Direct Research Journal of Agriculture and Food Science

Vol. 13(1), Pp. 180-191, April 2025,

https://journals.directresearchpublisher.org/index.php/drjafs

Research Article
ISSN: 2354-4147

Smart Food Innovation: Boosting Nutrition through Crafted Breakfast Cereal from Underutilized Crops, Fonio Millet (ACHA) (D*igitaria exilis*) Bambara Nut (*Vigna subterranean*) and Soybean (Glycine max)

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ABSTRACT

Breakfast is the first meal of the day usually made from fonio millet. Fonio millet is lacking in essential amino acids. The nutrient content of this meal can be improved by complementing it with legumes crops. The objective of this work is to improve and evaluate the nutritional and sensory profile of ready-to-eat breakfast cereal using blends of fonio millet, soybean and bambara nut flour. Five samples were prepared by mixing fonio millet, soybean and bambara nut flour blends in the ratio 100:0:0, 50:25:25, 50:20:30, 50:30:20, 60:20:20 respectively. The proximate composition, minerals analysis, anti-nutritional factors, functional properties and sensory parameters of the samples were determined using standard methods. The moisture, crude protein, crude fat, crude ash and carbohydrate contents ranged from 8.35%-9.48%, 7.88%-14.88%, 4.25%-10.84%, 1.28%-2.25% and 66.91%-72.82% respectively. The mineral contents of the samples depicted that sodium, magnesium, potassium, calcium, manganese and zinc ranged from 1.11-2.10mg/100g, 12.03-16.84 mg/100g, 46.74-55.94mg/100g, 9.38-12.49mg/100g, 26.46-30.30mg/100g, 1.09-8.76mg/g respectively. The energy contribution of the samples ranged from 378.29 to 412.84 kcal/100g, showing the highest contribution in sample B (50%, 25%, 25% fonio millet, bambaranut and soybeans respectively. Results for the anti-nutrients are as follows; saponin (0.00-0.04mg/100g), Alkaloid (0.00-0.20mg/100g), flavonoid (0.00-0.06mg/100g), tannin (0.00-0.52mg/g), phytates (0.30-0.40mg/100g). The sensory results revealed that the breakfast cereal blend 50:20:30 for fonio millet, soybean and bamabara nut was most acceptable. Formulation from 50:20:30 for fonio millet, soybean and bamabara nut respectively showed improved nutritional and sensory properties.

Keywords: *Breakfast, cereal blend, proximate, anti-nutritional factors, sensory properties*

Article Information
Received 7 MARCH 2025;
Accepted 19 APRIL 2025;
Published 22 APRIL 2025
https://doi.org/10.26765/DRJAFS53741894
Citation: Sogunle, K. A., Aliyu, A. A., Garba, A. I., Adaobi, T. F., Okafor, A. M., Puorizaa, T., and Ezeoma, C. C. (2025). Smart Food Innovation: Boosting Nutrition through Crafted Breakfast Cereal from Underutilized Crops, Fonio Millet (ACHA) (*Digitaria exilis*) Bambara Nut (*Vigna subterranean*) and Soybean (Glycine max). *Direct Research Journal of Agriculture and Food Science*. Vol. 13(1), Pp. 180-191.

INTRODUCTION

Breakfast is the nutritional foundation and the first meal of the day. In developing countries, particularly sub-Saharan Africa, breakfast meals for both adults and infants are based on local staple diet made from cereals, legumes, and few tubers. However, the most widely eaten breakfast foods are cereals and grains (Frimpong et al., 2022). Breakfast meals can be described as any food derived with or without supplementation through swelling, flaking, grinding, rolling, or roasting of any cereal. (Olurin et al., 2021). The common cereal products in Nigeria include

NASCO Cornflakes, Good morning corn flakes, Kellogg's cornflakes, NABISCO flakes, Weetabix, Quaker oats, Rice crisps among others. A study has clearly shown that 42% of 10-year-olds and 35% of young adults consumed cereal at non-breakfast occasions (Haines el al., 1996). Breakfast is widely referred to as the most important meal of the day. Studies on attention and working memory have shown that a breakfast rich in carbohydrates helps to maintain the same level of mental performance during morning. In addition, the grain are digested slowly, which result in a prolonged satiety and a gradually release of energy. It is therefore strongly advised to eat a breakfast with hot food (flakes, semolina spelled or millet with fruit and vegetables) because they provide a lasting satiety and a great appetite for lunch. Moreover, the combination of vegetables cooked cereal helps eliminate toxins. Generally, cereals and cereal products are the main breakfast in the most developing countries; these are maize, rice, sorghum or millet. These cereals constitute important sources of carbohydrates, vitamins, minerals and fibers; indeed, they contain low content of proteins and lipids. The germination transforms the appearance of seeds, but also improves the nutritional value of cereals while raising their content in lysine, tryptophan, and vitamins. To improve protein and fat quantities in cereal foods, attention is focused on processing technology and use of inexpensive sources of proteins. However, Regular consumption of foods from cereals such as maize without the addition of high-quality protein foods can cause protein-energy malnutrition as well as kwashiorkor in infants (Inyang, et al., 2019). To increase the protein content of fonio millet and improve the amino acid profile, especially lysine, the use of soybean flour as a protein supplement has been suggested. Soybean flour represents a high protein supplement relative to compositional, functional and nutritional properties; it contains approximately 40% of protein and 20% of fat (Kim, 2005).

