SUGAR, ANTINUTRIENT AND FOOD PROPERTIES LEVELS IN RAW, FERMENTED AND GERMINATED PEARL MILLET GRAINS

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Abstract: Bulrush or pearl millet is an important food as well as forage crop. This work contained the report on the sugar, ascorbic acid and antinutrients of raw, fermented and sprouted pearl millet; also reported were the various pH values and food properties. Sugars reported were dextrose, fructose, maltose, lactose (anhydrous) and lactose (hydrated) contents. The total sugars ranged between 99.4 – 329 mg/100g following this trend (mg/100g): fermented (99.4) <raw (105) < germinated (329). Samples representation were: fermented (A), germinated (B) and raw (C). Sugar ratios were; A:B (1.00:3.31), A:C (1.00:1.06) and B:C (1.00:0.320). The ascorbic acid range was 10.4 – 25.0 mg/100g. All pH values were within the acid range of pH 5.82 – 6.49. All the correlation coefficient levels were significant at $r_{=0.01}$ in the sample sugar compared levels of A/B, A/C and B/C. Values for all the antinutrients were low at mg/100g levels. Such antinutrients were phytate phosphorus, phytate, oxalate, tannin as well as fibre components of lignin (g/100g), cellulose (g/100g) and hemicellulose (g/100g); in the compared samples, significant differences at $r_{=0.01}$ existed in them. In the mineral molar ratios, only Ca: Phy and Fe: Phy had substantial levels of 57.3 -136 and 14.3-38.3, respectively; however, Phy: Zn and [Ca] [Phy]/[Zn] values were each lower than 1.00. In the mineral ratio comparisons at $r_{=0.01}$ only A/B had significant relationship. The food properties were having high values for water absorption capacity (WAC), fat absorption capacity (FAC), emulsion capacity (EC), emulsion stability (ES) but low in foaming capacity (FC), foaming stability (FS), least gelation capacity (LGC) and bulk density. The protein solubility from pH 1 to pH 12 showed close relationship in the three samples as evidenced in the variation whose values ranged from 10.8 – 21.1% with corresponding low Chi-square (χ^2) values of 1.10 – 4.64 which were not significant at $\chi^2_{0.01}$. However the r_{xy} value of A/C protein solubility values was significant at $r_{=0.01}$. Germinated sample exhibited two major different isoelectric point values at pH 3 ad pH 8, showing it might have two major forms of protein. However, pI for fermented was pH 4 and for raw, pI was at pH 4 as well.

Keywords: *Pennisetum, typhoides*, processed grains, sugar, antinutrients, food properties

Introduction

In the 21st century, climate changes, water scarcity, increasing world population, rising food prices and other socioeconomic impacts are expected to generate a great threat to agriculture and food security worldwide, especially for the poorest people who live in arid and subarid regions. Cereal grains are the most important source of the world's food and have a significant role in the human diet throughout the world (Saleh *et al.,* 2013). As one of the most important drought – resistant crops, millet is widely grown in the semiarid tropics of Africa and Asia and constitutes a major source of carbohydrates and proteins for people living in these areas (Saleh *et al.,* 2013).

Millet is one of the most important drought –resistant crops and the 6th cereal crop in terms of world agriculture production. Also, millet has resistance to pests and diseases, short growing season and productivity under drought conditions, compare to major cereals (Devi *et al*., 2011). Now, millet grains are receiving attention from the developing countries in terms of utilization as food as well as from developed countries in terms of its good potential in the manufacturing of bioethanol and biofilms (Li *et al*., 2008).

Millets are small-grained annual, warm – weather cereals belonging to the grass family. They are highly tolerant of drought and other extreme weather conditions and have a similar nutrient content to other major cereal (Fahad *et al*., 2017). Millets are of different varieties but they are all members of the family Poaceae (the grasses): pearl millet (*Pennisetumglaucum*), finger millet (*Eleusinecoracana*), kodo millet (*Paspalumsetaseum*), proso millet (*Penicummiliaceum*), foxtail millet (*Setaria italic*) little millet (*Panicumsumatrense*) and barnyard millet (*Echinochloautilis*). They are known as coarse cereals beside maize (*Zea mays*) sorghum (*Sorghum bicolor*), oats (*Aveniasativa*) and barley (*Hordeum vulgare*) (Bouis, 2000; Kaur *et al.,* 2012). In 2016, global production of millet was 28.4 million tonnes, led by India with 36% of the world total (Table 1). Niger Republic also had significant production (FAOSTAT, 2017). In 2010, the top world millet grains producers had world total of seed (tons) of 762712 (FAO, 2012) with India annual production of 43.85% (Table 1).

The use of millets as food fell between the 1970s and the 2000s, both in urban and rural areas, as developing countries such as India have experienced rapid economic growth and witnessed a significant increase in per capita consumption of other cereals. It has been reported that millet proteins are good sources of essential amino acids except lysine and threonine but are relatively high in methionine. Millets are also rich sources of phytochemicals and micronutrients (Mal *et al.,* 2010; Singh *et al.,* 2012). In addition to their nutritive value, several potential health benefits such as preventing cancer and cardiovascular diseases, reducing tumor incidence, lowering blood pressure, risk of heart disease, cholesterol and rate of fat absorption, delaying gastric emptying and supplying gastrointestinal bulk have been reported for millet (Truswell, 2002; Gupta *et al.,* 2012). These functions healthwise in millet can be explained as follows under millet benefits: aids weight loss (has low calorie content), keeps your blood sugar levels low (low glycemic index), it boosts your immunity (provides great source of protein), reduces cardiovascular risk (contains high essential fatty acids and potassium), helps digestion (a rich fibre source), prevent asthma (high magnesium in millet reduces frequent experience of migraines), acts as an

antioxidant (has antioxidant properties as quercetin, curcumin, ellagic acid, etc.). People affected by gluten – related disorders, such as coeliac diseases, non-celia gluten sensitivity and wheat allergy sufferers (ludvigsson *et al.*, 2013; Mulder *et al*., 2013; Volta *et al.*, 2015) who need a gluten – free diet, can replace gluten – containing cereals in their diets with millet (Rai *et al*., 2014). Nevertheless, while millet does not contain gluten, its grains and flour may be contaminated with gluten – containing cereals (Saturni *et al*., 2010; Koerner *et al*., 2013). It is a common ingredient in seeded bread. Millet is used primarily as a grain crop in Nigeria. It is used for making heavy bread or porridge and alcoholic beverages, *ogi* in Nigeria and is also used as animal feed, particularly for poultry and other birds (Kochhar, 1986).

Bulrush millet or pearl millet or spiked millet or cattail millet or candle millet (*Pennisetum typhoides* [Burm. F.] Stapf and Hubbard) would need further information on its chemical composition and food properties. This work would be reporting the effects of treatments (fermentation and sprouting) on the raw samples of *Pennisetum typhoides* as the treatments that affected the sugar content, ascorbic acid content, antinutrients content, lignin, cellulose and hemicellulose contents, the samples pH levels, the food functionality of millet grains concerning protein solubility in terms of pH effect, WAC, FS, FC, FAC, FEC, FES, LGC and bulk density determinations. The results obtained in these experiments would inform food scientists on further nutrient characters of *P. typhoides.* Work is however available on the amino acid levels of processed *P. typhoides* (Adeyeye, 2009).

Table 1: Pearl millet production in 2010 and 2016

2010 top world millet grains production		2016 world pearl millet production	
Country	**Seed (tons)**	**Country**	**Production (millions of tones)**
India	334500	India	10.3
Niger	108798	Niger	3.9
Nigeria	59994	China	2.0
Mali	43878	Mali	1.8
Senegal	30995	Nigeria	1.5
China	26429	Burkina Faso	1.1
Burkina Faso	20428		
Russian Federation	20000		
Chad	14775		
Uganda	11750		
Sudan (former)	11000		
World total	762712[A]		

Source: FAO (2012); A= may include official, semi – official or estimated data

Source: FAOSTAT (2017)

Materials and Methods

Collection of samples

Samples of pearl millet grains were purchased from the main market of Ado-Ekiti, Ekiti State in the southern part of Nigeria. About 1.5 kg of the grains were used for the experiments. After removing the stones, damaged grains, glumes and glumela manually, the endosperm was extracted from kernels and divided into three equal parts for use as raw, steeped and germinated pearl millet samples and labelled accordingly.

