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Research Article

Nutritional and Phytochemical Composition of Bambara Groundnut (*Vigna subterranea* [L.] Verdc) Landraces in Kenya

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Bambara groundnut (*Vigna subterranea*) is a highly nutritious legume with good drought tolerance attributes and is therefore a suitable candidate for food and nutritional security especially in drought prone areas. This study was conducted to determine the nutritional and phytochemical composition of seventeen Bambara groundnut landraces that were collected from Vihiga, Kakamega, Bungoma, Busia, and Kisumu Counties in Kenya. Prior to characterization, a field experiment was set up in Ishiara Ward in Mbeere North Sub-County in Embu County for two cropping seasons to standardize and multiply the seeds. The experiment was laid out in a Randomized Complete Block Design with three replicates. The harvested seeds were analyzed for their proximate, nutritional, and phytochemical composition using standard procedures. The moisture content ranged from 3.47 to 6.24%, total ash from 3.17 to 4.69%, crude protein from 21.18 to 26.00%, and fats from 4.56 to 7.02%. Iron levels ranged from 4.07 to 5.13 mg/100 g, sodium from 25.14 to 129.66 mg/100 g, potassium from 819.34 to 1,131.80 mg/100 g, and zinc from 0.06 to 0.42 mg/100 g. The tannin levels ranged from 0.01 to 0.04 mg/g, saponins from 0.82 to 1.06 mg/100 g, alkaloids from 0.01 to 0.12 mg/100 g, and flavonoids from 4.07 to 8.45 mg/100 g. The landraces BG-125, BS-148, and BS-145 with relatively higher nutrients composition and those with high levels of phytochemicals such as BS-104 and MU-137 are recommended to plant breeders for further selection and production of certified seeds. These selections will also be promoted to the farmers for production through various extension programs.

1. Introduction

Bambara groundnut (*Vigna subterranea*) is an underutilized legume in the Fabaceae family, mostly cultivated in Africa and Asia [1]. The crop is believed to have its origin in a place known as 'Bambara' in Central Mali in West Africa [2]. The suffix 'groundnut' is due to the fact that pod formation is similar to that of groundnut hence the popular name 'Bambara groundnut' [3]. Cameroon, Niger, and Burkina Faso are the major producers of Bambara groundnut. They contribute approximately 74% of the total world production [4]. In Kenya, Bambara groundnut is known by different local names including nzugu mawe (Giriama), njugu mawe (Swahili), and tsimbande (Luhya) [5]. It is mostly cultivated in western and coastal regions and some parts of Nyanza and less known in other parts of Kenya [6].

Bambara groundnut is normally referred as a "poor man's crop" or "women's crop" grown primarily to supply the family with sufficient food [7]. However, the crop was lately recognized as one of the crops for the new millennium [8] due to its nutritional value, drought tolerance traits, and its capacity to grow and yield in poor soils [1]. Bambara groundnut is among the list of climate-smart crops that needs to be promoted especially in drought prone areas. It is also a pest- and disease-tolerant crop and has a natural ability to fix nitrogen from the air which enriches the soil and reduce the use of inorganic nitrogenous fertilizers [9]. The crop is thus very valuable in areas with nutrient depleted soils and saves the poor-resource farmers from spending too much on fertilizers. Majola et al. [4] documented that the production of this crop in Sub-Saharan Africa ranges between 0.65 and 0.78 tonnes per hectare but with a potential of producing over 3 tonnes per hectare [10]. The use of low-yielding varieties, poor-quality seeds and poor agricultural practices are major production constrains of Bambara groundnut [4].

Changes in eating habits and the realization of the importance of locally available crops have led to the rise in utilization of underutilized crops as source of food for humans [11]. Bambara groundnut is basically cultivated for domestic use and is at times referred as "complete food" as it contains adequate macronutrients [1]. The crop contains 6.5% fat, 5.5% fiber, 64.4% carbohydrate, and 23.6% protein and appreciable levels of several minerals including Ca (360 mg), Na (75.25 mg), Fe (3.6 mg), and K (1723.25 mg) per 100 g of dry sample weight [12]. In developing countries, there is habitual consumption of carbohydrate-based diets by large proportion of population because of scarcity of affordable vitamins, minerals, and protein-based food [5]. Legumes and pulses such as Bambara groundnut are low-cost source of protein as compared to animal sources [13]. It is recommended that 60 to 100 g of Bambara groundnut seeds should be consumed by humans for at least 3-4 times per week to obtain the required amount of plant-based protein [14]. Bambara groundnut which is lysine-rich and methionine-poor makes it a good blend to cereals like maize that often have sufficient methionine but low lysine content [15]. Therefore, consumption of Bambara groundnut alongside other protein sources plays a major role in reducing malnourishment in less-developed areas [16].