Cereals, such as fonio millet (*Digitariaexilis*) known as acha in Nigeria, are one of the oldest West African cereals. It is among the four millets grown in the African semi-arid tropics (savannahs) and constitutes less than 0.1% of the total staple food and less than 0.25% of the total production in Nigeria. Acha (Digitaria exilis), not only in Nigeria but also it is among the domesticated and earliest grains in Africa and cultivated for over 5000 years in west African sahel (Mariotti, 2021; David et al., 2023).

Staple foods prepared from the grains are major sources of energy, protein, vitamins, and minerals, especially important for young adults, pregnant women, lactating mothers and children. Fonio millet is 3-5 times nutritionally superior to the widely promoted rice and wheat in terms of protein, mineral and vitamins (Bhohale, 2013). Beside other African traditional cereals, fonio grains have played a central role in the emergence and development of traditional agriculture, nutrition and indigenous medicine in the West African savannah. Cereal is an important agricultural commodity and a primary food ingredient worldwide and contains considerable beneficial nutritional components. Legumes or pulses are edible fruits or seeds of pod bearing plants (Sivasankar, 2005). Their seeds are put to a myriad of uses, both nutritional and industrial, and in some parts of the developing world they are the principal source of protein for humans (Trevor *et al*., 2005). The common legumes in Nigeria include, cowpea (*Vignaunguiculata),* soybeans (*Glycine max*), pigeon pea (*Cajanuscajan*), and peanut (*Arachishypogea*. Soybean (*Glycine max*) is one of the world's largest sources of plant protein and oil. Soybean protein has high crude protein and a balanced amino acid profile. Soybeans had been used to enrich other food stuffs such as cassava products, cereal products etc (Ayo *et al*., 2007). According to Tan et al. (2020), Bambara groundnut plays significant potential in combating malnutrition globally, particularly in Africa due to its richness in protein, amino acids, dietary fiber, and vitamins. In addition to its nutritional properties, Bambara nut also contains antioxidants such as phenolic compounds, flavonoids, and tocopherols, which contribute to its prevention of free radicals (Adedayo et al. 2021; Oyeyinka et al. 2021)

Research has continued to focus on the need and how to augment the low level of protein in the diets of the vulnerable group of people in developing nations. In these developing nations where protein deficiencies are endemic and where animal-proteins are not available in adequate quantities, a well-planned vegetarian diet, based on the concept of mutual supplementation seems to be a logical solution to the protein problem (Sanni *et al.,* 2004). It is now generally accepted that highly digestible plant proteins, which are heat treated to remove anti-nutritional factors and properly supplemented with essential amino acids where needed, can produce results equivalent or sometimes superior to those obtained with animal protein sources (Sanni *et al.,* 2004).

Fonio millet is an underutilized cereal grain in Nigeria as it is produced and consumed by the local farmers in northern parts of Nigeria. Where the grain is produced in large quantity and used for weaning of infants (Figure 1). There is prevalence of PEM among the fonio millet consuming population due to its limiting essential amino acids especially threonine and tryptophan, (Onweluzo and Nnamuchi 2009). But, it contains fiber, methionine and cysteine in considerable amount (Oladebeye et al., 2023). Recently, food product developers have incorporated legumes into traditional cereal formulations as nutrient diversification strategy as well as efforts to reduce the incidence of malnutrition among vulnerable groups. Results from a previous studies (Onweluzo and Nnamuchi, 2009), indicated that most cereals are limited in some essential amino acids especially theroine and tryptophan. Cereals can however be supplemented with oil seeds and legumes which are rich in essential amino acids particularly the sulphur-containing ones (Kanu *et al*., 2009). Due to an underutilization and limiting essential amino acids of fonio millet, a combination of this cereal with other cereals and/or with legumes will complement