Sample treatment

Raw sample (0.5 kg) was not specially treated but only dried to constant weight (6.38 g/100g, moisture content). For steeping, 0.5 kg grains were placed in plastic container covered with distilled water and leftin the laboratory at ambient temperature (30.9ºC) at 0.41 Im^2/ft light intensity. After four days, grains were washed with distilled water, dried in the sun to constant weight (6.45% moisture content) and stored in covered plastic container. For germination of samples, 0.5 kg grains were soaked in water at room temperature for 24 h; then spread on a damp fabric, protected from direct sunlight for approximately 49 h, until 5.04 cm long spouts developed. Germinated grains were dried in the sun for 3 days until constant weight (7.41% moisture content); the sproutswere manually removed and the desprouted grains were stored in a plastic container (WHO, 1999). [The flow chart detailing the processes in the preparation of steeped and germinated samples had been depicted in Fig. 1.]. Each sample was then homogenised, sieved using 200 mm mesh size and kept in plastic bottles in the refrigerator (2.8ºC).

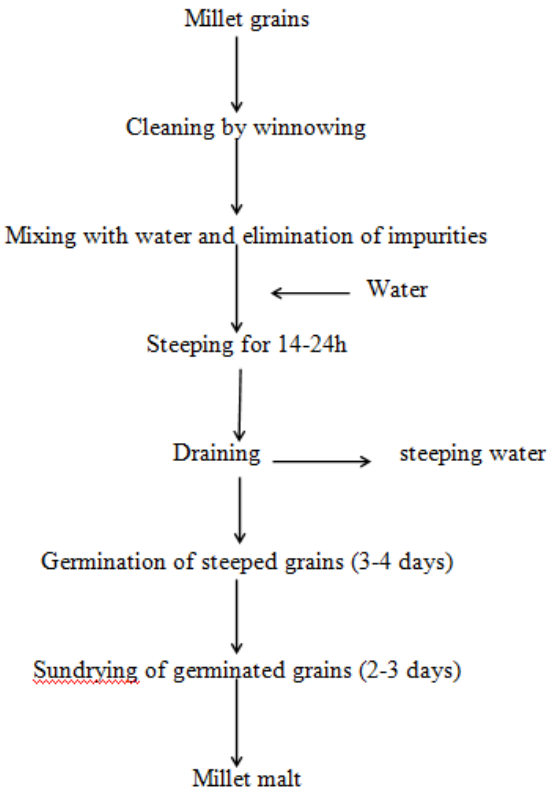

Fig. 1: General flow diagram of traditional malting of millet grains

Determination of pH, ascorbic acid and sugars

The pH of the samples was determined by the method described by Vogel (1978). The determination of ascorbic acid was as described by Barakat *et al*. (1955). The determination of the various sugar contents was as described by Lane and Eynon's method of food analysis (Usoro *et al*., 1982). Sugars determined in the samples were dextrose, fructose, maltose, lactose (anhydrous) and lactose (hydrated).

Determination of antinutrients

Phytateand phosphorus were quantified using the method described by Harland and Oberleas (1986). The blank was also prepared as described by Harland and Oberleas (1986). The colorimeter used was a Spectronic 20 (Gallenkamp, UK). The amount of phytate in the sample was calculated as hexaphosphate equivalent using the formula:

Phytate, mg/g sample = "mean k" x A x20/(0.282x 1000)

Where: A = absorbance; "mean K" – std P (µg) /A/n (stds); phytate = 28.2% P.

The phytate values were reported in mg/100g. The phytin phosphorus (Pp) was determined as described in Olaleye *et al*. (2013). The determination of oxalate was as described by Day and Underwood (1986). Tannin determination followed the method of Makkar and Goodchild (1996).

Determination of lignin, cellulose and hemicellulose

Lignin [neutral detergent fibre (NDE)] was determined following the procedure of Van-Soest and Robertson (1980). The determination of both cellulose and hemicellulose contents followed the procedures of Usoro *et al*. (1982).

Food properties (functional properties) of the samples

Bulk density: Bulk density of packed flour was determined according to the method of Wang and Kinsella (1976).

Water absorption capacity (WAC): This was determined according to the method of Beuchat (1977).

Fat absorption capacity (FAC): This was determined following the method of Sosulski (1962).

Foaming capacity (FC) and foaming stability (FS): FC and FS were studied according to the method of Coffmann and Garcia (1977).

Determination of emulsion capacity (EC): The procedure of Inklaar and Fortuin (1969) was followed.

Fat emulsion stability (FES): Emulsion was prepared according to Beuchat's procedure (1977).

Least gelation concentration (LGC): The method of Coffmann and Garcia (1977) was employed with slight modifications.

Protein solubility (PS): The method of Oshodi and Ekperigin (1989) was used. 0.2 g of the flour and 10 cm^3 of distilled deionized water were thoroughly mixed with a magnetic stirrer at room temperature. The pH of the slurries prepared from samples was adjusted to values between 1 and 12 using either 0.1M HCl or 0.1M NaOH. Insoluble materials were removed by centrifuging for 30 min at 3500 rpm. The supernatant was digested and the nitrogen content determined by the micro-Kjeldahl method (Pearson, 1976). The percentage nitrogen was converted to crude protein by multiplying the percentage nitrogen by 6.25.

Determination of iron, zinc and calcium

These minerals were determined from solutions obtained by first dry-ashing the samples at 550°C and dissolving the ash in flasks using distilled deionized water. Iron, zinc and calcium were determined by means of atomic absorption spectrophotometer (PyeUnicamSp 9 Cambridge, UK) (AOAC, 2006).

Calculation of the mole ratios

The [Phytate]: [Zn], [Ca]: [Phytate], [Fe]: [Phytate] and [Ca] [Phytate]: [Zn] mole ratios were calculated as previously described by IZiNCG (2004) and Wyatt and Triana-Tejas (1994). Their equations:

$$[\text{Phytate}] : [\text{Zn}] = \frac{\text{Phytate (mg/100g)}/660}{\text{Znc}\left(\frac{mg}{100g}\right)/65.38}$$

$$[\text{Ca}] : [\text{Phytate}] = \frac{Calcium\ (mg/100g)/40.08}{Phytate\ (mg/100g)/660}$$

$$[\text{Fe}]: [\text{Phytate}] = \frac{Iron\ (mg/100g)/55.85}{Phytate\ (mg/100g)/660}$$

$$[\text{Ca}] : [\text{Phytate}]: [\text{Zn}] = \frac{[Calcium\ (mg/100g)/40.08]x[Phytate\ (mg/100g)/660]}{[Zinc\ (mg/100g)/65.38]}$$

Statistical evaluation

In the statistical evaluation, both descriptive and inferential statistics were used in discussing the data generated. For the descriptive statistics, values evaluated for were the grand mean, standard deviation (SD), coefficient of variation (CV%) and percentage values were all calculated as appropriate. In the inferential calculations, the followings were evaluated: chi-square (x^2), correlation coefficient (r_{xy}), variance (r_{xy}^2) and regression coefficient (R_{xy}) setting the critical value at $r_{=0.01}$ as appropriate (Oloyo, 2001). Furthermore, the r_{xy} was further subjected to the calculation of coefficient of alienation (C_A) and index of forecasting coefficient (IFE) (Chase, 1976).

Results and Discussion

Several methods have been generally adopted to improve the nutritional and organoleptic qualities of cereal – based foods. These include: genetic modification, amino acid fortification, supplementation or complementation with protein-rich sources and processing techniques which include malting, milling and fermentation (Chavan and Kadam, 1989; Ugwu and Oranye, 2006; Mohammed *et al*., 2011). Taylor and Robbins (1993) identified malting as the most inexpensive traditional processing technique for the elimination of the nutritional impediments of sorghum – based foods. Malting is a biotechnological technique which involves the controlled germination of a cereal grain which aims at activating enzyme systems that catalyze the hydrolysisof polymerized reserved food materials, notably, proteins, starches and cell-wall substances, thus extracting fermentable materials (MacLeod, 1977; Gopalan *et al*., 1997).

The major carbohydrate in cereals is starch which provides the most calories in developing countries (Chaves-Lapoze *et al*.,

2014). Fermentation activates starch-hydrolyzing enzymes such α-amylase and maltase which degrade starch into malto-dextrins and simple sugars (Osman, 2011), respectively.

