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Chemical and Functional Evaluations of Raw, Steeped and Germinated Sorghum Bicolor

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Abstract

Chemical composition and functional properties of raw (Rs), steeped (Sts) and germinated (Gms) sorghum samples were studied following standard analytical procedures. The proximate compositions were (g/100g): moisture (6.99-8.20); crude protein (6.99-12.1); crude fat (1.25-3.23); total ash (0.335-2.05); crude fibre (1.30-2.92); carbohydrate (73.6-80.1). fat, ash and fibre were relatively low. The total metabolizable energy was high at 1543-1600 Kj/100 g and highest percentage energy contribution was due to carbohydrate (PEC%) (81.1-86.1%). Rs had the highest concentration of all the minerals detected followed by Sts and Gms had the least (except in phosphorus where Sts<Gms and nickel where Sts=Gms). However, Co, Cu, Cd and Pb were not detected in any of the samples. The Ca/P ratios (0.026-0.160) were far below the recommended value of 0.50 for proper Ca absorption and Na/K ratios (0.621-0.814) were slightly above 0.60. However, [K/(Ca+Mg)] milliequivalent (0.587-1.72) were less than the maximum critical level of 2.2. The results of Mineral Safety Index (MSI) showed that the body would be overloaded with only Zn in all the samples and Fe in Rs and Sts. The following functional properties were high in the samples: water absorption capacity (150%-200%), oil absorption capacity (112%-130%), emulsion capacity and stability (46.9%-47.4% and 49.0%-55.0% respectively) and bulk density (76.7-80.6 g.cm^{-3}). The minimum protein solubility was observed at Ph 3, 5 and 9 (Rs), Ph 3 (Sts) and Ph 4 (Gms). Generally, there were varied compositions among the samples in many of the parameters determined as evident in the statistical analysis.

Keywords: ***Chemical composition; Functional properties; Sorghum bicolor***

Introduction

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Sorghum is an important cereal, staple grain for farmers in semi-arid areas of Asia and Africa for many years. It belongs to the kingdom Plantae, order poles, tribe Andropogonae, supertribe Andropogonodae, grass family Poaceae and subfamily panicoideae. Sorghum is treated as an annual crop, although it is a perennial grass which and its harvesting period could be more than one time in the tropics [1]. Sorghum is drought-tolerant and it is usually grown where cultivation of maize is risky due to low rainfall and high temperature. Sorghum grain is used in the preparation of many traditional foods and in bakery preparations such as bread and cakes. One species, Sorghum bicolor [2] native to Africa with many cultivated forms now, is an important crop worldwide, used for food, animal fodder, the production of alcoholic beverages, and biofuels. Sorghum bicolor has the following local names in Nigeria: Dawa in Hausa, Oka baba in Yoruba, Okili in Ibo. The second major component of sorghum grains after carbohydrate is protein. In sorghum, the variability is large, probably because the crop is grown under diverse agroclimatic conditions which affect the grain composition [3]. One of the most common thick porridge consumed in Nigerian is ogi. The flour from dehulled or whole sorghum is mixed with water and cooked into a thick stiff porridge that is eaten with a soup (sauce) composed of vegetables, meat, and other items depending upon the availability of the ingredients. Tuwo is usually a thin porridge, processed from dry-milled non fermented whole grain flour [4].

Literature had shown that African and Asian countries are the major consumers of sorghum for food [5]. It was also reported that human consumption accounts for almost three-quarters of total utilization of sorghum in Africa as it represents a large portion of the total calorie intake in many countries [1]. This research work is therefore aimed at investigating the effects of steeping and germination on the proximate and mineral compositions as well as the functional properties of Sorghum bicolor for the benefit of the consumers.

Materials and Methods

Collection and treatment of samples

The samples (sorghum grains) were purchased from the main market, Odo-Ayedun, Ekiti State, Nigeria. Stones and defective grains were manually removed. The grains were divided into three equal parts. The first part, labeled as the raw sample was dried in the sun four three days and stored in a plastic container. The second, part labeled as the steeped sample was soaked in a plastic container with distilled water for three days after which the grains were washed with distilled water and were later dried in the sun and stored. The last portion tagged as the germinated sample was fully soaked in water at room temperature for 28 h, removed from the water and were spread on a damped fabric, shielded from direct sun for two days when some sprouts of about 5 cm^3 were observed. The grains were allowed to dry in the sun for three days and the sprouts were manually removed. The desprouted grains were later stored in a plastic container. The three samples were dry milled separately to a fine powder and kept in a refrigerator prior to use.