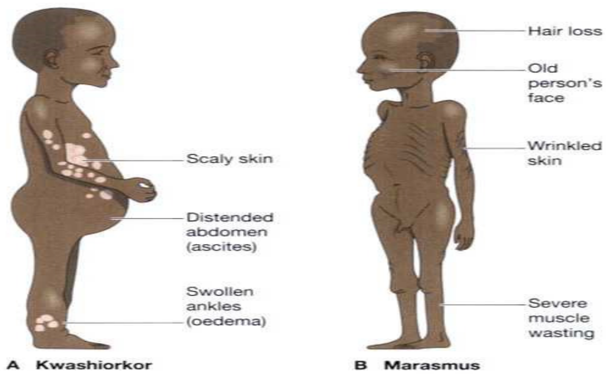

Figure 1: Two types of under-nutrition that can be prevented and Ameliorate by nutritionally dense food from cereals supplemented with legumes.

each other in order to improve nutritional quality, develop a new product that will benefit hungry and malnourished individuals to improve the utilization of fonio millet, provide income for farmers and product processors of fonio millet-based breakfast cereals. In addition, Economic constraints are limiting people to access animal-based foods that could supplement nutrients deficiencies. Therefore, using locally available ingredients to developing affordable, nutrient-dense cereal blends is critical for improving public health (Ayo et al., 2025). Thus, a combination of such food stuffs will improve the nutritional value of the resulting blend compared to the individual components alone. Therefore, the aim of this research work is to develop and evaluate nutritional and sensory properties of breakfast cereals from flour blends of Acha, Bambaranut and soybeans.

MATERIALS AND METHODS

Materials

The Fonio millet (*Digitariaexilis*), bambara groundnut (*Vignasubterranean*) and soybeans *(Glycinemax)* were purchased from Dawaki market in Kanke Local Government Area of Pleateau state North central Nigeria and identified in the Department of crop production, Federal University Dutsin-ma Katsina State. The processing of samples and experiments were carried out using the facilities available at the Department of crop production Laboratory, Federal University Dutsin-ma Katsina State.

Sample preparation

Fonio millet, bambara nut and soybeans seeds were subjected to pre-cleaning operations and processing methods with the aim of producing a safe and wholesome product.

Processing of fonio millet (acha) grains to flour

Acha was processed into flour using the method described

Acha
↓
Cleaning and sorting
↓
Washing
↓
Drying (at50^{0}C for 6hrs)
↓
Milling
↓
Sieving
↓
Acha flour

Figure 2: Production of acha flour, Flow chart for acha flour preparation.
Source: Olapade et al. (2011; Ubbor et al. (2022)

by Olapade et al., (2011; Ubbor et al., 2022) with slight modification in drying time from 4-6 h. Two kilograms 2 kg of the grains were cleaned by sorting and winnowing, then washed in several changes of excess water to separate stone and sand. The cleaned Acha was dried in an oven (Fulton, model-NYC-101) at 50°C for 6 hours. The dried acha was milled into flour using hammer mill (Thomas Wiley mill ModelED-5), packaged in an air tight container and stored for further use (Figure2).

Processing of Bambara nut flour

The Bambaranut seeds (1kg) were sorted, cleaned, washed and soaked for 48 hours (2 days) in a stainless-steel bucket containing clean tap water. The water was replaced with fresh tap water after every 6 hours to avoid fermentation and growth of some microorganisms. The Bambara nut seeds were spread on a clean jute bag under direct sun light. The bambaranut seeds were dehulled by rubbing with a bottle on a hard cleaned surface, and winnowed to remove the testa then milled into flour using hammer mill (Bremmer, Germany). The flour was sieved with the aid of a 425 µm sieve to obtain a uniform particle size of flour which was packaged in polyethylene bag and stored in a refrigerator at 4-6°C till needed (Figure 3).

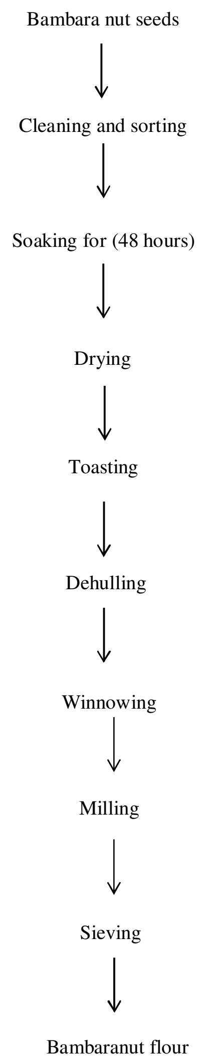

Figure 3: Production of Bambaranut flour (Lalude and Fashakin 2006).