Table 2 depicted the concentration values of sugars, ascorbic acid with the pH values of processed and unprocessed *Pennisetum typhoides*. The simple sugars in the results were dextrose (glucose) and fructose. These two sugars had very close values in the samples; in comparison we have: dextrose/fructose (mg/100g), respective percentage values: A (fermented), 15.4/16.3, 15.5/16.4; B (germinated), 51.2/54.4, 15.6/16.5 and C (raw), 16.4/17.4, 15.6/16.6. However, dextrose was consistently lower in concentration than the fructose with the following respective other values mean= 27.6± 20.4 mg/100g/29.4 ± 21.7 mg/100g; variation of 73.7/73.8% and chi-square (χ^2) values of 30.0/32.0 with both$\chi^2_{0.01}$ being significantly different. The dextrose released during fermentation is a preferred substrate for microorganisms fermenting the food and could partly explain the decrease in total carbohydrate after 24 h of fermentation (Osman, 2011). When both glucose and fructose were present during fermentation of pearl millet, microorganisms preferred glucose (dextrose) to fructose as a source of energy since the level of fructose remained constant (Table 2). Furthermore, fermentation had been said to reduce starch content in millet varieties with subsequent increase in carbon dioxide and ethanol production throughout fermentation period (Nkhata *et al*., 2018). Moreover, pH had been known to be significantly reduced which activated phytase enzyme (El-Hag *et al*., 2002). This had been manifested in this report where the pH of fermented sample was the lowest (pH = 5.82) relative to 6.27 in germinated and 6.49 in raw; with significant value difference of 20.6 at$\chi^2_{0.01}$. The disaccharides in the samples as determined were maltose, lactose (anhydrous) and lactose (hydrated). The maltose concentration followed this trend (mg/100g/% value): A (25.4/25.6) < B (84.7/25.7) >C(27.1/25.8) although the maltose values had high value of standard deviation (SD) (33.8) and high variation (73.8%), the percentage values of the maltose in the total sugar were very close and they were: A(25.6%) < B (25.7%)< C (25.8%). The$\chi^2_{0.01}$ for maltose was significant. Both the anhydrous and the hydrated lactose had values that were close as observed in dextrose and fructose. The comparison goes thus: anhydrous lactose/hydrated lactose (mg/100g, percentage level): A (20.9/21.3, 21.0/21.4), B (67.6/71.2, 20.5/21.6) and C (21.6/22.8, 20.6/21.7); SD was 26.2/28.4; mean was 37.0/38.4; variation was 70.8/73.8 and $\chi^2_{0.01}$ was 39.0/41.9 (both being significant). The observations in both lactose results followed virtually similar observations in dextrose/fructose. The ascorbic acid content was highest in A (fermented) and followed this trend (mg/100g): A (25.0) > B (10.4) < C (10.8) but values were not significant at $\chi^2_{0.01}$. Total sugars had this trend (mg/100g): A (99.4) < B (329) > C (105) and significant and from these total sugar values, sugar ratios had these values, A:B (1.00 :3.31); A:C (1.00 :1.06) and B:C (1.00:0.320).

Present sugar, ascorbic acid and pH values showed that the sugar values were all correspondingly lower than the sugars (both mono-and di-saccharides) of *Chrysophyllumalbidum* (mesocarp and endocarp), *Malus pumila* (red and green coloured) and *Psidiumguajava* fruits; similar observations were made in pH but in *M. pumila* (red) acid values of 5.60 and 11.9 mg/100g; whereas present ascorbic acid value was much higher than the literature cited in fermented (25.0 mg/100g), both germinated (10.4 mg/100g) and raw (10.8 mg) were comparable to *M. pumila* (green coloured) value of 11.9 mg/100g (Adeyeye and Agesin, 1999). Germination and malting facilitate the enzymatic breakdown of carbohydrates into simple sugars through activation of endogenous enzymes such as α-amylase thereby improving digestibility (Oghbaei and Prakash, 2016) as a result of degradation of starch to provide energy for the seed development (Zhang *et al.,* 2015). Both germination and malting increased activity of α-amylase (Traore *et al.,* 2004) and consequently increased the digestibility of starch, making it a good method in the preparation of complementary and infant foods (Desai *et al*., 2010; Svanberg and Lorri, 1997).

In Table 3, the differences in the sugars, ascorbic acid and pH values determined in C-A, C-B and A-B together with their percentage difference values. In C–A (%), C was greater than A in all the parameters with the exception of ascorbic acid as indicated by their frontal signs. [e.g. in dextrose, C – A (%) gave +0.99 (+6.05) meaning that C > A]. In ascorbic acid where we have -14.2 (-131) meant that A > C to the value of 14.2 mg/100g to the tune of 131%. In C – B (%), C > B (%) in ascorbic acid (+0.400, +3.70%) and pH (+0.22, +3.39%) whereas in other parameters, C<B. As we have in C–A (%) similar scenarioexisted in A-B where only in acid (this time positive) was A>B (%) with values of +14.6 (+58.4%). A look at the percentage differences showed that values in C-A (%) were generally close with positive values ranging from +3.19 to +10.3 but the only negative value was high at -131% (ascorbic acid). In C–B (%), the positive values were low at +3.39 to +3.70 whereas the negative values were high at -212 to -213 which were close but much higher. The observations in A-B (%) were not as consistent as were observed in C-A (%) and C-B (%); for the only positive value, it was slightly high at +58.4% whereas the negative values were in two classes: class I (-7.73 which was low) and class II (-231 to -234 which were very high but close values).

Table 2: Sugar and ascorbic acid contents (mg/100g) and pH levels of *Pennisetum typhoides* (fermented, spouted and raw)

Parameter	Fermented (A) (%)	Germinated (B) (%)	Raw (C) (%)	Mean	SD	CV	χ^2
Dextrose	15.4 (15.5)	51.2 (15.6)	16.4(15.6)	27.6	20.4	73.7	30.0*
Fructose	16.3(16.4)	54.4 (16.5)	17.4 (16.6)	29.4	21.7	73.8	32.0*
Maltose	25.4 (25.6)	84.7 (25.7)	27.1(25.8)	45.7	33.8	73.8	158*
Lactose (anhydrous)	20.9 (21.0)	67.6 (20.5)	21.6(20.6)	37.0	26.2	70.8	39.0*
Lactose (hydrated)	21.3 (21.4)	71.2 (21.6)	22.8(21.7)	38.4	28.4	73.8	41.9*
Ascorbic acid	25.0 (-)	10.4 (-)	10.8(-)	15.4	8.32	54.0	8.98
Total sugars	99.4 (100)	329 (100)	105(100)	178	131	73.6	193*
pH	5.82	6.27	6.49	6.19	0.342	5.51	20.6*
Sugar ratios; A:B (1.00: 3.31); A: C (1.00: 1.06); B : C(1.00: 0.320)							

Significant values for χ^2 at $\chi_{0.001}$ when n-1 = 4-1 = 3 (df) and critical value of 16.27

Table 3: Sugar and ascorbic acid contents (mg/100g) and pH levels of *Pennisetum typhoides* showing differences in raw/fermented (C-A), raw/sprouted (C-B) and fermented/sprouted (A-B)

Parameter	C – A (%)	C-B (%)	A-B (%)
Dextrose	+0.99 (+6.05)	-34.8 (-212)	- 35.8 (-233)
Fructose	+1.06 (+6.09)	-37.0 (-213)	-38.0 (-233)
Maltose	+1.72 (+6.35)	-57.6 (-213)	-59.3 (-234)
Lactose (anhydrous)	+0.69 (+3.19)	-46.0 (-213)	-46.7 (-223)
Lactose (hydrated)	+1.46 (+6.41)	-48.4 (-212)	-49.8 (-234)
Ascorbic acid	-14.2 (-131)	+ 0.400 (+3.70)	+14.6 (+58.4)
Total sugars	+5.92 (+5.62)	-224 (-213)	-230 (-231)
pH	+0.67 (+10.3)	+0.22 (+3.39)	-0.450 (-7.73)

Table 4: Statistical analysis result of the data from Table 2 on sugar and ascorbic acid contents (mg/100g) and pH levels of *Pennisetum typhoides* (fermented, sprouted and raw)

Statistics	Fermented/Sprouted		Fermented/Raw		Sprouted/Raw	
	A	B	A	C	B	C
r_{xy}	0.9694		0.9845		0.9967	
r_{xy}^2	0.9398		0.9692		0.9933	
R_{xy}	3.41		1.07		0.3078	
Mean	28.7	84.3	28.7	28.5	84.3	28.5
SD	29.2	103	29.2	31.7	103	31.7
CV%	102	122	102	111	112	111
C_A	0.2454		0.1754		0.0817	
IFE	0.7546		0.8246		0.9183	
Remark	*		*		*	

All r_{xy} values were significant at r_{xy} being $r_{=0.01}$ at n-2 = 8-2 = 6 (df) at critical level of 0.834