Proximate analysis

Analysis of the proximate composition of the samples for moisture, crude fat, crude ash, and crude fibre was carried out using the methods described by A.O.A.C. [6]. Determination of nitrogen was done by micro-Kjedahl method [7] and crude protein was calculated by multiplying the nitrogen content by 6.25. Carbohydrate was determined by difference. The calorific values were determined by multiplying the results of protein, carbohydrate and crude fat by 17, 17 and 37 respectively. Each analysis was carried out in duplicate.

Mineral analysis

The analysis of the minerals was done from the solution obtained by dry-ashing the samples at 550ºC to constant weight. Sodium and potassium contents were determined using flame photometer and phosphorus was determined by Vanadomolybdate method [6]. Other metals were determined using atomic absorption spectrophotometer (Bulk Scientific Instrument). All analyses were done in duplicate.

Functional properties

Water and oil absorption capacities were determined following the methods described by Beuchat [8]. Emulsion capacity and stability were determined following the methods of Sathe and Salunkhe [9]. Determination of foaming capacity and stability and least gelation concentration were carried out using the methods of Coffman and Garcia [10]. The method of Wand and Kinsella [11] modified by Narayana and Narasinga Rao [12] was followed to determine the bulk density of the samples. The variation of protein solubility with pH was determined using the method described by Oshodi and Ekperigin [13]. The protein of the supernatant was determined using the micro-Kjeldahl method [6] and expressed as mg protein per cm^3. All the results were means of two determinations.

Statistical analysis

The data generated were statistically analyzed to determine to the mean, standard deviation and coefficient of variation percent. Other parameters determined were linear correlation coefficient (rxy), coefficient of determination (rxy2), coefficient of alienation (CA) and index of forecasting efficiency (IFE) between raw (Rs)/steeped (Sts), raw (Rs)/germinated (Gms) and steeped (Sts)/germinated (Gms) samples [14].

Results and Discussion

TABLE 1 presents the results of the proximate composition of raw (Rs), steeped (Sts) and germinated (Gms) sorghum samples. Samples with highest concentrations where (g/100 g): raw: total ash (2.05), crude protein (12.1) and crude fiber (2.92); steeped: crude fat (3:23) and carbohydrate (80.1); germinated: moisture (8:20). Whilst germinated recorded the least value (g/100 g) in ash (0.335), crude fat (12.5) and crude fiber (1:30), steeped had the least in moisture and crude protein (6.99 each) and raw in carbohydrate (73.6). Some of the literature reports on proximate composition are (Prosopis africana, %): moisture (1.9), total ash (4.4), ether extract (12.8), crude protein (23.6), crude fiber (3.3) and carbohydrate (54.0) [15]; groundnut kernels (g/100 g); moisture (5.0), protein (27.0) lipids (47.0), carbohydrate (17.0), fiber and ash (2.0 each) [16]. Most of these literature results were higher than those of the current study. The levels of ether extract in this study (1.25-3.23 g/100 g) were lower than 6.99 g/100 g reported by Olaleye [17] for dehulled bambara groundnut. The ash content indicated that the raw sample would likely produce the highest levels of minerals because ash is a rough estimate of the mineral contents of any sample. The concentrations of crude protein in this report were comparatively lower than the recommended 23.56 g/100 g human daily protein requirement [18]. The carbohydrate content (73.6-80.1 g/100 g) were higher than the following literature values for both plant and animal sources (g/100 g): Prosopis africana (54.0) [15]; bambara groundnut seed flour (64.9) [19]; processed groundnut seed flour (92.26-4.14) [20]; Anaphe infracta (47.2) [21]; Callinectes latimanus (46.2) [22]. Levels of total ash, crude fat and crude fiber were generally low in this study.