Bambara groundnut is primarily consumed by humans [17] as a snack after boiling or roasting when fresh [18] and eaten as confectionery [19], or crushed and used with or without condiments to make soup [20]. Bambara groundnut seeds are very caloric and their flour can be used to make a thick porridge [21]. Due to their toughness, dehydrated seeds are difficult to crush into powder, but when crushed, delicious bread and flat cakes can be made [22]. Powdered beans can also be used to make slurry which can be brewed into a gel known as Okpa [23]. Immature seeds can also be cooked or eaten while fresh [24]. The legume can be utilized as fodder to feed livestock [25]. In addition, Bambara groundnut has several medicinal uses. In South Africa, raw seeds of Bambara groundnut are chewed and swallowed by pregnant women to treat morning sickness as it is thought to be a remedy to vomiting and nausea [26]. The grains are often chewed to relieve a swelling jaw [27] while flour is used to treat skin rashes [4]. Green leaves are eaten to prevent vomiting [28]. In Senegal, sap from Bambara groundnut leaves is used in treatment of epilepsy, infected wounds, and eyes while seed powder can be mixed with water and used to treat cataracts [5]. Water from steamed seeds of Bambara groundnut is used to treat diarrhea by Kenyan Luo tribe [29].

Approximately, 36% of Kenyans are reportedly suffering from malnutrition [30] and 4–8% are in need of food-related emergency assistance at any given time particularly in arid and semiarid areas where farming activities are constrained [31]. This realization prompted the Kenyan government to put into action some coping strategies including the launch of National Food and Nutrition Security Policy (FNSP) [32] and the Big Four Agenda whose one of the pillars is anchored on food and nutritional security. Despite the nutritional and medicinal value of Bambara groundnuts, their utilization is limited by presence of phytochemicals including saponins, condensed tannins, phytic acids, and flavonoids, which have also been found to possess some antinutritional factors [33]. These phytochemicals have been reported to reduce the absorption of nutrients by the body [34]. However, most of these phytochemicals have been reported to have some medicinal values hence promoting good health [35]. Other phytochemicals such as saponins play an important role in plant defense mechanism [36]. The testa color of Bambara groundnut has been linked to tannin concentration and may also be used as a phenotypic marker for drought tolerance traits in that the dark variant seeds have been reported to germinate faster than light variant seeds under drought due to the presence of tannins [37]. This paper outlines the nutritional and phytochemical compositions of Bambara groundnut and its potential in mitigating food and nutritional insecurity.

2. Materials and Methods

2.1. Bambara Groundnut Seeds Collection. The study assessed seventeen Bambara groundnut landraces that were randomly collected from farmers in Kisumu, Vihiga, Busia, Bungoma, and Kakamega Counties in Western Kenya region (Table 1) where the crop is mainly cultivated.

2.2. Description of Experimental Site. Field experiments were set up in a farm in Ishiara location, in Mbeere North Sub-County in Embu County, Kenya. The area lies in the lower midland 4 (LM4) agroecological zone within the coordinates 0.4548°S, 37.7849°E at an elevation of 853 m above sea level [44]. The area is characterized by hot, semiarid conditions with a mean temperature of 23°C and receives an average rainfall of 800 mm per annum, which is usually bimodal [45]. Long rains (LRs) are experienced from March to May while short rains (SRs) are experienced from mid-October to December, thus two cropping seasons is possible [45]. Long rains (LRs) define the cropping season characterized by less interannual variability [46] and heavy rains that last for a longer period [47]. Short rains (SRs) season on the other hand takes shorter period and shows more interannual variability [46]. The site has reddish brown and blackish grey sandy soils [48].

2.3. Experimental Design and Layout. The experiments were laid out in a Randomized Complete Block Design (RCBD) with three replicates. The experiments were conducted for two cropping seasons from April to June 2021 (season 1) and October to December 2021 (season 2). The experimental plot consisted of single rows measuring 3.0 m each spaced 1 m apart with 30 cm between plants. There was a 2.0 m path separating one replicate from the other. Two Bambara

Table 1: Description of locality where the tested Bambara groundnut landraces were collected.