Table 4 contained the statistical analysis of the data in Table 2. The correlation coefficient (r_{xy}) values among the compared pairs were all positively high and significant at $r_{=0.01}$; the r_{xy} values being A/B (0.9694) < A/C (0.9845) < B/C (0.9967); variance (r_{xy}^2) values were also high ranging from 0.9398 < 0.9692 < 0.9933 following the trend of r_{xy}. The regression coefficient (R_{xy}) values were high to low reversing the trend in both r_{xy} and r_{xy}^2, values being A/B (3.41) > A/C (1.07) > B/C (0.3078). The implication of R_{xy} was that when the first member of a pair in a group increases by a value of 1.00 mg/100g, the second partner in the group increased by the value shown in Table 4. For example in the A/B group, when the value of A (fermented) increased by 1.00 mg/100g then the value of B (germinated) would increase by 3.41, etc. This followed the ratio trends as observed in Table 2. The mean, SD and variation trends in Table 4 were widely spread. For A, we had 28.7±29.2 mg/100g, B had 84.3±103 mg/100g and C had 28.5±31.7 mg/100g showing the SD values to be high for the samples, they were greater than the mean in each case resulting in high variation (CV%): A (102) < B (122)> C (111). The coefficient of alienation (C_A) had low values of 0.0817-0.2454 with corresponding high index of forecasting efficiency (IFE) levels (in reverse order) with values of 0.7546 – 0.9183. Whereas C_A value indicated lack of relationship between two compared entities or the error of prediction of relationship in two compared entities, IFE on the other hand measures the reduction in the error of prediction of relationship between two compared entities. However, it should be noted that C_A + IFE = 1.00 or 100.00%. In the Table 4, all the IFE values were thereby reducing the error of prediction of relationship by between 75.5 – 91.8% thereby making the prediction of relationship easy. Since all the IFE values were high, then each pair of A/B, A/C and B/C would be able to carry out the biochemical functions of each member of a pair.

The Table 5 had values for antinutrients, cellulose, hemicellulose and lignin contents. Phytate levels in the fermented (A) sample at 18.1 mg/100g, lowest in sprouted (B) at 10.7 mg/100g and close to A in C at 15.7 mg/100g. The phytate phosphorus was comparatively low in all the samples (again being highest in A and lowest in B); the trend being (mg/100g): A (5.11) > B (3.02) < C(4.41). It is interesting to know that the CV% for phytate and phytate phosphorus were very close at respective values of 25.4 and 25.5%. The percentage phytate phosphorus values were very low at 1.02 (A), 0.504 (B) and 1.03 (C) meaning that the phosphorus values would highly be available since the fraction due to phosphate was low.

Phenolics and phytates are known antioxidants present in bran layers of cereal grains. Phytic acid forms chelation complexes with various divalent minerals (e.g. iron), suppressing the iron-mediated free – radical oxidant damage created by the colonic bacteria (Slavin, 2004). Phytates are also inhibitors (antinutrients) and they have been shown to have some beneficial effects also. Phytate has been reported to reduce the risk of colon and breast cancer in animals, lowers plasma glucose, insulin and / or improve blood lipid profile in humans (Slavin *et al*., 1999). Shamsuddin (1999) has shown that only phytate in the form of inositol trisphosphate (IP3) can inhibit the absorption of minerals.

A few studies show that the Asian diet contains very high amounts of phytate compared with western diets. For example, a study in India showed that the phytate content in their foods ranged from 480 to 520 mg/100g (Pushpanjali and Santosh, 1995). The phytate content of Korean foods ranged between 191.7 to 973.3 mg/100g for cereals and 508.5 to 1371.8 mg/100g for legumes (Joung *et al.*, 2004), while a study in Indonesia showed that phytate content ranged between 8 to 319 mg/100g for cereals and 24 to 108 mg/100g for legumes (Sanny *et al.*, 2007). Results of 13 spices found in Nigeria had their phytate levels ranging between 390 to 6210 mg/100g (Adeyeye and Fagbohun, 2005). In the samples of Bambara groundnut, phytic acid values (mg/100g) were 29.2 (testa), 17.5 (dehulled) and 14.4 (whole seed), phytin phosphorus had values of 8.24 (testa), 4.93 (dehulled) and 4.06 (whole seed) and percentage phytin phosphorus of phosphorus ranged between 10.2-49.3 (Olaleye *et al.*, 2013). The result of 5.11 – 3.02 mg/100g Pp could be favourably compared to the values of 4.8 – 8.24 mg/100g recorded for Pp in bambara groundnut seed parts (Olaleye *et al*., 2013) but fell

below 9.43 – 10.7 mg/100g in groundnut seed flour (Adeyeye, 2011) and also fell below 0.06-0.29 g/100g in 17 wild leguminous crop seeds (Balogun and Fetuga, 1986) but comparable with 1.7 – 4.3 mg/100g in *M. prupriens* and 1.4 – 5.44 mg/100g in *C. ensiforms* (Agbede and Aletor, 2005). The Pp as % of P were lower than 10.2 – 49.3 (Olaleye *et al*., 2013), 2.28 – 2.67 in groundnut seed flour (Adeyeye, 2011). Pp as % of P shows how much P is linked to Pp and abnormal change in levels will affect the utilization of divalent minerals and also will render some essential amino acids unavailable. However the Pp in the samples were positive for animals and other monogastric animals since all the Pp % values were all low. Also, seven varieties of Nigerian garden egg fruits had phytate levels of 507-2788 mg/100g (Adeyeye and Fagbohun, 2006). In Adeyeye *et al.* (2000), various food phytate values were reported: legumes (14–344 mg/100g) and cereals (112-287 mg/100g). Values reported for *Canavaliaensiformis* ranged as 5.1-18.5 mg/100g; 6.0-15.3 mg/100g for *Mucunaprurіens* seed flours (Agbede and Alector, 2005) and 33.4-37.8 mg/100g for groundnut seed samples (Adeyeye, 2011).

Other antinutrients determined were oxalate and tannin. Tannin values were generally low with these values (g/100g): A=B = 0.68 and C = 0.50 with CV% of 16.8 whereas oxalate ranged from 2.88-4.86 (mg/100g). Whereas tannin was enhanced in the processed samples to equal level, oxalate was reduced as shown: raw (4.86 mg/200g) > sprouted (3.87 mg/100g) > fermented (2.88 mg/100g). During fermentation, roasting and alkalization, mono and oligomeric – catechins may be partially polymerized into tannins. Tannins is known to possess antioxidative properties in vitro as well as certain potential preventive effects against a number of chronic conditions including cancer and cardiovascular disease (Adeyeye, 2016). In natural cocoa cake, cocoa liquor and alkalized cocoa powder sourced in Nigeria, tannin contents ranged from 4.72 – 8.72 g/100g (Adeyeye, 2016). Other literature values of tannin were: 0.09 – 0.84 mg/100g in bambara groundnut seed parts (Olaleye *et al*., 2013); 0.35 – 0.85 mg/100g reported for groundnut samples (Adeyeye, 2011); 0.3-0.9 g/100g for *Canavaliaensiformis* and 0.8-7.8 g/100g for *M. prupriens* (Agbede and Aletor, 2005). Tannins have been reported to bring about their antinutritional influences (especially in monogastric animals) largely by precipitating dietary proteins and digestive enzymes to form complexes which are not readily digestible (Aletor, 1993). The present levels of oxalate (2.88 – 4.86 mg/100g) were lower than in bambara seed parts (5.02 – 8.59 mg/100g) (Olaleye *et al*., 2013), 4.08 – 6.42 mg/100g reported for groundnut seed flours (Adeyeye, 2011); comparable to 2.46-6.03 mg/100g reported for natural cocoa cake, cocoa liquor and alkalized cocoa powders sourced in Nigeria (Adeyeye, 2016). The presence of oxalate has an undesirable effect on calcium absorption and utilization. Oxalate combines with calcium to form a compound known as calcium oxalate, which passes through the intestine without being absorbed. Calcium oxalate is responsible for most of the kidney stone formation. About half of all the kidney stones are calcium oxalate either alone or mixed with the salts of calcium phosphate, magnesium ammonium phosphate and calcium carbonate. The amount of oxalate formed will depend on the amount of oxalic acid in the food (Fleck, 1976). Formation of these stones frequently reflects chronic alkalinity of bladder and renal pelvic urine caused by infection with bacteria that hydrolyze urea, releasing ammonia (White *et al*., 1973). On this basis, fermented *P. typhoides* would be the best option.