Processing of toasted soybean flour

Toasted Soybean flour was produced using the method of Iwe (2003) as shown in (Figure 4). Soybean seeds (1kg) were sorted, cleaned, washed in clean tap water and soaked for 48 hours in a stainless-steel bucket. The water was replaced with fresh tap water after every 6 hours to avoid fermentation and growth of some microorganisms. The soybean sample was spread on a clean jute bag under direct sun light after the 48 hours. It was therefore be toasted using a pan at controlled flame on a cooking gas. The toasted soybean was dehulled using a pestle and mortar and winnowed to remove the testa then milled into flour using hammer mill (Bremmer, Germany). The flour was sieved with the aid of a 425 μm sieve to obtain a uniform particle size of flour which was packaged in polyethylene bag and stored in a refrigerator at ambient temperature until needed.

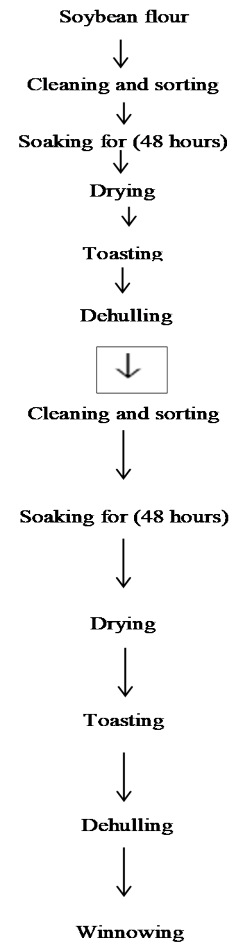

Figure 4: Production of Soybean Flour

Formulation of composite flour

Composite flour was formulated by mixing Acha, Bambara groundnut and soybeans. Five samples were generated by mixing the composite flour in different proportions (100:00:00: 50:25:25, 50:20:30, 50:30:20, 60:20:20). Table 1 shows the composite flour proportions for the three samples. Based on preliminary preparations, about 3 to 4 tablespoons of the composite breakfast flour was pasted with 100 ml of clean tap water. Boiled water of about 300 ml was added with initial vigorous stirring followed by intermittent stirring for about 4 min, to obtain a desirable consistency (Figure 5).

Analysis of samples

Proximate compositions of formulated samples

The proximate composition of the samples was determined using standard methods (AOAC, 2012). While Carbohydrate content was determined by difference

Table: 1: Composite Flour Formulations for Breakfast Cereals made from Blends of Acha, Bambaranut and soybeans Flours.

SAMPLES	FORMULATIONS			
	Acha (%)	Soybean (%)	Bambaranut (%)	Total (%)
A	100	00	00	100
B	50	25	25	100
C	50	20	30	100
D	50	30	20	100
E	60	20	20	100

Frame A. Frame B Frame C

Figure 5. Breakfast cereal blends components. **Frame A**; Acha grain. **Frame B**; Dehulled Bambara nut. Frame C; Soybean seed and flour.

(Pearson, 1976)
% carbohydrate =100- (% of moisture + %Ash + %Protein + %Fat)

Determination of total energy

The total energy was determined using the method described by (Kanu et al., 2009).

Mineral content analysis

The mineral content of the products was determined by the AOAC (2012) method.

Determination of anti-nutritional factors

Determination of Phytic acid/ Phytate

Phytate was determined using (Thompson and Erdman, 1982).

Determination of tannins

The analysis of tannins content was performed according to the AOAC (2012) method.
Calculation:

Tannins content (%) = $\frac{(V-V0)X0.004157X250X100}{gx25}$

Determination of saponins

Saponin determination was carried out using AOAC (2012) method.

Determination of alkaloid

Alkaloid determination was done using alkaline precipitation method as described by (Harbone, 1998).

Determination of Flavonoids

Flavonoids determination was done using the method reported by (Ejikeme, 2005).

Determination of functional properties

The bulk density, foam capacity, swelling power, dispersibility, water and oil absorption capacity were determined for each of the formulated sample using the method described by (Onwuka, 2005).

Preparation of complementary food

Method described by (Olapade *et al*., 2010) was used for the preparation of the meal. Different blends of breakfast cereal flour Acha, Bambaranut, and soybeans at 100:0:0, 50:25:25, 50:20:30, 50:30:20 and 60:20:20 (w/w) respectively were stirred to consistent paste, and each was sweetened with 25 g granulated sugar. Breakfast cereal of 100% fonio millet was used as control.