	Landraces	Source	Latitude	Longitude	Altitude (m a.s.l)	Annual rainfall (mm)	Mean temp. (°C)	Dominating soil type	Total landraces
1	BG-125; BG-112; BG-109	Bungoma	0.6167°N	34.7667°E	1,523	400–1800	0–32	Lithosols	3
2	BS-104; BS-145; BS-148; BS-103; BS-114; BS-142; BS-141; BS-102;	Busia	0.4600° N	34.1117°E	1,227	760–1750	21–23	Orthic acrisols	8
3	MU-137	Kakamega	0.2827°N	34.7519°E	1,535	1250–1750	10.3–30.8	Ferralsols and acrisols	1
4	KS-108; KS-116; KS-118	Kisumu	0.0917°S	34.7680°E	1,335	600–1630	18–34	Lithosols and eutric cambisols	3
5	LU-123; LU-124	Vihiga	0.0768°N	34.7078°E	1,500	950–1600	24–26	Acrisols and cambisols	2

Key: The landraces are coded based on the location of collection and assigned series numbers. BG = Bungoma, BS = Busia, MU = Mumias, KS = Kisumu, and LU = Luanda. Temp. = temperature; *m* a.s.l = metres above sea level. Sources of weather and soil data: [38–43].

groundnut seeds were sown per hill at a depth of 3 cm and later thinned to one seedling two weeks after germination. Di-ammonium phosphate (DAP) fertilizer was applied at the rate of 50 kg·ha^{-1} at planting and mixed thoroughly with soil before the seeds were sown. Hand weeding was done twice in every season that is, at the third and sixth week after planting. Harvesting was done after all the foliage in the plants had dried up which coincided with 15th to 19th week after planting. Mature pods were harvested manually by digging out the entire crop and picking the individual pods and thereafter sun-dried and threshed.

2.4. Seeds Preparation and Laboratory Analysis. Harvested seeds were sorted and cleaned manually to remove foreign materials and damaged seeds and thereafter dry-milled to a fine powder using high-speed universal disintegrator (FW 80–1). The fine powder was stored in airtight containers in a cool and dry place in the laboratory prior to analysis following the procedure of Olaleye et al. [49]. The biochemical and nutritional analysis was carried out in triplicates using 100 g ground seed samples. Alkaloids were determined using the method described by Dike et al. [50]. Saponins determination was done according to the procedure described by Obadoni and Ochuko [51]. Tannin was determined using the Folin-Ciocalteu method as described by Wabali et al. [52] while flavonoid levels were quantified as described by Olaleye et al. [49]. The unit of measure was mg/100 g except for tannin which was quantified in mg·g^{-1}.

Proximate analysis was determined using the Association of Official Analytical Chemists (AOAC) methods for moisture content [53], total ash content [54], and crude fat [55]. The protein content was determined by micro Kjeldahl method by first quantifying the nitrogen content and then multiplying it by 6.25 to get the protein content [56]. The approximate values obtained from the analysis were reported in g/100 g of sample. Minerals were determined following the methods described by Olaleye et al. [49]. Sodium and potassium were determined using flame photometry model FP640; zinc was determined using atomic absorption spectrometer (AAS)–PG–990; iron was determined using UV spectrophotometer model ME 801. The unit of measure for all the minerals was mg/100 g.

2.5. Data Analysis. The biochemical and nutritional data collected were subjected to analysis of variance (ANOVA) using XLSTAT software version 2022. The means that were significantly different were separated using Tukey's Honest Significant Difference (HSD) at 95% level of confidence. Data were also subjected to cluster analysis using Agglomerative Hierarchical Clustering (AHC) to determine the diversity among the landraces on the basis of their biochemical and nutritional composition. Pearson correlation analysis was conducted to determine the association between the biochemical and nutritional components.

3. Results

3.1. Proximate and Nutritional Composition of the Bambara Groundnut Landraces. The proximate and nutritional composition of the Bambara groundnut landraces used in this study is shown in Table 2. There was significant difference ($P \leq 0.05$) in all the nutritional and phytochemical traits evaluated in the combined data for both seasons. The results from the first and second cropping seasons analyzed separately had no significant difference at ($P \leq 0.05$) levels of confidence. The moisture content ranged from 3.467% in landrace LU-123 to 6.238% in landrace BG-125. The total ash content ranged from 3.171% in BS-141 to 4.694% in BS-114. The landrace BS-114 also had the highest mean value of crude protein (26.002%) while KS-116 had the lowest mean value of crude protein (21.178%). The fat content ranged from 4.563% in BS-114 to 6.930% in KS-116. Therefore, BS-114 had the highest protein and total ash content but the lowest fat content. The landrace BG-125 had the highest iron content of 5.125 mg/100 g while BG-112 had the lowest iron content of 4.068 mg/100 g. Zinc content ranged between 0.057 mg/100 g and 0.422 mg/100 g in landraces BS-104 and BG-125, respectively. Potassium ranged from 819.335 mg/100 in landrace BS-103 to 1,134.80 mg/100 g in landrace BS-145. The highest sodium content was obtained in landrace LU-123 with 129.663 mg/100 g while landrace MU-137 had the lowest value of 25.140 mg/100 g .