TABLE 1. **Proximate composition (g/100 g) of Raw, steeped and germinated sorghum samples.**

Parameter	**Rs**	**Sts**	**Gms**	**Mean**	**SD**	**CV%**
Moisture	7.06	6.99	8.2	7.42	0.679	9.15
Ash	2.05	1.37	0.335	1.25	0.864	69.1
Fat	2.33	3.23	1.25	2.27	0.991	43.7
Crude protein	12.1	6.99	9.96	9.68	2.57	26.5
Crude fibre	2.92	1.35	1.3	1.86	0.921	49.5
Carbohydrate	73.6	80.1	79	77.6	3.48	4.48

Rs: raw sample; **Sts**: steeped sample; **Gms**: germinated sample; **SD**: standard deviation; **CV%**: coefficient of variation percent

The differences in the values of the proximate composition between Rs and Sts and between Rs and Gms are shown in **TABLE 2**. The results of Rs-Sts showed that moisture, ash, crude fat, crude protein, and crude fiber were all positive in favor of Rs whereas crude fat and carbohydrate were more concentrated in Sts. In Rs-Gms, ash, crude fat, crude protein, and crude fiber were more concentrated in Rs and vice versa in moisture and carbohydrate; highest level of difference was observed in moisture with the highest value of CV% (125).

TABLE 2. **Differences in proximate composition between Rs and Sts and between Rs and Gms.**

Parameter	**Rs-Sts**	**Rs-Gms**	**Mean**	**SD**	**CV%**
Moisture	+0.070 (+0.992%)	-1.14 (-16.1%)	0.605	0.757	125
Ash	+0.680 (+33.2%)	+1.72 (+83.7%)	1.2	0.735	61.3
Fat	-0.90 (-38.6%)	+1.08 (+46.4%)	0.99	0.127	12.9
Crude protein	+5.11 (+42.2%)	+2.14 (+17.7%)	3.63	2.1	57.9
Crude fibre	+1.57 (+53.8%)	+1.62 (+55.5%)	1.6	0.035	2.21
Carbohydrate	-6.50 (-8.83%)	-5.40 (-7.34%)	5.95	0.778	13.1

TABLE 3 depicts the percentage energy values contributed by protein (PEP%) fat (PEF%) and carbohydrate (PEC%) and utilizable energy due to protein (UEDP%). The results are as follows: PEP% (7.43-13.3), PEF% (2.97-7.47), PEC% (81.1-

86.1) and UEDP% (4.46-8.00). The samples with the highest concentrations of fat and protein also had the highest proportions of energy contributions due to fat (PEF%) and protein (PEP%). Energy contribution by carbohydrate was highest in the germinated sorghum sample (86.1) and the highest UEDP% in this study was comparatively lower than those in differently processed groundnut seeds flour [20]. The fat contribution (2.97-7.47%) of total energy was far below the 30% recommended energy intake from fat [23].

TABLE 3. **Energy values contributed by protein, fat, and carbohydrate in raw, steeped and germinated sorghum samples.**

Parameter	Rs	Sts	Gms	Mean	SD	CV%
Total energy	1543	1600	1559	1567	29.4	1.88
PEP%	13.3	7.43	10.9	10.5	2.95	28.1
PEF%	5.59	7.47	2.97	5.34	2.26	42.3
PEC%	81.1	85.1	86.1	84.1	2.65	3.15
UEDP%	8	4.46	6.52	6.33	1.78	28.1

PEP: proportion of total energy due to protein; **PEF**: proportion of total energy due to fat; **PEC**: proportion of total energy due to carbohydrate; **UEDP**: utilizable energy due to protein

The differences in energy contributions between Rs-Sts and Rs-Gms are shown in **TABLE 4**. Rs-Sts revealed that PEP% and UEDP% were more abundant in Rs whereas the reverse was the case in total energy, PEF%, and PEC%. In RS-Gms, Rs was better than Gms in PEP%. The CV% were high except in PEF% (23.3) and PEC% (15.7).