Sensory analysis

The sensory evaluation of gruels produced from the breakfast cereal formulations was conducted at the food

Table 2. Proximate composition of innovative breakfast cereal

Samples	Moisture (%)	Protein (%)	Lipid (%)	Fiber (%)	Ash (%)	Carbohydrate (%)	Energy (kcal) /100g
A	9.43±0.35[b]	14.88±0.18[c]	4.25±0.64[a]	2.00±0.12	1.32±0.31[a]	68.13±1.09[b]	370.29
B	8.48±0.11[a]	8.70±0.07[ab]	10.84±0.48[c]	2.40±0.17	1.88±0.11[bc]	67.70±0.55[b]	403.16
C	8.35±0.14[a]	7.88±1.24[a]	9.69±0.83[bc]	2.94±0.32	1.28±0.25[a]	69.86±0.52[c]	398.17
D	8.70±0.42[a]	13.10±1.23[c]	9.05±0.50[b]	3.04±0.14	2.25±0.07c	63.86±0.37[a]	393.70
E	9.48±0.04[b]	10.47±0.00[b]	9.54±0.07[bc]	3.20±0.16	1.62±0.04[ab]	65.69±0.07[b]	390.50

Values are means ± standard deviation of duplicate determination; Means with different superscript in the same column are significantly different at p<0.05

Key:

A = 100 % Fonio millet
B = 50 % Fonio millet 25 % soybean, 25 % Bambaranut
C = 50 % Fonio millet, 20 % soybean, 30 % Bambaranut
D = 50 % Fonio millet, 30 % soybean, 20 % Bambaranut
E = 60 % Fonio millet, 20 % soybean, 20 % Bambaranut.

laboratory of Federal University Dutsinma and performed by effective testing (Iwe, 2003). Twenty students were randomly selected, and evaluated the breakfast cereal for color, aroma, taste, mouth feel, and general acceptability, using a nine-point hedonic scale that is ranked from 1 – 9, where 9 represents like extremely, 8 - like very much, 7 - like moderately; 6 - like slightly, 5 - neither like nor dislike, 4 - dislike slightly, 3 - dislike moderately; 2 - dislike very much, and 1 - dislike extremely.

Statistical analysis

The data obtained were subjected to one way analysis of variance (ANOVA) and mean separation was done by LSD test (p< 0.05) using Statistical Package for Social Sciences (SPSS) version 17.0.

RESULTS AND DISCUSSION

Proximate composition of breakfast cereals

Table 2 depicted the mean values for the proximate composition of the formulated samples. The moisture contents of the sample blends ranged from 8.35 to 9.48% with sample E as the highest and sample C the lowest. Sample C is preferred to enhance shelf stability, which minimizes the microbial activities that reduce the shelf life of the product (Lohita et al., 2024)

However, there is significant differences between sample A, B, C and D, but sample E was similar to sample A at (<0.05). The result is slightly lower and comparable to (9.22%-10.79%) reported article by (Olurin et al., 2021). The decrease in moisture could be as a result of increase in protein content caused by the supplementation with legumes as protein is known to bind moisture and make them unavailable. The moisture content of any food is index of its water activity and is used as a measure of stability and susceptibility to microbial contamination (Uyoh *et al.,* 2013).

The protein content of the samples ranged from 7.88 to 14.88% with sample C having the lowest value and sample A the highest. The finding is lower and in contrast with the reported article by Usman, (2012) in which protein content ranged from 15.68% to 18.26% in breakfast cereal made from maize and defatted coconut flour. Higher percentage of protein obtained in sample A is surprisingly unexpected when compared to previous literature. However, variation may occur due to the use of different varieties, analytical procedure and expertise of the personnel involved in the analysis. Furthermore, significant differences (p<0.05) exist among the formulated samples. The progressive solubilization and leaching out of the nitrogenous substances during soaking and boiling of the legumes may be responsible for the slight protein reduction in the samples (ukachukwu and Obioha, 2000).

Lipid contents of the samples were ranged from 4.25%, to 10.84. There were significant differences in the fat content (p<0.05) in the samples. Sample C and E were similar to both D and B and different from sample A. Higher values were recorded (8.70-14.32) for fortified breakfast cereals made from AYB, maize, sorghum and soybean (Agunbiade and Ojezele, 2010) and breakfast made from sorghum and pigeon pea composite flour 8.70 -14.2 reported by (Mbaeyi, 2005) The low-fat content of the developed products would be suitable for weight watcher. However, moderate fat levels contribute to energy density, and mitigate the risk of rancidity and off-flavor development, ensuring product stability during storage (Adepeju et al., 2024).The fiber content of the formulated samples ranged from 2.00% to 3.14% which is lower than (4.07 to 7.11%) recorded by Ayo et al. (2025). Fiber helps to maintain human health and has been known to reduce cholesterol level in the body Bell *et al*. (2008), but a low fiber and moisture diets presumably contain sufficient calories per serving (Saldanha 1995). The values of ash content ranged between 1.28 to 2.25% with sample C having the least while sample D had the highest value, and significant differences exist among the samples at (P < 0.05). However, higher ash content values of 3.1 to 3.8% have been reported by Agunbiade and Ojezele, (2010). The variation in the ash content may be as a result of the differences of the raw materials used in the formulations.