3.2. Antinutrient Composition of the Bambara Groundnut Landraces. The results for antinutrient components are presented in Table 3. There were significant ($P \leq 0.05$) differences between the landraces for their antinutrient components. The composition of tannins ranged from 0.011 mg·g^{-1} in landrace KS-108 to 0.037 mg·g^{-1} in landrace BS-114. Saponins composition ranged between 0.815 mg/100 g in landrace KS-108 and 1.057 mg/100 g in landrace MU-137. The alkaloids content ranged from 0.011 mg/100 g in landrace BG-109 to 0.116 mg/100 g in landrace BS-103. Among the test landraces, BS-104 had the highest mean composition of flavonoids (4.067 mg/100 g) while KS-108 had the lowest mean value (8.450 mg/100 g). There were significant differences ($P \leq 0.05$) between seasons for tannins, flavonoids and saponins concentrations but no significant difference ($P \leq 0.05$) between the two seasons for alkaloid content in the tested landraces. Landrace × season interactions were not significant ($P \leq 0.05$) for all the tested biochemical components.

3.3. Cluster Analysis. Cluster analysis based on the nutritional and phytochemical components was used to estimate the degree of similarity and diversity among the different Bambara groundnut landraces used in this study. The 17 landraces were grouped into five (5) supported clusters (Figure 1) with a diversity of 94.02% between clusters and 5.98% within clusters. Cluster 1 was a singleton of landrace

Table 2: Proximate and mineral composition of the tested Bambara groundnut landraces (combined seasons).

Landraces	Moisture (%)	Total ash (%)	Fats (%)	Protein (%)	Fe (mg/100 g)	Zn (mg/100 g)	K (mg/100 g)	Na (mg/100 g)
LU-123	3.467 i	4.195 bcde	6.553 b	24.535 bc	4.743 bcd	0.257 abc	1031.110 bcd	129.663 a
BS-114	4.892 def	4.694 a	4.563 h	26.002 a	4.623 cde	0.173 abc	1063.190 abc	118.307 c
MU-137	5.852 b	4.226 bcd	5.808 de	22.043 ij	4.917 abc	0.111 c	934.837 ef	25.140 o
BG-125	6.238 a	4.070 def	7.024 a	21.812 j	5.125 a	0.422 a	994.542 cde	27.290 n
BS-148	4.620 fg	4.272 bcd	4.969 g	24.900 b	4.855 abcd	0.092 c	1082.862 ab	44.910 k
BS-104	5.815 b	3.936 ef	6.242 bc	22.490 hi	4.960 ab	0.057 c	820.393 g	27.467 n
KS-118	3.787 hi	4.029 def	6.218 bc	22.438 hij	4.623 cde	0.226 abc	1044.433 bcd	104.515 d
BS-102	5.648 bc	4.459 ab	5.493 ef	23.247 fg	4.843 abcd	0.226 abc	964.153 def	64.965 g
LU-124	3.490 i	4.231 bcd	6.136 cd	24.188 cd	4.840 abcd	0.224 abc	997.355 cde	52.050 h
BS-103	5.072 d	3.590 g	5.983 cd	22.918 gh	4.842 abcd	0.373 ab	819.335 g	49.475 i
BS-145	4.677 efg	4.139 cde	5.395 f	24.357 bc	4.683 bcde	0.127 bc	1133.800 a	66.520 f
BS-141	4.987 de	3.171 h	6.053 cd	24.395 bc	4.585 de	0.070 c	983.067 cde	36.622 l
KS-116	3.678 i	3.827 fg	6.930 a	21.178 k	4.822 abcd	0.086 c	974.678 de	29.360 m
BS-142	4.503 g	4.054 def	5.605 ef	23.915 cde	4.370 ef	0.242 abc	982.713 cde	80.787 e
BG-112	4.032 h	4.398 bc	5.811 de	23.165 fg	4.068 f	0.079 c	1108.542 ab	81.082 e
KS-108	5.438 c	4.096 def	5.618 ef	23.405 efg	4.095 f	0.267 abc	882.490 fg	122.253 b
BG-109	4.710 efg	4.012 def	5.593 ef	23.660 def	4.105 f	0.186 abc	991.513 cde	46.825 j
p value	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001***
Standard error	0.065	0.056	0.068	0.124	0.063	0.051	16.261	0.209
Season 1	4.786	4.088	5.886	23.492	4.675	0.192	988.805	65.198
Season 2	4.732	4.077	5.878	23.408	4.630	0.187	988.725	65.065
p value	0.093 NS	0.679 NS	0.806 NS	0.165 NS	0.147 NS	0.843 NS	0.992 NS	0.193 NS
Standard error	0.022	0.019	0.023	0.042	0.022	0.012	5.578	0.072
Landrace × season	0.906 NS	1.000 NS	1.000 NS	1.000 NS	1.000 NS	1.000 NS	1.000 NS	1.000 NS