Dietary fibre is one of the major phytochemicals present in cereals, which can be divided into two categories according to their water solubility. Water – soluble fraction (soluble fibre) consists mainly of nonstarchy polysaccharides such as beta-glucans and pentosan (arabinoxylan). Soluble fibre is known to decrease serum cholesterol, postprandial blood glucose and insulin levels in humans (Edge *et al*., 2005). Water insoluble fraction (insoluble fibre) consists of lignin, cellulose, hemicellulose (water – insoluble arabinoxylan). Starch, water – soluble and water – insoluble pentosans, beta – glucans and several free sugars, such as sucrose, maltose, fructose, glucose (dextrose), stachyose, xylose and arabinose, are the major carbohydrate constituents of the cereal grains and their content varies depending on cultivars (Becker and Hanners, 1991). The higher amounts of free sugars and amino acids present in the growth medium (especially due to the cereal malts) supports better cell growth for *Lactobacillus plantarum* and other lactic acid bacteria (Charalampopoulos *et al*., 2002). Due to their slow fermentability and higher water – holding capacity, some cereal bran components, such as lignin and cellulose are shown to be protective against cancer. In Table 5, lignin was not detected in fermented (A) and sprouted (B) samples showing A and B processes degraded lignin to not detectable level, although lignin was even low in the raw sample (0.78 g/100g). On both cellulose and hemicellulose, evidence showed that fermentation and sprouting reduced both of them. Whereas sprouting was more pronounced in cellulose, fermentation was more pronounced in hemicellulose. It is interesting to observe that the variations in both samples were very close with cellulose being 16.1% and hemicellulose being 16.2% as also observed in Pp/phytate/oxalate. Cellulose values of 46.4 g/100g (A) > 39.4 g/100g (B) < 54.4 g/100g (C) were all higher than in bambara testa (23.3 g/100g), dehulled (1.36 g/100g) and whole seed (2.41 g/100g) (Olaleye *et al*., 2013). The values of hemicellulose (g/100g) for A (14.6) < B (15.6) < C (19.7) were each lessthan 26.5 g/100g in bambara seed testa but higher than in dehulled (2.05) and whole seed (0.84 g/100g) (Olaleye *et al*., 2013). Cellulose is a major part of the structural fibre in forages and can be utilized by microorganisms in the rumen. Like cellulose, hemicellulose is a carbohydrate that exists in almost all plant cell wall along with cellulose. Cellulose is composed of only glucose whereas hemicellulose is composed of many different other sugars (e.g. glucose, xylose, mannose, galactose, arabinose, etc). Cellulose is also the framework in which starch granules are deposited. While herbivorous animals are able to get caloric value from cellulose, man cannot utilize its carbohydrate content as there are no enzymes in the body that can digest it. Its chief value for man is gastrointestinal health.

Table 5: Antinutrients, cellulose, hemicellulose and lignin contents of raw and processed *Pennisetum typhoides*

Parameter	F	S	Raw	Mean	SD	CV%	χ^2
Phytatephosphorus(mg/100g)	5.11	3.02	4.41	4.18	1.06	25.5	0.541
Phytate (mg/100g)	18.1	10.7	15.7	14.8	3.77	25.4	1.92
Oxalate (mg/100g)	2.88	3.87	4.86	3.87	0.99	25.6	0.507
Tannin (g100g)	0.68	0.68	0.50	0.62	0.104	16.8	0.035
Lignin (g/100g)	ND	ND	0.78	–	–	–	–
Cellulose (g/100g)	46.4	39.4	54.4	46.7	7.52	16.1	2.42
Hemicellulose (g/100g)	14.6	15.6	19.7	16.6	2.70	16.2	0.878
Phosphorus (mg/100g)	500	599	430	510	84.9	16.7	47.4
% phytate phosphorus	1.02	0.504	1.03	0.851	0.301	35.3	0.213

F = Fermented; **S** = Sprouted; ND = not detected; – = not determined; phosphorus $\chi_{0.01}$ was significant

Table 6: Antintrients, cellulose, hemicellulose and lignin contents of *Pennisetum typhoides* showing differences in raw/fermented (C–A), raw/sprouted (C–B) and fermented/sprouted (A–B)

Parameter	C–A (%)	C–B (%)	A–B (%)
Phytatephosphorus(mg/100g)	-0.70 (-15.9)	+1.39 (+3.15)	+2.09 (+40.9)
Phytate (mg/100g)	-2.47(-15.8)	+4.94 (+31.6)	+7.41 (+40.9)
Oxalate (mg/100g)	+1.98(+40.7)	+0.99 (+20.4)	-0.99 (-34.4)
Tannin (g/100g)	-0.18(-36.0)	-0.18 (-36.0)	0.00 (0.00)
Lignin (g/100g)	- (-)	-(-)	- (-)
Cellulose (g/100g)	+8.08 (+14.8)	+15.0 (+27.6)	+6.95 (+15.0)
Hemicellulose (g/100g)	+5.10 (+25.9)	+4.10 (+20.8)	-1.00 (-6.85)
% phytate phosphorus	+0.010 (+0.971)	+0.526 (+51.0)	+0.516 (+50.5)

The differences (and percentage differences) in the parameters depicted in Table 5 had been shown in Table 6. In C – A (%), C > A values in four parameters (4/7 or 57.1%) whereas A > C values in three parameters (3/7 or 42.9%); in C – B (%), C > B in six parameters (6/7 or 85.7%) and B > C in one parameter (1/7 or 14.3%); finally in A – B (%), A > B in four parameters (4/6 or 66.7%) and B > A in two parameters (2/6 or 33.3%). The statistical analysis from the data from Table 5 had been depicted in Table 7. Both r_{xy} and r_{xy}^2 value were high with all values of r_{xy} being significant at $r_{=0.01}$. The R_{xy} values were generally lower than the observed values in Table 4 R_{xy}. All the mean values were generally lower compared to mean values in Table 4 but the CV% values were highly comparable with values in Table 4. The C_A< IFE in all the samples; however, forecasting efficiency of relationship was easy in all the samples since IFE > C_A.

Table 8 showed the mineral molar ratios of the samples. Bioavailability is a general term that refers to how well a nutrient can be absorbed and used by the body. It can be affected by many factors such as the presence of anti-nutrients, for examples, phytates, oxalates, tannins and polyphenols in foods, a person's need, fibre, competition with other nutrients and acidity of intestinal environment (Paul *et al.*, 2004). Minerals classified as micronutrients are needed by our body in small amounts. Deficiency in minerals, however, can have a major impact on health such as anaemia and osteoporosis that commonly occur in both developed and developing countries. This study focuses only on Fe, Zn and Ca. In Malaysia, the incidence of anaemia due to deficiency of Fe is nearly one million cases (969, 645), osteoporosis due to Ca deficiency is 2,421, 432 cases (Norhaizan and Nor Faizadatul Ain, 2009). The cause of mineral deficiency is commonly due to its low bioavailability in the diet. One of the factors is the presence of phytate. Phytate, which is also known as inositol hexakisphosphate, is a phosphorous containing compound that binds with mineral and inhibits mineral absorption. The presence of phytate in foods has been associated with reduced mineral absorption due to the structure of phytate which has high density of negatively charges phosphate groups which form very stable complexes with mineral ions causing non-availability for intestinal absorption (Walter *et al*., 2002). Phytates are generally found in food high in fibre especially in wheat bran, whole grains and legumes (Lori *et al.*, 2001).

There are many techniques used to determine the bioavailability of minerals in the human body. One of the methods is by measuring the molar ratio of phytate/minerals in the food and diet (Morris and Ellis, 1989). The proportion of samples with ratios above suggested critical values has been calculated: phytate: calcium > 0.24 (Morris and Ellis, 1985), phytate**:**iron > 1.00 (Hallberg *et al*., 1989), phytate**:**zinc > 15 (Turnlund *et al*., 1984; Sandber *et al*., 1987; Morris and Ellis, 1989), calcium: zinc > 200 (Davies *et al*., 1985; Bindra *et al*., 1986).

The Phy: Zn, Ca: Phy, Ca: Zn and [Ca] [Phy]: [Zn] levels of the samples were depicted in Table 8. A high incidence of suboptimal Zn status may exist among rural populations of low income countries consuming cereal – based diets, low in animal products (Prasad, 1983). Indeed, the first cases of severe Zn deficiency in humans were reported among rural populations in Egypt and Iran (Prasad *et al.*, 1963; Sandstead *et al*., 1967; Halsted *et al*., 1972). The high phytic acid level of cereals in these diets was probably a significant etiological factor in the development of Zn deficiency (Davies, 1982).