Table 3. Mineral composition of innovative breakfast cereal.

Samples	Sodium (mg/Kg)	Magnesium (mg/Kg)	Potassium (mg/Kg)	Calcium (mg/Kg)	Manganese (mg/Kg)	Zinc (mg/Kg)
A	*1.33*±0.04^{ab}	*13.85*±0.00^{b}	*55.48*±0.28^{c}	*12.49*±1.41^{b}	*26.46*±0.00^{a}	1.09±0.00^{a}
B	*1.57*±0.01^{b}	*12.03*±0.04^{a}	*50.93*±0.00^{b}	*11.04*±0.57^{ab}	*30.30*±0.14^{b}	5.04±0.57^{b}
C	*1.94*±0.06^{c}	*16.84*±0.00^{e}	*46.74*±1.44^{a}	*9.38*±0.14^{a}	*29.35*±0.00^{ab}	8.67±0.06^{d}
D	*1.11*±0.16^{a}	*16.00*±0.07^{d}	*53.95*±0.00^{c}	*9.54*±0.14^{a}	*30.03*±0.04^{b}	7.80±0.14^{c}
E	*2.10*±0.14^{c}	*15.75*±0.07^{c}	*55.95*±1.41^{c}	*10.00*±1.41^{a}	*27.77*±2.83^{ab}	7.60±0.14^{c}

Values are means ± standard deviation of duplicate determination; Means with different superscript in the same column are significantly different at p <0.05

Key:

A = 100 % Fonio millet

B = 50 % Fonio millet 25 % soybean, 25 % Bambaranut

C = 50 % Fonio millet, 20 % soybean, 30 % Bambaranut

D = 50 % Fonio millet, 30 % soybean, 20 % Bambaranut

E = 60 % Fonio millet, 20 % soybean, 20 % Bambaranut.

The ash content gives an indication of the mineral composition preserved in the food materials (Omotoso 2006; Nnamani *et al*., 2009).

Carbohydrate content ranged from 63.86 to 69.86 % in the various flour formulations. Sample C was the highest while sample D was the lowest. There were significant differences among the samples at (p<0.05), but sample A, B, and E were similar. Carbohydrate content of 100% fonio millet flour was 70.13%, this is closely comparable to 72 - 79.5% reported by Bhatt *et al.* (2003) in finger millet.

The carbohydrate content in the formulated samples decreases with the increase supplementation of fonio millet (acha). The high carbohydrate content in these blends makes them ideal for infants as they require energy for their rapid growth. Sample D with lowest carbohydrate content might be preferable for diabetic but must be balanced with the benefits of other nutrients, as highlighted by Ijarotimi et al. (2021).

The mean energy contribution of the formulated samples ranges from 370.29 to 403.16 kcal/100g. Sample A (100% fonio millet) has the lowest energy contribution while sample B (50% fonio millet, 25% each bambaranut and soybeans) has the highest, the higher energy value obtained from sample B may be as a result higher lipid content of the sample. Inclusion of legumes significantly increases the energy and lipid content of the samples. The energy value obtained is higher than (339.10 kcal/100 g) reported by Ekpeno and Charles, (2020) in the production of breakfast cereal blend from African yam bean. Furthermore, Okwunodulu, et al. (2020), highlighted that dietary energy is required for basic metabolic processes, movement, and for new tissue formation during growth and pregnancy. For an active healthy adult, the formulation above is capable to provide 26% of daily protein requirement, 21.8% of carbohydrate requirement, 13% of lipid requirement and 16% of daily energy requirement as found in sample B. the lower lipid content is desirable to prevent risk of cardiovascular diseases.

Minerals content of innovative breakfast cereal

Table 3 shows the mean values of the mineral composition of formulated flour samples in mg/100g. The sodium content of the formulated samples ranged from 1.11mg/100g to 2.10mg/100g with the highest value found in sample E. This ranged value is far less than the value recorded for the control- Weetabix (387mg/100g) and the USRDA (500mg/100g). Higher sodium values (97.5-187.3mg/100g) were also reported for fortified breakfast cereals (Mbaeyi, 2005). However, sodium is one of the minerals whose intake is considered a factor in the etiology of hypertension, hence its low intake is encouraged (Okaka, 2005).

Excessive sodium intake is associated with an increased risk of heart related diseases, and stroke (Wang et al., 2020), the lower sodium content in the formulated breakfast cereals is desirable to prevent aforementioned health risks to consumers.