TABLE 4. **Energy value differences as contributed by protein, fat, and carbohydrate.**

Parameter	Rs-Sts	Rs-Gms	Mean	SD	CV%
Total energy	-57.0 (-3.69%)	-16.0 (-1.04%)	36.5	29	79.4
PEP%	+5.87 (+44.1%)	+2.40 (+18.0%)	4.14	2.45	59.3
PEF%	-1.88 (-33.6%)	+2.62 (+46.9%)	2.25	0.523	23.3
PEC%	-4.00 (-4.93%)	-5.00 (-6.16%)	4.5	0.707	15.7
UEDP%	+3.54 (+44.3%)	+1.48 (+18.5%)	2.51	1.46	58

TABLE 5 shows the mineral levels of raw, steeped and germinated sorghum seed samples. The following elements were not detected in any of the samples: Co, Cu, Cd, and Pb. All the major minerals were high in Rs and Sts; calcium and magnesium were low in Gms. Na and K are required to maintain the osmotic balance of the body fluid, the pH of the body, control glucose absorption and enhance normal retention of protein during growth [18]. Calcium is a major component of bones and teeth and an important constituent of body fluid. Ca tends to coordinate other inorganic elements; it corrects the excessive amount of Na, Mg, and K in the body. If Ca is adequately enough in the diet, there is better utilization of Fe; this is an

instance of sparing action [24]. Magnesium is an activation of many enzyme systems and maintains the electrical potential in nerves [25]. Among the trace elements, Zn had the highest concentration (34.0-73.5 mg/100 g); Fe contents were also high (10.6-30.9 mg/100 g). High levels of Zn in this study contradicts the report of Pew Initiative on Food and Biotechnology [26] that Zn is one of the several trace minerals that are deficient in the diets. Fe requirement by a human is as follows: children (10-15 mg), women (18 mg) and men (12 mg) [24]. Fe is required for proper growth, healthy blood cells and hemoglobin formation and its deficiency had been associated with abnormal functioning of the brain [18]. High Fe concentration in this study would make them good substitutes for conventional sources as they are capable of proving adequate Fe to meet human iron requirements.

TABLE 5. **Mineral composition (mg/100 g) of raw, steeped and germinated sorghum samples.**

Mineral	**Rs**	**Sts**	**Gms**		**Mean**	**SD**	**CV%**
Sodium	69.6	56	32.5		52.7	18.8	35.6
Potassium	89.3	68.8	52.3		70.1	18.5	26.4
Calcium	98.3	85.5	11.7		65.2	47.7	71.7
Magnesium	43.4	31.7	18.3		31.1	12.6	40.4
Zinc	73.5	57.1	34		54.9	19.8	36.1
Iron	30.9	19.5	10.6		20.3	10.2	50.1
Magnesium	0.29	0.19	0.01		0.16	0.142	87.1
Cobalt	ND	ND	ND		-	-	-
Copper	ND	ND	ND		-	-	-
Cadmium	ND	ND	ND		-	-	-
Lead	ND	ND	ND		-	-	-
Nickel	0.19	0.01	0.01		0.07	0.104	148
Phosphorus	614	533	457		535	78.5	14.7

TABLE 6 presents the Rs-Sts and Rs-Gms in the mineral composition. Rs was better than both Sts and Gms in all the detected minerals. However, Ni had the highest percentage difference in Rs-Sts (+94.7%) but in Rs-Gms, it was Mn (+96.6%). The Rs-Sts and Rs-Gms in Ni had the same value of +0.18, the percentage value of +94.7% and CV% of 0.00.

TABLE 6. **Differences in mineral content between Rs and Sts and between Rs and Gms.**

Mineral	**Rs-Sts**	**Rs-Gms**	**Mean**	**SD**	**CV%**
Na	+13.6 (+19.5%)	+37.1 (+53.3%)	25.4	16.6	65.4
K	+20.5 (+23.0%)	+37.0 (+41.4%)	28.8	11.7	40.5
Ca	+12.8 (+13.0%)	+86.6 (+88.1%)	49.7	52.2	105