Key: values with the same letters within the column are not significantly different at $\alpha = 0.05$.

Table 3: Antinutrients in the assessed Bambara groundnut landraces (combined seasons).

Landraces	Alkaloids (mg/100 g)	Tannins (mg/g)	Saponins (mg/100 g)	Flavonoids (mg/100 g)
LU-123	0.034 ab	0.033 a	0.907 de	6.553 g
BS-114	0.036 ab	0.037 a	0.945 cd	6.220 h
MU-137	0.039 ab	0.034 a	1.057 a	8.170 b
BG-125	0.023 b	0.029 ab	0.875 ef	8.085 b
BS-148	0.031 ab	0.028 ab	0.980 bc	7.480 d
BS-104	0.036 ab	0.029 ab	1.003 b	8.450 a
KS-118	0.032 ab	0.033 a	0.942 cd	6.175 h
BS-102	0.024 b	0.029 ab	0.872 efg	6.822 f
LU-124	0.030 ab	0.018 cd	0.843 fgh	8.185 b
BS-103	0.116 a	0.023 bc	0.903 de	7.877 c
BS-145	0.019 b	0.031 ab	0.870 efg	6.967 f
BS-141	0.039 ab	0.029 ab	0.868 efg	6.837 f
KS-116	0.023 b	0.034 a	1.002 b	7.277 e
BS-142	0.021 b	0.032 ab	0.875 ef	5.440 i
BG-112	0.027 b	0.018 cd	0.828 fgh	4.490 j
KS-108	0.019 b	0.011 d	0.815 h	4.067 l
BG-109	0.011 b	0.032 ab	0.820 gh	4.317 k
p value	0.047*	<0.0001***	<0.0001***	<0.0001***
Standard error	0.017	0.002	0.010	0.031
Season 1	0.039	0.030 a	0.920 a	6.695 a
Season 2	0.027	0.027 b	0.893 b	6.647 b
p value	0.171 NS	0.003**	<0.0001***	0.002*
Standard error	0.006	0.001	0.003	0.011
Landrace × season	0.480 NS	1.000 NS	0.992 NS	1.000 NS

Key: means with the same letters within the column are not significantly different at $\alpha = 0.05$. *Significant at 5%, **significant at 1%, and ***significant at 0.1%. NS: not significant.

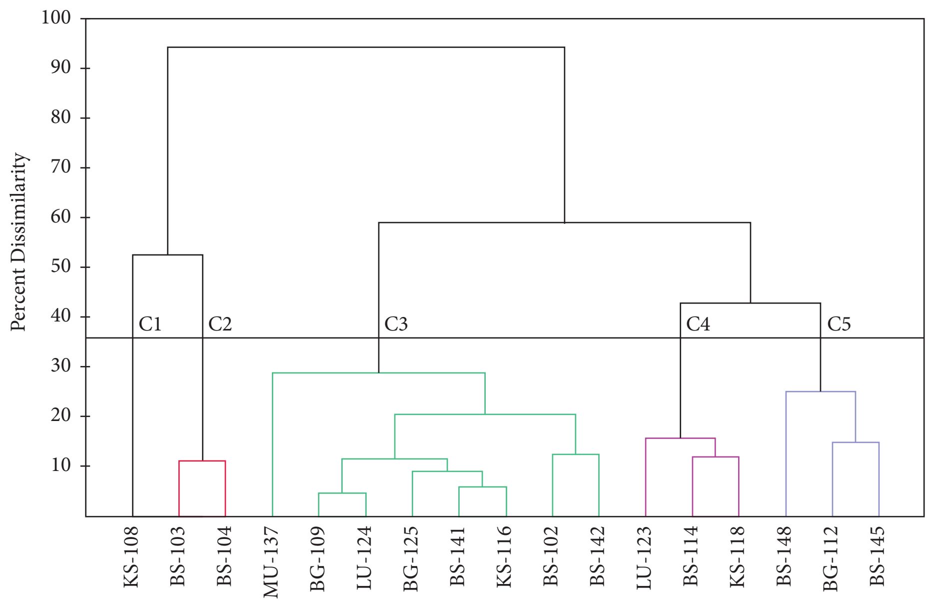

Figure 1: Dendrogram depicting the diversity of the 17 Bambara groundnut landraces based on nutritional and phytochemical composition.