Minerals are vital for the overall mental physical well-being and are important constituents of bones, teeth, tissues, muscles, blood and nerves cells (Soetan *et al.,* 2010). Furthermore, they help in the maintenance of acid-base balance, response of nerves to physiological stimulation and blood clotting (Hanif *et al.,* 2006). The Magnesium content obtained ranged from 12.03±0.04mg/100g to 16.84±0.00mg/100g with the highest value found in sample C (50:20:30 formulation) and the lowest is sample B. These values were lower than the values recorded for the magnesium content of the (25.19 mg/100 g to 32.45 mg/100g) and the US RDA. Magnesium is an activator of many enzyme systems and maintains the electrical potential in the nerves (Adeyeye and Agesin, 2007; Ayo et al., 2025). It works with calcium to assist in muscle contraction, blood clotting, regulation of blood pressure, and lung functions (Swaminathan, 2003). The potassium content of the breakfast cereals ranged from 46.74 to 55.95 mg/100g. The highest value was found in the sample E (60:20:20 formulation), and sample C had the least value (46.74mg/100g) which shows that the supplemented grains probably increased the potassium content of the samples significantly (p<0.05). Higher values of potassium (70.19±6.82mg/kg) were recorded for fortified breakfast cereals (Agunbiade and Ojezele, 2010). Potassium is critical for human cardio function as it is

Table 4. Functional Properties of composite flour for innovative breakfast cereal production.

Samples	Bulk Density (g/ml)	Water Absorption (g/g)	Swelling Power (g)	Foaming Capacity (%)	Dispersibility (%)	Reconstitution Time (mins)
A	*0.87*±0.03[d]	*1.15*±0.01[c]	*4.00*±0.00[b]	*8.00*±0.00[b]	*77.00*±0.00[c]	12.00±2.83[a]
B	*0.74*±0.04[e]	*1.20*±0.00[b]	*5.00*±0.00[a]	*26.00*±0.00[d]	*73.00*±0.00[e]	15.00±2.83[c]
C	*0.71*±0.01[a]	*1.18*±0.03[e]	*4.87*±0.00[d]	*24.00*±0.00[a]	*72.00*±0.00[a]	13.00±2.83[e]
D	*0.67*±0.03[c]	*1.21*±0.00[d]	*3.78*±0.01[e]	*18.00*±0.00[c]	*74.00*±0.00[a]	15.00±2.83[d]
E	*0.77*±0.00[b]	*1.18*±0.00[a]	*4.89*±0.04[c]	*22.00*±0.00[e]	*73.00*±0.00[b]	13.00±1.41[b]

Values are means ± standard deviation of duplicate determination; Means with different superscript in the same column are significantly different at p<0.05

Key:
A = 100 % Fonio millet
B = 50 % Fonio millet 25 % soybean, 25 % Bambaranut
C = 50 % Fonio millet, 20 % soybean, 30 % Bambaranut
D = 50 % Fonio millet, 30 % soybean, 20 % Bambaranut
E = 60 % Fonio millet, 20 % soybean, 20 % Bambaranut

primarily an intercellular cation, which influences osmotic pressure and contributes to normal pH equilibrium (Adeyeye and Agesin, 2007). The Calcium content obtained from the samples ranges between 9.38 mg/100g and 12.49 mg/100g. The highest value occurred in the sample containing 100% fonio millet, while the least value occurred in the sample with 50:20:20 formulation. The result obtained was drastically lower than the findings reported by Bachar *et al*. (2013) where the calcium content of finger millet was reported to be between 84.71-567.45mg/100g among different varieties. Calcium is the most important mineral that the body requires and its deficiency is more prevalent than any other mineral (Kanu *et al.*, 2009). Calcium is crucial for bone and dental health and in combination with phosphorus and vitamin D, plays a vital role in preventing conditions such as rickets in children and osteomalacia in adults (Uday & Högler, 2020).

The manganese content of the samples ranged from 26.46 to 30.30 mg/100g. The highest value was found in sample D while sample A was the lowest. Sample A had the least zinc content of 1.09 mg/100 g and the incorporation of soybean and bambaranut blends significantly increased the zinc content up to 8.67mg/100g found in sample C with 50% supplementation. This finding is in line with the amount of zinc 6.94 – 16.67 mg/100g) found in breakfast cereal blends of cereals and legumes reported by Idris et al. (2019). Considering the above result and proximate compositions, the blends containing legumes supplements are more balanced as they contain all nutrients required for adequate nutrition and to achieve balance diet.