Mg	+11.7 (+27.0%)	+25.1 (+57.8%)	18.4	9.48	51.5
Zn	+16.4 (+22.3%)	+39.5 (+53.7%)	28	16.3	58.3
Fe	+11.4 (+36.9%)	+20.3 (+65.6%)	15.9	6.29	39.6
Mn	+0.01 (+34.5%)	+0.280 (+96.6%)	0.145	0.191	132
Co	-	-	-	-	-
Cu	-	-	-	-	-
Cd	-	-	-	-	-
Pb	-	-	-	-	-
Ni	+0.180 (+94.7%)	+0.180 (+94.7%)	0.18	0	0
P	+81.0 (+13.2%)	+157 (+25.6%)	119	53.7	45.2

The calculated mineral ratios of Rs, Sts, and Gms are presented in **TABLE 7**. The ratios of Ca/P in the samples (0.026-0.160) were far below the recommended values of 1.00 and below the minimum 0.50 requirement for favorable Ca absorption in the intestine and for bone formation [27]. However, the Ca/Mg ratios in Rs and Sts (2.26 and 2.70 respectively) were above the recommended value of 1.00 [18]. Na/K ratios (0.621-0.814) were slightly higher than 0.60, a ratio that favors non-enhancement of high blood pressure [27]. The calculated [K/Ca+Mg)] milliequivalent ratios ranged from 0.587-1.72. The report of Marton and Andersen [28] showed that the milliequivalent of [K(Ca+Mg)] must be less than 2.2 in order to prevent hypomagnesaemia. The results of this study showed that the samples would be adequately useful for this preventive function. The ratios of Zn/Cu and Fe/Cu could not be determined because Cu was not detected in the samples. Also, Ca/Pb, Fe/Pb and Zn/Cd were not calculated due to the absence of Cd and Pb.

TABLE 7. **Calculated mineral ratios of raw, steeped and germinated sorghum samples.**

Parameter	**Rs**	**Sts**	**Gms**	**Mean**	**SD**	**CV%**
Ca/P	0.16	0.16	0.026	0.115	0.077	67.3
Na/K	0.779	0.814	0.621	0.738	0.103	13.9
Ca/K	1.1	1.24	0.224	0.855	0.551	64.4
Na/Mg	1.59	1.77	1.74	1.7	0.096	5.67
Ca/Mg	2.26	2.7	0.626	1.86	1.09	58.8
[K/(Ca+Mg)]	0.63	0.587	1.72	0.979	0.642	65.6
Zn/Cu	-	-	-	-	-	-
Fe/Cu	-	-	-	-	-	-
Ca/Pb	-	-	-	-	-	-
Fe/Pb	-	-	-	-	-	-
Zn/Cd	-	-	-	-	-	-

The Mineral Safety Index (MSI) of the sorghum samples are depicted in **TABLE 8**. The table values of MSI for the elements are also given in **TABLE 8** Na (4.50), Ca (10.0), Mg (15.0), Zn (33.0), Fe (6.70), Cu (33.0) and P (10.0) [29]. The calculated MSI for Na ranged from 0.312-0.668 with the calculated differences between the table values (TV) and calculated Value (CV) ranging from 4.13-4.49. This implied that none of the samples would overload the body with Na, therefore reducing the risk of secondary hypertension. In the same vein, calculated MSI for Ca, Mg and P were all lower than the standard (table) MSI and are therefore within the United States Recommended Dietary Allowance (USRDA) [29]. For Zn, the CV in all sample was more than TV. This means Zn overload would come from all the samples. Fe overload would come from Rs and Sts as a result of CV being greater than TV. Abnormally high levels of Zn are not desirable as excess Zn can interact with other elements such as Cu and Fe, thereby decreasing their absorption [27]. High levels of Fe in Rs and Sts could lead to iron poisoning especially in children [30]. However, the MSI of Cu could not be determined due to the absence of Cu in the samples.

