2014, Article ID 472129, 9 pages, 2014.

[60] A. E. Unigwe, E. Doria, P. Adebola, A. S. Gerrano, and M. Pillay, "Anti-nutrient analysis of 30 Bambara groundnut (*Vigna subterrane*a) accessions in South Africa," *Journal of Crop Improvement*, vol. 32, no. 2, pp. 208–224, 2018.

[61] N. D. Ribeiro and G. R. Kläsener, "Physical quality and mineral composition of new Mesoamerican bean lines developed for cultivation in Brazil," *Journal of Food Composition and Analysis*, vol. 89, Article ID 103479, 2020.

[62] F. Fauziah, S. Mas'udah, L. Hapsari, and S. Nurfadilah, "Biochemical composition and nutritional value of fresh tuber of Water Yam (Dioscorea alata L.) local accessions from east Java, Indonesia," *AGRIVITA, Journal of Agricultural Science*, vol. 42, no. 2, pp. 255–271, 2020.

[63] M. Vogelsang-O'Dwyer, I. L. Petersen, M. S. Joehnke et al., "Comparison of Faba Bean protein ingredients produced using dry fractionation and isoelectric precipitation: techno-functional, nutritional and environmental performance," *Foods*, vol. 9, no. 3, p. 322, 2020.

[64] O. S. Olanrewaju, O. Oyatomi, O. O. Babalola, and M. Abberton, "GGE biplot analysis of genotype × environment interaction and yield stability in Bambara groundnut," *Agronomy*, vol. 11, no. 9, p. 1839, 2021.

[65] O. S. Olanrewaju, O. Oyatomi, O. O. Babalola, and M. Abberton, "Genetic diversity and environmental influence on growth and yield parameters of Bambara groundnut," *Frontiers of Plant Science*, vol. 12, no. 2967, Article ID 796352, 2021.