KS-108. Cluster 2 contained only two landraces, BS-103 and BS-104, both of which were collected from Busia County. These two landraces had medium levels of moisture, total ash, fat, protein, iron and potassium, but low levels of zinc and sodium. Cluster 3 was the largest comprising of eight landraces namely MU-137, BG-109, LU-124, BG-125, BS-141, KS-116, BS-102 and BS-142 which had no clear unique attributes. Cluster 4 consisted of landraces LU-123, BS-114 and KS-118 characterized with high levels of alkaloids and tannins. Cluster 5 consisted of landraces BS-148, BG-112 and BS-145 with high potassium levels and moderate to low sodium levels. The cluster analysis did not depict any significant influence of the origin of the landraces but was based mainly on the nutritional and phytochemical composition of selected Bambara nut landraces.

3.4. Principal Component Analysis. The principal component analysis (PCA) was used to show the relationship between the Bambara groundnut landraces and the nutritional and phytochemical traits evaluated (Figure 2). The PCA was useful in determining the most important components that were used in discriminating the different landraces. The first two variability factors (F1 and F2) explained 52.11% of the total variation with F1 explaining variability of 32.19%, F2 with 19.92%. The landraces that were plotted closer to specific components indicated that those components had a relatively higher contribution in discriminating those landraces from the others. The tannins, saponins, flavonoids, and iron were very important in separating the landraces MU-137, BS-104, and KS 116. The content of moisture, fats, alkaloids and zinc had a higher contribution in discriminating the landraces BS-141, BG-125, and BS-103. Total ash, potassium, and protein contents were the most important components in separating the landraces BS-114, BS-145, BS-148, and BS-102. Sodium content was the most important component in discriminating the landraces LU-123, KS-108, BG-112, KS-118, BS-142, BG-109, and LU-124.

3.5. Pearson Correlation of the Nutritional and Phytochemical Components. Pearson correlation of the nutritional and phytochemical components of Bambara groundnut landraces is presented in Table 4. The saponins were found to be positively correlated to tannins and flavonoids. There was significant negative correlation between the alkaloids and potassium content while the flavonoid content was positively correlated to iron content but negatively correlated to the sodium content (Table 4). The protein content was negatively correlated to the fat content but positively correlated to the sodium content which was negatively correlated to the iron content.

4. Discussion

The study showed significant variation in proximate, mineral, and antinutrient contents of Bambara groundnuts that were evaluated. Results showed that moisture content of the landraces ranged from 3.467% to 6.238%. This was lower than the one reported by Olaleye et al. [49] that ranged between 5.23 and 9.23 g/100 g. Yao et al. [57] reported moisture content of Bambara groundnut to be 11.7%. The seeds with significantly lower moisture content such as for LU-123, LU-124 and KS-116 are likely to have a longer postharvest life since they are less susceptible to pest attack [58]. On the other hand, the ash content observed among the tested landraces in this study was comparable to the values reported in similar previous studies [5, 24, 59]. The low ash content of Bambara groundnut seeds indicated low level of inorganic substances in the sample with minerals being the main components [60].