Oberleas and Harland (1981) showed that foods with a molar ratio of Phy: Zn < 10 showed adequate bioavailability of Zn but problems were encountered when the value was > 15. The Phy: Zn molar ratio has been variously reported as an index of Zn bioavailbility (Gargari *et al*., 2007) and its range of 5-15 had been described by WHO (1996) as being equivalent to moderate Zn bioavailability. All the Phy: Zn values were even <5 which is equivalent to high Zn bioavailbility (WHO, 1996). Calcium has a sparing effect on Zn and Wise (1983) suggested that the solubility of the phytates and the proportion of Zn bound in a mineral complex in the intestines depend on the levels of calcium. In this model, phytate precipitation is not complete until dietary Ca: Phy molar ratios attain a value of approximately 6:1; that is critical Ca: Phy molar ratio is $\underline{>}$ 6:1; here phytate is completely precipitated from the solution. Thus, Zn is available in solution and for absorption (Ojiako *et al*., 2010). This means that both the solubility of phytate and availability of Zn in the intestine are dependent on Ca levels (Igwe *et al*., 2016). All the presently reported Ca: Phy had values > 6:1, it meant that the Zn would be bioavailable. Ferguson *et al*.(1989) showed that the molar ratio varies with different foods and recommended that this value be used in conjunction with other data to explain the availability of Zn using the Ca: Phy ratio. Our results for [Ca] [Phy]/[Zn] that is [Ca x Phy: Zn] were shown in Table 8. Ellis *et al*. (1987) and Davies and Warrington (1986) indicated that the ratio of Ca x Phy: Zn is a better predictor of Zn bioavailability and said that if the value were greater than 0.50 mol/kg, there would be interference with the availability of Zn. The Ca x Phy: Zn values in the samples were each lower than the critical value of 0.50mol/kg thereby making the Zn very bioavailable from the samples. Ca: Zn values were all < critical level of 200.

Table 7: Statistical analysis result of the data from Table 5 on antinutrients of raw and processed *Pennisetum typhiodes*

Statistics	Fermented/Sprouted		Fermented Raw		Sprouted/Raw	
	A	B	A	C	B	C
r_{xy}	0.9829		0.9897		0.9990	
r_{xy}^2	0.9660		0.9795		0.9979	
R_{xy}	0.8348		1.16		1.38	
Mean	14.6	12.2	14.6	16.6	12.2	16.6
SD	17.0	14.4	17.0	19.9	14.4	19.9
CV%	116	118	116	120	118	120
C_A	0.1844		0.1432		0.0458	
IFE	0.8156		0.8568		0.9542	
Remark	*		*		*	

All r_{xy} values were significant whenr_{xy} was $r_{=0.01}$ at n-2 = 6-2 4(df) at critical level of 0.917

Table 8: Phy: Zn, Ca: Phy, Fe: Phy and [Ca] [Phy]/[Zn] molar ratios of the raw and processed *P. typohoides* analysed

Concentration ratio	Samples			Mean	SD	CV%	X^2
	Fermented	Sprouted	Raw				
Ca: Phy[a]	84.4	136	57.3	92.6	40.0	43.2	34.5*
Phy: Zn[b]	0.050	0.033	0.056	0.046	0.012	25.2	0.006
Fe: Phy[c]	14.3	38.3	26.4	26.3	12.0	45.6	11.0
[Ca][Phy] / [Zn][d]	0.001	0.007	0.001	0.003	0.004	118	0.009
Ca : Zn	4.22	4.53	3.20	9.00	0.696	7.73	5.96

*χ^2 value significant at $\chi^2_{0.01}$ when n-1 = 4-1 = 3(df) and critical value of 16.27; [a]mg of Ca/AW (atomic weight) of Ca: mg of Phy/AW ofPhy; [b]mg of Phy/AW of Phy: mg of Zn/AW of Zn; [c]mg of Fe/AW of Fe : mg of Phy/AW of Phy; [d](mol/kg Ca) (mol/kg Phy)/(mol/kg Zn)

Table 9: statistical analysis result of the data on mineral molar ratios depicted in Table 8

Statistics	Fermented/Sprouted		Fermented/Raw		Sprouted/Raw	
	A	B	A	C	B	C
r_{xy}	0.9931		0.9534		0.9822	
r_{xy}^2	0.9863		0.9090		0.9647	
R_{xy}	1.58		0.6433		0.4168	
Mean	24.7	43.6	24.7	20.9	43.6	20.9
SD	40.4	64.2	40.4	27.2	64.2	27.2
CV%	164	147	164	130	147	130
C_A	0.1172		0.1878		0.3016	
IFE	0.8828		0.8122		0.6984	
Remark	*		NS		NS	

*Only r_{xy} values for A/B was significant when r_{xy} was $r_{=0.01}$ at n-2 = 4-2 =2 (df) at critical level of 0.990; Ca: Zn was not involved in the calculation; NS = not significant value of $r_{=0.01}$

The statistical data analysis of the data from Table 8 was depicted in Table 9. The r_{xy} values were high at these values: r_{xy} A/B (0.9931), r_{xy} A/C (0.9534) andr_{xy} B/C (0.9822) with r_{xy} A/B being the only one that was significant as $r_{0.01(0.9931)} > r_{0.01\text{critical value }=0.990)}$; the r_{xy}^2 values were also high at 0.9090 – 0.9863. The R_{xy} ranged from low to slightly high value of 0.4168 – 1.58. The mean values in Table 9 were higher than the values in Table 7 with corresponding much higher levels of standard deviation and variation (CV%). The C_A values were low at 0.1172 – 0.3016 with corresponding high levels of IFE thereby making prediction of relationship easy and highly positive.

In Table 10, we have food properties displayed. The water absorption capacity (WAC) had similar value in each of the sample, that is %WAC was A = B = C = 160. Although cellulose was supposed to have enhanced the WAC in the samples, the difference observed in the cellulose and hemicellulose values (Tables 5 and 6) among the samples appeared not to have affected the WAC values. WAC is considered a critical property of protein in viscous foods like soups, gravies, doughs, baked products, etc., hence the pearl millet flour may be useful in these food formulations. The crude protein in the samples had values of 6.77±1.7% (A), 8.72±0.948% (B) and 9.22 ± 0.488% (C) which were all close, hence similar WAC values. The pearl millet WAC values were lower than many literature values: it was 280% in bambara groundnut whole seed (Adeyeye *et al*., 2013); 357.5% in *Clariasanguillaris*, 260% in *Cynoglossussenegalensis* and 280% in *Oreochronusniloticus* (Adeyeye, 2010); 230% in *Amarantushybridus* (Adeyeye and Omolayo, 2011); 200 to 288.8% in three varieties of melon (Ige *et al*., 1984); but higher than these literature values: 130.15 – 134.8% for whole seed flours and from 135.81 – 164.39% for cotyledons of African yam bean seed (AYB) (Adeyeye *et al*., 1994); 138% reported for pigeon flour (Oshodi and Ekperigin, 1989); 130% for soya flour (Lin *et al*., 1974); 60.2% in wheat flour and 107.1% in sunflower (Lin *et al*., 1974); 140.63% in *Triticum durum* flour (Adeyeye and Aye, 2005); 144.5% in *Anapheinfracta* larvae (Adeyeye, 2008) and 95.0% in *Telfairiaoccidentalis* (Adeyeye and Omolayo, 2011).

Table 10: Some functional properties of the raw, steeped and germinated samples of *Pennisetum typhoides* grains

Food property (%)	Steeped	Germinated	Raw	χ^2
Water absorption capacity (WAC)	160	160	160	-
Oil absorption capacity (OAC)	130	149	130	1.69
Foaming capacity (FC)	6.00	10.0	12.0	2.00
Foaming stability (FS)	2.00	2.00	4.00	1.00
(Rate change): % min^{-1}	0.40	0.27	0.13	-
Emulsion capacity (EC)	51.0	50.0	55.1	0.280
Emulsion stability (ES)	65.0	54.0	65.0	1.32
(Rate change): mlh^{-1}	1.25	1.25	1.25	-
Least gelation concentration(LGC)	8	4	4	2.00
Bulk Density (gcm^{-3})	0.731	0.700	0.798	0.007

The oil absorption capacity (OAC) values were varied (unlike WAC) with these values range: 130% (A) < 149% (B) > 130% (C) with insignificant $\chi^2_{0.01}$of 1.69. It is interesting to note that fermentation had virtually no effect on the sample in this regard as fermented = raw = 130%. OAC is the ability of flour to absorb oil and this is expedient as oil acts as a flavour retainer and improves mouth feel. The present OAC values were lower than the values in *A. hybridus* (182.9%) and *T. occidentalis* (146.3%) (Adeyeye and Omolayo, 2011); 244.4% in *C.anguillaris*, 223.4% in *C. senegalens* and is 204.8% in *O. niloticus* (Adeyeye, 2010); in between in the AYB: for its whole seed flours, range was 100.55 – 133.38% and from 84.73 to 167.70% for cotyledons (Adeyeye *et al.*, 1994); sunflower four (207.8%) (Lin *et al*., 1974); 2006.7% in whole seed flour of *Adenopus breviflorus* Benth flour (Oshodi, 1992); but higher than 89.7% for pigeon pea flour (Oshodi and Ekperigin, 1989), wheat flour (84.2%) and soya flour (84.4%) (Lin *et al*., 1974); 125.9% for dehulled *A. breviflorus* Benth flour (Oshodi, 1992) and values obtained for three varieties of Lima beans by Oshodi and Adeladun (1993) that ranged from 82.3 to 91.5%. The OAC values in the pear millet show that it may be a better flavor retainer than wheat, lima beans, pigeon pea, etc. (Kinsella, 1976).