TABLE 8. **Mineral safety index (MSI) of raw, steeped and germinated sorghum samples.**

		Rs			**Sts**			**Gms**		
Minerals	**RAI (mg)**	**TV**	**CV**	**D**	**TV**	**CV**	**D**	**TV**	**CV**	**D**
Sodium	500	4.8	1	4.13	4.8	0.5	4.3	4.8	0.31	4.49
Calcium	1200	10	1	9.18	10	0.7	9.3	10	0.1	9.9
Magnesium	400	15	2	13.4	15	1.2	14	15	0.69	14.3
Zinc	15	33	162	-1.2	33	126	-92.6	33	74.8	-41.8
Iron	15	7	13.8	-1.2	6.7	8.7	-2.01	6.7	4.73	2
Copper	3	33	-	-	33	-	-	33	-	-
Phosphorus	1200	10	5	4.88	10	4.4	5.6	10	3.81	6.19

RAI: recommended adult intake; **TV**: table value; **CV**: calculated value; **D**: difference

TABLE 9 presents the functional properties of raw, steeped and germinated sorghum samples. The percentage of water absorption capacity (WAC%) in this study (150%-200%) was lower than 340% reported for Prosopis Africana flour [15]. They were, however, higher than those of Sunflower (107%) and Soya beans (130%) as reported by Lin et al. as well as lima bean samples (130%-142%) [13]. The high WAC in this study would make the samples useful in the formulation of some foods such as soups and baked products.

The Oil Absorption Capacity (OAC) in this report ranged from 112% in Rs to 130% in both Sts and Gms. Some literature values for OAC were (%): cowpeas (281-310) [31]; Prosopis africana (120) [15]; Zonocerus variegatus (46.7) [13]. The samples OAC would make them useful as flavor retainers and improves the mouthfeel of certain foods. Both foaming capacity (FC) and foaming stability (FS) were low in this study compared to the values reported for hulled and dehulled

African Yam Bean (AYB) [32], Pigeon pea [13] and raw cowpea flour [33]. The low FC and FS would reduce the usefulness of the samples in the production of some foods where foaming is important and as a whipping agent [34]. The study showed the emulsion capacity (EC) to be higher than those from soybean (18%) [35] and Pigeon peas (7%-11%) [13] but lower compared to benni seed (63%) and guinoa (104%) [35]. The samples would, therefore, find application in the production of soups and cakes [36]. The values obtained for emulsion stability (ES) (49.0%-55.0%) were better than what was reported for pearl millet (34.0%). The Least Gelation Concentration (LGC) varied from 4.0% in Rs and Sts to 8.0% in Gms. These values were lower than 16.0% in Prosopis Africana [15] and 14.0% in lupin seed [37]. Padmashree et al. [33] showed that the ability of the protein to form gels and provide a structural matrix for holding water, sugars, flavors, and other food ingredients are useful in food application. The bulk density (BD) varied between 76.7-80.6 $g.cm^{-3}$. These values were higher than 0.527$gm.l^{-1}$ reported by Aremu et al. [15] for Prosopis Africana seed flour.

TABLE 9. **Functional properties of raw steeped and germinated sorghum samples.**

Parameter	**Rs**	**Sts**	**Gms**	**Mean**	**SD**	**CV%**
WAC(%)	150	200	160	170	26.5	15.6
OAC (%)	112	130	130	124	10.4	7.99
FC (%)	10	8	6	8	2	25
FS (%)	2	2	2	2	0	0
EC (%)	47.4	47.4	46.9	47.2	0.289	0.612
ES (%)	49	50	55	51.3	3.21	6.3
LGC (%w/v)	4	4	8	5.33	2.31	43.3
BD ($g.cm^{-3}$)	80.6	78.9	76.7	78.7	1.96	2.48

WAC: Water Absorption Capacity; **OAC**: Oil Absorption Capacity; **FC**: Foaming Capacity; **FS**: Foaming Stability; **EC**: Emulsion Capacity; **ES**: Emulsion Stability; **LGC**: Least Gelation Concentration; **BD**: Bulk Density

TABLE 10 contains the summary of the differences in the functional properties of the samples. The following properties were enhanced both in steeped (Sts) and germinated (Gms) samples: WAC, OAC, and ES whereas FC and BD were more concentrated in the raw sample (Rs) than Sts and Gms. The 0.00% difference recorded for both Rs-Sts and Rs-Gms indicated that the three samples had the same level of FS. The higher percentage of OAC in Sts and Gms showed higher denaturation of proteins in the treated samples.