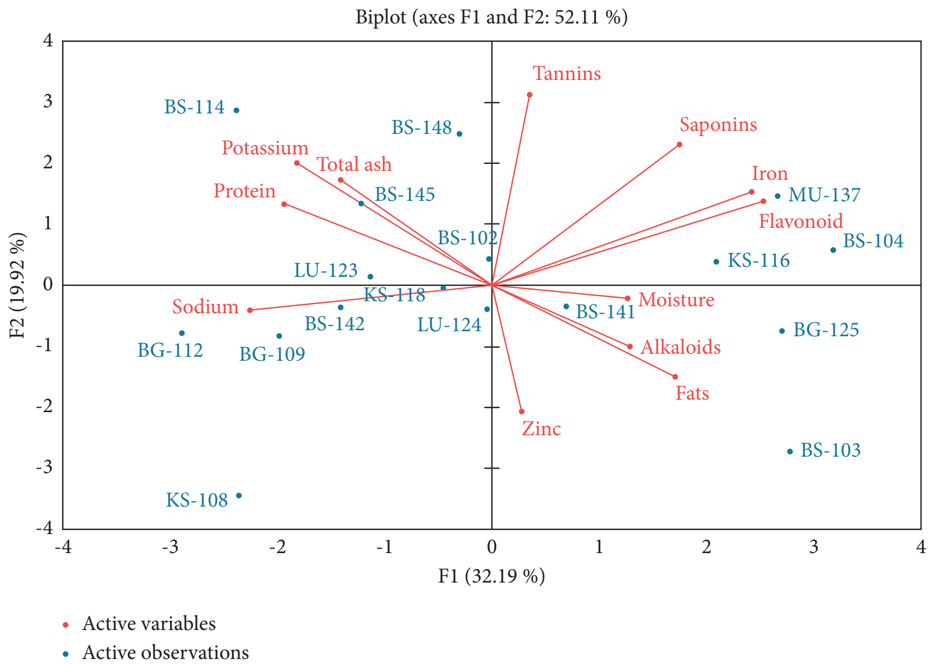

Figure 2: Biplot showing the principal components in different landraces and their relatedness based on their nutritional composition.

Table 4: Pearson correlation among 11 nutritional and phytochemical components of tested Bambara groundnut landraces (combined seasons).

Variables	Moisture										
Total ash	−0.042	Total ash									
Alkaloids	0.113	−0.358	Alkaloids								
Tannins	0.050	0.165	−0.188	Tannins							
Saponins	0.140	0.044	0.177	**0.490**	Saponins						
Flavonoids	0.221	−0.169	0.368	0.283	**0.590**	Flavonoids					
Fats	−0.113	−0.461	−0.006	−0.162	0.068	0.324	Fats				
Protein	−0.229	0.276	−0.027	0.206	−0.285	−0.239	**−0.721**	Protein			
Iron	0.263	−0.060	0.263	0.382	**0.595**	**0.956**	0.345	−0.253	Iron		
Sodium	−0.376	0.418	−0.115	−0.128	−0.316	**−0.597**	−0.313	**0.489**	**−0.485**	Sodium	
Potassium	−0.473	0.429	**−0.489**	0.347	−0.169	−0.254	−0.287	0.438	−0.195	0.285	Potassium
Zinc	0.177	0.009	0.253	−0.250	−0.373	0.007	0.269	−0.130	0.141	0.231	−0.253

NB: values in bold are not equal to zero at alpha = 0.05 significance level.

Bambara groundnut is known to be rich in high quality protein compared to other legumes such as cowpea, soybean, and groundnut [61]. The crude protein observed in this study were comparable to those observed in velvet bean by Vadivel and Janardhanan [62] which contained 20.2 to 29.3%. However, the genotypes in this study had relatively higher crude protein content than the documented content for Bambara groundnuts [63]. Variation in the protein composition among different studies could be attributed to environmental conditions, genetics [64], and also the differences in techniques of estimations for instance nitrogen conversion factor [18]. Like other legumes, Bambara groundnuts is lysine-rich and methionine-poor, making it a good blend to cereals like maize that often have sufficient methionine but low lysine content [65].

The content of crude fat in the tested Bambara groundnut landraces was relatively higher than those found in cereals though may not be adequate to be utilized as oil source [15]. However, Mabhaudhi et al. [11] reported that a tribe in Congo was successfully extracting oil from Bambara seeds. Even so, the levels of crude fat reported in Bambara groundnut would not make them to be classified together with other oil rich legumes such as soybeans with around 19.5% and groundnut with 25% fat content [66]. The results from the present study showed that the landrace, BS-114, with dark colored seeds had the highest protein content but the lowest fat content. Nti [59] also observed highest levels of crude protein and lowest levels of fat in dark variants (red and black) of Bambara groundnut and concluded that protein levels are negatively correlated to fat content [59].

Further characterization of the nutritional components showed that all the landraces had considerable amount of minerals higher than the mineral levels reported in other legumes that are mostly consumed such as mung beans [67]. According to Olaleye et al. [49], potassium, iron, zinc, phosphorus and magnesium are the most dominant mineral elements found in Bambara groundnut seeds. These nutrients are important especially in economically developing nations where there is habitual consumption of cereals hence Bambara groundnut is a super candidate for such areas. Genetic origin, level of soil fertility and geographical source of landraces are the factors that cause differences in mineral composition in plants of the same species [68]. The observed levels of potassium were lower than what was reported in other Bambara groundnut genotypes by Chandra et al. [12] and Dansi et al. [69] but higher that what is contained in most consumed legumes such as mung beans [67]. Potassium helps in maintaining the balance of alkaline-acid in the body [70] and also reduces vasoconstriction and blood pressure and acts as vasodilator [68].