The foaming capacity (FC) in pearl millet was low as it ranged from 6.00-12.00%. The FC reflected the trend in the values of protein in the samples. Also, the probability that the microorganisms had better effect during fermentation than in

germination might also had dictated the observation on the FC values. The volume values of FC were: A (6% = 3 ml), B (10% = 5 ml) and C (12% = 6 ml). Foaming stability was low but both fermented (A) and germinated (B) recorded similar values of 2.00% whereas raw (C) recorded 4.00%. FS time values were A (10 min), B (30 min) and C (60 min) with corresponding rate of change as follows: A (0.40%/min) B (0.27%/min) and C (0.133%/min) showing that stability increased from A → B → C. In whole seed flours of AYB, FC varied between 54.0 and 55.0%; in soya flour, FC was 70% and sunflower (230%) reported by Lin *et al*. (1974). Also, the FS after 2 h in AYB ranged from 6.00 to 15.0 cm^3 or from 21.82 to 54.55% (Adeyeye *et al*., 1994); in soya flour (20.0 cm^3) and in sunflower (420.0 cm^3) (Lin *et al*., 1974) for the same time period; pigeon pea has as FS of 20% (Oshodi and Ekperigin, 1989). FS is important since the success of a whipping agent depends on its ability to maintain the whip as long as possible (Lin *et al*., 1974). In AYB, the cotyledons FC ranged from 20.0 to 27.0% while the FS ranged from 1.00 to 3.00 cm^3 or 10.0 to 22.2% after 2 h (Adeyeye *et al*., 1994); for Lima bean flours dehulled varieties, FS range was 8.8 to 15.2% (Oshodi and Adeladun, 1993) and for boiled cowpea value was 97.0% (Padmashree *et al*., 1987). FC was 56.0% and FS was 7.1% at 1,050 min and rate of 0.09%/min for *T. durum* whole meal flour (Adeyeye and Aye, 2005). *C. senegalensis* FC and FS (at 30 min) values were 12.0%/33.3%, 10.0%/20.0% and 16.0%/17.5%, respectively (Adeyeye, 2010). *T. occidentalis* FC and FS (30 min) were 5.0/40% and 6.0/50.0% respectively (Adeyeye and Omolayo, 2011). Both pear millet FC and FS values were generally lower than literature values. Oil emulsion capacity (EC) of the samples in Table 10 had values of 50.0–55% following this trend: A (51.0%) >B (50.0%) < C (55.1%). These values are highly comparably to 20.0 - 70.0% for whole seed flours and 10.0 - 20.0% for cotyledons of AYB (Adeyeye *et al*., 1994); sunflower flour had 95.1%, wheat (11.7) and 18.0 % (soya flour) (Lin *et* al., 1994); for benth flour (whole seed) was 20.46% and for dehulled full-fat Benth flour was 35.81% (Oshodi, 1992). These literature values showed that pearl millet may prove to be more useful as an additive for the stabilization of fat emulsions in the production of sausage, soup and cake (Althschul and Wilke, 1985); EC in *A. infracta* was 20.0% (Adeyeye, 2008); 100% in *T. durum* (Adeyeye and Aye, 2005); 25.3% (*C. anguilaris*), 29.0% (*O. niloticus*) and 24.0% *C. senegalensis*; 47.5% in *A. hybridus*, 48.7% in *T. occidentalis.* Emulsion stability (ES) values at 4h ranged from 54.0-65.0% as demonstrated: A = C = 65.0.% and B = 54.0% meaning that germination had high effect on the samples to produce low ES whereas virtually fermentation produced no visible effect on pearl millet since both raw and fermented samples had equivalent values of ES. Although the samples had varied ES values, each sample had 1.25 ml/h as the rate of change. The capacity of protein to aid the formation and stabilization of emulsions is important for many applications in cake batters, coffee whiteners, milks, mayonnaise, salad dressings, comminuted meats and frozen desserts (Kinsella *et al*., 1985). At 24 h, ES values in AYB (whole seed) ranged from 50.40 – 52.00 cm^3 and AYB (cotyledons) ranged from 45.50-60.50 cm^3 (Adeyeye *et al*., 1994). The enhanced ES for fermented and raw pearl millet might be due to the fact that the binding domain had been more exposed. In fish samples, ES values were low or even 0.00 at 4 min: *C. anguilaris* (2.0%) (Adeyeye, 2010), 55.0% (*A. hybridus*) and 52.0% (*T. occidentalis*) at 5 min (Adeyeye and Omolayo, 2011); 11.0 cm^3 at 24 h and rate of 1.83 cm^3/h in *T. durum* (Adeyeye and Aye, 2005).

The least gelation concentration (LGC) gave values where the value in fermented (A) doubled each of germinated (B) and raw (C) with the following values: 8% (A), 4% (B) and 4% (C). In the LGCresults, both samples B and C would be better than sample A in their nutritional function because of their lower LGC. These values were better than for AYB (whole seeds) with values of 8–10% and 10% for cotyledons (Adeyeye *et al.*, 1994); pigeon pea (12% w/v) (Oshodi and Ekperigin, 1989); 10% (w/v) for great Northern bean flour (Sathe and Salunke, 1981); 14% (w/v) of lupin flour (Sathe *et al*., 1982); 10% for mung bean protein isolate (Coffman and Garcia, 1977); for three varieties of lima beans, 8-12% (w/v) (Oshodi and Adeladun, 1993) and for full fat fluted pumpkin seed flour (36% w/v) (Fagbemi and Oshodi, 1991). Protein gels provide a structural matrix for holding water, flavours, sugars and food ingredients; this is useful in food applications and in new product development. Gelation is responsible for the setting of stews prepared from pearl millet grains in terms of this property. This may make it more useful in the production of curd or as an additive to other materials for gel formation in food products. The LGC value in *A. infracta* was 8.0% (w/v) (Adeyeye, 2008); in *T. durum*, it was 8.0% (w/v) (Adeyeye and Aye, 2005); it was 4.0% (w/v) in *A. hybridus* and 6.0% in *T. occiddenalis* (Adeyeye and Omolayo, 2011); 6.0% (w/v) in *C. anguilaris*, 8.0% (w/v) in *O. niloticus* and 8.0% (w/v) in *C. senegalensis* (Adeyeye, 2010).

The bulk density (BD) results were 0.700 to 0.798 g/cm^3. Bulk density of meal is influenced by number and packing density of protein bodies and starch granules. High protein content and protein – lipid interactions are said to contribute to increase in fat absorption capacity of food (Oyarekua and Adeyeye, 2008). The BD values compared favourably with the BD in fish samples: 35.6% (*C. anguilaris*), 37.0% (*O. niloticus*) and 56.8% (*C. senegalensis*), (Adeyeye, 2010) but higher than 23.4 – 44.6 g/100ml reported for various samples of extrusion texturized soya products with varied protein and soluble sugar contents (Cherry, 1981). In Oyarekua and Adeyeye (2008), BD was 0.75 cm^3 (maize/cowpea) and 0.71 cm^3 in maize/cowpea *ogi*.

The protein solubility (PS) was reported as (NS x 6.25%)

PS as a function of pH

The solubility of a protein under given conditions (pH, ionic strength and temperature) is the manifestation of the equilibrium between protein – solvent and protein – protein interactions (Kinsella *et al*., 1985).