TABLE 10**. Summary of Table 9 showing differences in functional properties between Rs and Sts and between Rs and Gms.**

Parameter	**Rs-Sts**	**Rs-Gms**	**Mean**	**SD**	**CV%**
WAC (%)	-50.0 (-33.3%)	-10.0 (-6.67%)	30	28.3	94.3
OAC (%)	-18.0 (-16.1%)	-18.0 (-16.1%)	18	0	0

FC (%)	+2.00 (+20.0%)	+4.00 (+40.0%)	3	1.41	47.1
FS (%)	0.00 (0.00%)	0.00 (0.00%)	0	0	0
EC (%)	0.00 (0.00%)	+0.80 (+1.68%)	0.4	0.566	141
ES (%)	-1.00 (-2.04%)	-6.00 (-12.2%)	3.5	3.54	101
LGC (%w/v)	0.00 (0.00%)	-4.00 (100%)	2	2.83	141
BD ($g.cm^{-3}$)	+1.70 (+2.11%)	+3.90 (+4.84%)	2.8	1.56	55.6

The results of protein solubility of the samples as a function of pH are shown in **TABLE 11**. The solubility of proteins is greatly influenced by pH, as might be expected from their amphoteric nature. The graphical representation is also provided in **FIG. 1**. The isoelectric point (pI) of Sts was at pH 3 and was observed to be 50.0%. For Gms, pI at pH 4 was recorded to be 48.0% whereas, it was 33.0% (at pH 3, 5 and 9) for Rs.

In the acidic medium, highest solubility was observed at pH 1 for all the samples with % solubility recorded as: 47.0% (Rs), 63.0% (Sts) and 66.0% (Gms); in the basic medium it was pH 12 (51.0%) for Rs, pH 8 (88.0%) in Sts and pH 8 (70.0%) in Gms. This implied that the samples were more soluble in the basic medium of the pH. This might reduce their functionality in the formulation of acid foods such as milk analog products [36]. The levels of protein solubility (%) at various pH in this study were, however, higher than those reported by Adeyeye [38] for Anaphe infracta larvae.

TABLE 11. **Protein solubility (%) of raw, steeped and germinated sorghum samples at various pH values.**

pH	**Rs**	**Sts**	**Gms**	**Mean**	**SD**	**CV%**
1	47	63	66	58.7	10.2	17.4
2	44	56	57	52.3	7.23	13.8
3	33	50	53	45.3	10.8	23.8
4	36	53	48	45.7	8.74	19.1
5	33	56	57	48.7	13.6	27.9
6	44	63	62	56.3	10.7	19
7	47	75	66	62.7	14.3	22.8
8	44	88	70	67.3	22.1	32.9
9	33	81	66	60	24.6	40.9
10	44	75	62	60.3	15.6	25.8
11	47	63	57	55.7	8.08	14.5
12	51	81	53	61.7	16.8	27.2

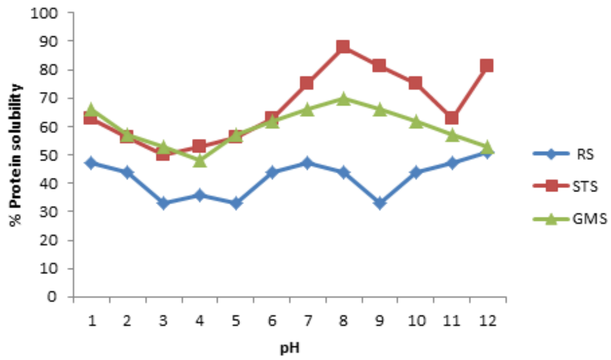

FIG. 1. **Effect of pH on protein solubility of raw steeped and germinated sorghum samples.**

The differences and percentage differences of protein solubility between Rs-Sts and Rs-Gms are presented in **TABLE 12**. The result showed better enhancement of solubility in the treated samples as both Sts and Gms levels were higher than Rs at all pH values. The Table also showed that CV% were low except at pH 12 where the variation was high at 124%; others were less than 40%.