The levels of zinc in the Bambara groundnut seeds in this study were relatively lower than what was reported by Murevanhema and Jideani [5] but higher than what was reported by Olaleye et al. [49] in other Bambara groundnuts. Iron is an important element especially in synthesis of haemoglobin in the blood [68]. The results of further showed that sodium content was highly variable among the tested landraces as it ranged from 25.16 to 129.67 mg/100 g. Chandra et al. [12] reported a value of 75.25 mg of sodium in Bambara groundnut grown in India. It is recommended that adults should consume not more than 6 g of sodium in a day [71] and high levels of sodium in the body is a health risk as it may cause problems such as cardiovascular diseases [12]. Therefore, the sodium content in Bambara groundnut is low enough to cause health risks.

The mean value of tannins between 0.011 mg/g and 0.037 mg/g observed in this study was comparable with 0.039 mg/g and 0.046 mg/g reported by Ijarotimi and Esho [72] and Mazahib et al. [73] among Bambara seeds cultivated in Nigeria and Sudan, respectively but lower than 4.5 and 15 mg CE $^{g-1}$ reported by Nti [59]. Although tannins are important in defense to seeds grown in unfavorable environments [74], they lower the palatability of the crops by causing bitter taste in plants [75]. Low tannins ensure absorption of essential micronutrients and digestion of protein [76]. The flavonoids content observed among the Bambara groundnut landraces in our study was much lower than what was reported by Olaleye et al. [49] but the saponins content in our study corroborated the findings of Olaleye et al. [49]. Alkaloids content observed in our study was comparable to what was reported by Mbagwu et al. [77] in Bambara groundnut in Eastern Nigeria. Alkaloids have been reported to have anti-cancer activity [78], anti-malarial activity [79] and helps to prevent stroke [80].

The diversity among the 17 genotypes was further assessed using cluster analysis based on their nutritional and phytochemical composition. The high percentage of diversity observed between different clusters and the low diversity observed within clusters was a good indication that the nutritional and phytochemical components can be successfully used to discriminate between different Bambara groundnut genotypes. The cluster analysis did not group the landraces based on their place of origin indicating that the landraces may have a wider environmental adaptability hence can be widely exploited by the farmers based on the nutritional and phytochemical preferences. This observation was also supported by the principal component analysis (PCA) where the genotypes were separated based on the components that captured the largest share of explained variance. The PCA also uses factor loading to show which features correlate with the most important components. Therefore, both cluster analysis and PCA are useful tools in selecting landraces with desirable traits that can be exploited in a plant breeding program.

Correlation analysis helps in determining the relationship between traits and it's useful in assessing trait combinations during selection. The study showed that saponins were positively correlated to tannins and flavonoids. Positive correlation between the phytochemical is especially important when the objective is to improve the pharmaceutical properties of the genotypes. A negative correlation was observed between the alkaloids and potassium content as well as between flavonoids and sodium content. This means that lowering the level of alkaloids would increase the level of potassium and increasing the level of flavonoids would lower the content of sodium and vice-versa. The flavonoid content was found to positively correlated to iron indicating that the two traits may cosegregate hence enabling their combined selection. This may also be possible when targeting a high protein content with low fat content since the two traits were found to be negatively correlated. However, the protein content was positively correlated to the sodium content indicating that improvement of the protein content using conventional breeding methods without increasing sodium content would be difficult unlike for iron which was negatively correlated to sodium. Lack of significant correlation between various traits was an indication that such traits may not be linked hence their selection should be considered on single trait basis.

5. Conclusion and Recommendations

This study confirmed that the Bambara groundnut is a good source of nutrients mainly protein and minerals. The observed diversity in the proximate, nutritional and phytochemical composition of the tested landraces provides the basis for selection for enhanced nutritional and phytochemical composition of this high value legume. The landraces with high nutritional value such as BG-125, BS-148, and BS-145, among others, are recommended to plant breeders for production of certified seeds to facilitate their adoption by the farmers for enhanced food and nutritional security. Although the landraces LU-123, BS-114, and KS-108 have high nutritional value, their nutritional composition should be improved by reducing the sodium content before seed multiplication. The landraces with high levels of phytochemicals are also recommended to plant breeders for production of certified seeds targeting their utilization by pharmaceutical and nutraceutical industries.

These may include BS-104 for flavonoids and MU-137 for saponins. All the selections should also be promoted to the farmers for adoption through various extension programs.

Data Availability

Some of the data used to support the findings of this study are included in the article. Additional data are available from the corresponding author upon request.

Conflicts of Interest

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

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