Protein – solvent protein $\rightleftharpoons$ protein + solvent – solvent

Conditions that shift the equilibrium in favour of protein – protein interactions decrease the solubility and conditions that favour protein – solvent interactions increase the solubility. The major forces involved in such interactions are electrostatic, hydrophobic and hydrogen bonding. Generally, the degree of solubility of a protein in a given aqueous system is the net result of both electrostatic and hydrophobic interactions between the protein molecules. The observed effects of pH and ionic strength on the solubility of proteins is a simple manifestation of the above two effects (Kinsella *et al*., 1985). The results of the pH effect on the protein solubility of pearl millet were shown in Table 11. The pH solubility values were varied between pH 1 to 12 for each of the sample. In fermented (A), solubility ranged from 32 to 65%; in germinated (B), solubility range was 40-60% and in raw (C) range was between 47-71%. The variation values were generally low at 10.8 – 22.4% which could be described as being close. The $\chi^2_{0.01}$ values were all low and none significant at 1.10 to 4.64. Highest solubility values at alkaline pH were 65% (A) at pH 9 and 71% (C) at pH 9 but B had two high similar protein solubility values at 60% (pH 6) and 60% (pH12) meaning either acidic or alkaline medium.

Table 11: Protein solubility profiles of the raw and processed *Pennisetum typhoides* samples

pH	Fermented (A)	Germinated (B)	Raw (C)	Mean	SD	CV%	Chi-square (x^2)
1	58	50	62	56.7	6.11	10.8	1.10
2	52	45	57	51.3	6.03	11.7	1.42
3	45	40	52	45.7	6.03	13.2	1.59
4	32	50	47	43.0	9.64	22.4	4.33
5	39	55	52	48.7	8.50	17.5	2.97
6	45	60	57	54.0	7.94	14.7	2.33
7	52	50	62	54.7	6.43	11.8	1.51
8	58	45	66	56.3	10.6	18.8	3.99
9	65	48	71	61.3	11.9	19.5	4.64
10	52	50	62	54.7	6.43	11.8	1.62
11	45	55	57	52.3	6.43	12.3	1.58
12	39	60	52	50.3	10.6	21.1	4.47

SD = Standard deviation; **CV** = Coefficient variation

Table 12: Protein solubility profiles of *Pennisetum typhoides* showing differences in raw/fermented (C-A), raw/sprouted (C-B) and fermented/sprouted (A-B)

Parameter pH	C-A (%)	C-B (%)	A – B (%)
1	+4.0 (+6.45)	+12.0 (+19.4)	+8.00 (+13.8)
2	+5.0 (+8.77)	+12.0 (+21.1)	+7.00 (+13.5)
3	+7.0 (+13.5)	+12.0 (+23.1)	+5.00 (+11.1)
4	+15.0 (+31.9)	-3.00 (-6.38)	-18.0 (-56.3)
5	+13.0 (+25.0)	-3.00(-5.77)	-16.0 (-41.0)
6	+12.0 (+21.1)	-3.00 (-5.26)	-15.0 (-33.3)
7	+10.0 (+16.1)	+12.0 (+19.4)	+2.00 (+3.85)
8	+8.00 (+12.1)	+21.0 (+31.8)	+13.0 (+22.4)
9	+6.00 (+8.45)	+23.0 (+32.4)	+17.0 (+26.2)
10	+10.0 (+16.1)	+12.0 (+19.4)	+2.00 (+3.85)
11	+12.0 (+21.1)	+2.00 (+3.51)	-10.0 (-22.2)
12	+13.0 (+25.0)	-8.00 (-15.4)	-21.0 (-53.8)

The differences in the protein solubility values from the results in Table 11 were shown in Table 12. The C-A (%), all the values in C >A as shown by the arithmetical signs carried by each member; the percentage differences values from +6.45 to +31.9 in pHs 5 and 12, each had solubility value of 25.0%. In C – B (%), C was greater than B in eight pHs (8/12 = 66.7%) whereas B > C in four pHs (4/12 = 33.3%). The percentage differences valued from +3.53 to +31.8. In A – B (%), A > B in seven pH parameter values (7/12 = 58.3%) whereas B > A in five pH values (5/12 or 41.7%) with % change values of +3.85 to -56.3 where pHs 7 and 10 had equivalent percentage levels of 3.85 in each case. The closeness or variation of the percentage differences had this trend: C-A (%) < C-B (%) < A-B (%).

The statistical analysis of the data from Table 11 had been reported in Table 13. The r_{xy} levels were low to high ranging from -0.2359 (B/C), -0.4130 (A/B) and 0.9547 (A/C); only A/C being significant in the r_{xy} results. The r_{xy}^2 followed similar low value trend for A/B and B/C (0.0556 – 0.1705) but high in A/C (0.9114). The R_{xy} values were negative for A/B and B/C but low and positive (0.6910) in A/C. The mean values were higher than in Table 9, low SD values (6.02 – 9.43) and relatively generally low CV%. The C_A values were high to low values [0.9107 – 0.9718] (high) and 0.02977 (low)]. Reverse values were observed for the IFE making prediction of relationship low in A/B and B/C but easy in A/C.

Table 13: Statistical analysis result of the data from Table 11 on the protein solubility profile of raw, fermented and germinated *Pennisetum typhoides*

Statistics	Fermented/Sprouted		Fermented/Raw		Sprouted/Raw	
	A	B	B	C	A	C
r_{xy}	-0.4130		-0.2359		0.9547	
r_{xy}^2	0.1705		0.0556		0.9114	
R_{xy}	-0.2635		-0.2676		0.6910	
Mean	48.5	50.7	50.7	58.1	48.5	58.1
SD	9.43	6.02	6.02	6.83	9.43	6.83
CV%	19.5	11.9	11.9	11.8	19.5	11.8
C_A	0.9107		0.9718		0.2977	
IFE	0.0893		0.0282		0.7023	
Remark	NS		NS		*	

Only A/C r_{xy} was significant at $r_{=0.01}$ with n-2 = 12-2 = 10 (df) and significant level of 0.708

For better visualization, the data in Table 11 had been converted into a Fig. 2. At pH 9, samples A and C became denatured and had reduced solubility at this pH whereas germinated sample solubility went on still increasing. Whereas sample B had two p*I* values (suggesting two major proteins) at pH 3 (40% solubility) and pH 8 (45% solubility), p*I* for sample A was at 4 (32% solubility) and raw also pI at pH 4 (48% solubility). All the samples showed high solubility at both acid and alkaline media.

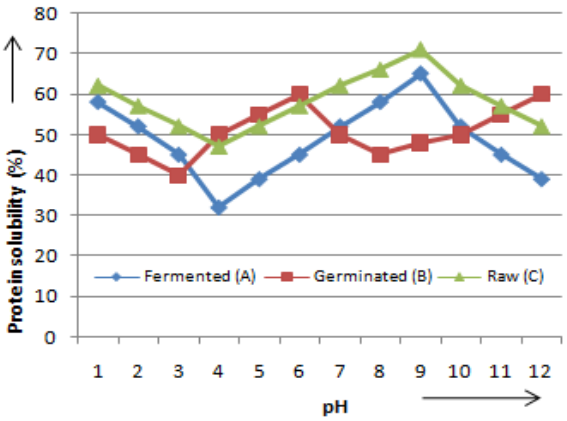

Fig. 2: Protein solubility curve profiles of raw, germinated and fermented *Pennisetum typhoides* grains

The high solubility of the protein of these flours in the acid region of pH indicates that the protein may be useful in the formulation of acid food, for example, protein – rich carbonated beverages (Kinsella, 1977). These protein solubility profiles are similar to the pH dependency of solubility for casein which has an isoelectric point of 4.6 (Wolf and Cowan, 1977). This suggests that pearl millet protein isolates may substitute for casein and caseinates in food products. The shape of the protein solubility profiles in pearl millet resembled those of *C. anguilaris*, *O. niloticus*and *C. senegalensis* (Adeyeye, 2010), salt effects on *A. infracta* protein (Adeyeye, 2008), protein solubility profiles in *A. hybridus* and *T. occidentalis* (Adeyeye and Omolayo, 2011).

Conclusion

Both germination/sprouting increased the activity of α-amylase and consequently increased the digestibility of starch, making it a good method in the preparation of complementary and infant foods (total sugar in germinated sample was 329 mg/100g). Phytate, phytate phosphorus (Pp) and %Pp were all low with %Pp range of 0.504 – 1.03 making phosphorus highly bioavailable for its nutritional advantages. Generally all the antinutrients were low as well as lignin, cellulose and hemicellulose with germinated sample being lowest in Pp, phytate, oxalate, cellulose and %Pp. All mineral molar ratios were all within the bioavailability level of zinc. p*I* for raw and fermented samples had coincided pH 4 whilst germinated had two p*I* values at pH 3 and pH 8 showing the likelihood of two major proteins in pearl millet. The pearl millet grains demonstrated great potential for human food formulations because of their good functional properties which compare favourably with wheat, soya bean, melon, pigeon pea and lima bean flours.

Conflict of Interest

Authors have declared that there is no conflict of interest reported in this work.

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