TABLE 12. **Differences in protein between Rs and Sts and between Rs and Gms.**

pH	Rs-Sts	Rs-Gms	Mean	SD	CV%
1	-16.0 (-34.0%)	-19.0 (-40.4%)	17.5	2.12	12.1
2	-12.0 (-27.3%)	-13.0 (-29.5%)	12.5	0.707	5.66
3	-17.0 (-51.5%)	-20.0 (-60.6%)	18.5	2.12	11.5
4	-17.0 (-51.5%)	-12.0 (-33.3%)	14.5	3.54	24.4
5	-23.0 (-69.7%)	-24.0 (-72.7%)	23.5	0.707	3.01
6	-19.0 (-43.2%)	-18.0 (-40.9%)	18.5	0.7	3.82
7	-28.0 (-59.6%)	-19.0 (-40.4%)	23.5	6.36	27.1
8	-44.0 (-100%)	-26.0 (-59.1%)	35	12.7	36.4
9	-48.0 (-145%)	-33.0 (-100%)	40.5	10.6	26.2
10	-31.0 (-70.5%)	-18.0 (-40.9%)	24.5	9.19	37.5
11	-16.0 (-34.0%)	-10.0 (-21.3%)	13	4.24	32.6
12	-30.0 (-58.8%)	-2.00 (-3.92%)	16	19.8	124

TABLE 13 shows the statistical analysis of the summary of the result in **TABLES 1, 3, 8** and **11**. The linear correlation coefficient was subjected to critical (table) value at r=0.05, n-2 degree of freedom [14]. The rxy levels were highly and significantly positive in **TABLES 1, 3** and **9**. In **TABLE 11**, only Sts/Gms was significantly positive; Rs/Sts and Rs/Gms were positively low and not significantly different at r=0.05 and n-2 degree of freedom. The CA which represents the coefficient of non-relationship were all low except in **TABLE 11** where the values ranged from 76.3% in Sts/Gms to 97.1%

in Rs/Gms. On the contrary, the index of forecasting efficiency (IFE) was high except in **TABLE 11**. The lower the CA, the higher the IFE value and the easier it is to predict the relationship between samples under comparison, e.g. for Rs/Sts (**TABLE 3**), the reduction in error of prediction (IFE) was 100-96.8=3.2. This showed that the biochemical functions of the various energy contributed by Rs could also be achieved when replaced by Sts.

TABLE 13. **Statistical analysis of the data in TABLES 1, 3, 9 and 11.**

Table	**Parameter**	r_{xy}	r_{xy}^2	**CA**	**IFE**	**TV**	**Remark**
1	Rs/Sts	0.997	0.994	7.75	92.3	0.811	*
	Rs/Gms	0.999	0.998	4.47	95.5	0.811	*
	Sts/Gms	0.998	0.997	5.48	94.5	0.811	*
3	Rs/Sts	0.999	0.999	3.16	96.8	0.878	*
	Rs/Gms	0.999	0.999	3.16	96.8	0.878	*
	Sts/Gms	0.999	0.999	3.16	96.8	0.878	*
9	Rs/Sts	0.989	0.979	14.5	85.5	0.707	*
	Rs/Gms	0.995	0.99	10	90	0.707	*
	Sts/Gms	0.988	0.977	15.2	84.8	0.707	*
11	Rs/Sts	0.411	0.169	91.2	8.8	0.576	+
	Rs/Gms	0.239	0.057	97.1	2.89	0.576	+
	Sts/Gms	0.647	0.418	76.3	23.7	0.576	*

rxy: linear correlation coefficient; **rxy^2**: coefficient of determination; **CA**: coefficient of alienation; **IFE**: index of forecasting efficiency; *: significant at r=0.05 and n-2 degree of freedom; +: not significant at r=0.05 and n-2 degree of freedom; **TV**: table (critical) value

Conclusion

The results of this study showed that the samples are good sources of carbohydrate with low contents of fat, ash, and crude fibre. The samples contained reasonable amounts of major minerals and some trace metals especially zinc and iron. Co, Cu, Cd, and Pb were completely absent in the samples. All the samples were poor in Ca/P and Na/K but are good in [K(Ca+Mg)] milliequivalent ratio (<2.2). Zinc overload would come from all the samples whereas the overload of Fe could only come from Rs and Sts. The samples are good in the following functional properties: water and oil absorption capacities, emulsion capacity and stability, bulk density and protein solubility, making the samples suitable in some food formulations. Generally, the samples contained diverse compositions of many of the parameters determined.

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