Functional properties

The result of the functional properties of the formulated breakfast cereals is presented in (Table 4). The bulk density of the formulated breakfast cereal ranged from 0.67 – 0.87 g/ml with the highest value found in sample A. in addition, sample A was significantly different (p<0.05) from all other samples. Low bulk density is influenced by the loose structure of the starch polymer (Olu *et al*., 2012). The bulk density values obtained in this study are slightly comparable to 0.534-0.7267g/ml reported by (Mbaeyi, 2005). The results obtained for water absorption capacity of the formulated breakfast cereals ranged from 1.15 to 1.21g/g. Water absorption capacity among the samples showed significant differences (p<0.05) with the 100 % fonio millet flour having the least water absorption capacity. The low water absorption seen in 100% fonio millet could be due to high proportion of hydrophilic group and polar amino acid on the surface of the protein molecules, and the increase may be due to the water binding properties of the flour blends. The result agreed with Culetu et al. (2021), who reported that blends with legumes have improved water absorption due to their protein content. The increased water absorption capacity (WAC) observed in this study indicates improved hydration, leading to a moist and appealing texture in the final product (Ola et al., 2020)

The swelling power of the products ranged from 4.00 to 5.00g/g. The low viscosity observed may be due to less disruption of intermolecular hydrogen bonds that brought about noticeable swelling of the granules and gelation (Ihekoronye and Ngoddy, 1985). The values for foaming capacity increased from 8.00 in sample A, to 26.00 in sample B. all samples were significantly different (p<0.05). This is as expected as protein has the ability to form foam, and the inclusion of soybean and Bambara nut has improved the protein content of the breakfast cereal. Similar observation was reported by Ejikeme, (2005). Foam is produced in a liquid when air is introduced resulting in formation of bubbles. The differences in the foaming capacity of the flours may be attributed to the different composition and nature of the protein fractions. It may also be explained on the basis of presence of globular proteins which makes denaturing of the surface difficult. The dispersibility values observed in this study ranges from 72.00- 77.00% with sample A having the highest and sample B the lowest. There were significant differences (p<0.05) among the samples. Sample A was significantly different from other three samples.

Table 5: Anti-Nutrients composition of innovative breakfast cereal.

Samples	Saponin	Alkaloid	Flavone	Tannin	Phytate
A	0.00 ± 0.00^{a}	0.00	0.06 ± 0.01^{b}	0.00	0.34 ± 0.06^{a}
B	0.03 ± 0.01^{b}	0.03 ± 0.01^{b}	0.06 ± 0.00^{b}	0.50 ± 0.14^{b}	0.32 ± 0.03^{a}
C	0.03 ± 0.28^{b}	0.00	0.00	0.00	0.40 ± 0.00^{a}
D	0.03 ± 0.00^{b}	0.20 ± 0.28^{b}	0.06 ± 0.01^{b}	0.00	0.40 ± 0.14^{a}
E	0.04 ± 0.01^{b}	0.04 ± 0.05^{b}	0.00	0.52 ± 0.03^{b}	0.30 ± 0.28^{a}

Values are means $\pm$ standard deviation of duplicate determination; Means with different superscript in the same column are significantly different at p<0.05. **Key:**
A = 100 % Fonio millet
B = 50 % Fonio millet 25 % soybean, 25 % Bambaranut
C = 50 % Fonio millet, 20 % soybean, 30 % Bambaranut
D = 50 % Fonio millet, 30 % soybean, 20 % Bambaranut
E = 60 % Fonio millet, 20 % soybean, 20 % Bambaranut.

Flour with a higher dispersibility indicate its ability to form uniform distribution in water (Kulkarni *et al.,* 1991). Generally, the dispersibility of all the flours formulations decrease as the percentage of acha flour increase indicating that acha flour did not enhance the distribution of the flours in water. The results for reconstitution time increase from sample A with a mean value of 12.00 minutes up to 15 minutes found in sample B and D. Similarly, sample C and E have the same reconstitution time of 13.00minutes. Sample B and D took the highest period to disperse in the solvent and this was as expected simply due to presence of constituents in soybean and bambaranut such as fats that are not readily soluble in water. Similar result was reported by Ejikeme (2005).

Anti-nutritional content of innovative breakfast cereal

The anti-nutritional contents of the formulated samples were presented in (Table 5). The saponin content of the formulated breakfast cereal samples were remarkably low with values ranging from 0.00 to 0.04mg/100g. There were significant (P <0.05) differences among the samples. The highest value was obtained in sample E while sample A was the least.

The result revealed that the saponin contents of the breakfast cereal decreased with increased addition of the soybean and bambaranut flour in the formulation as evident in the sample A having the least saponin value. Saponins were found to reduce the bioavailability of nutrients decrease enzyme activity and also affect protein digestibility by inhibiting various digestive enzymes including chymotrypsin and trypsin (Liener, 2003). The absent of saponin agrees with the study reported by Hamma and Mohammed (2025) in which both black and white fonio contained zero saponin value. The alkaloid contents in the formulated breakfast cereal samples were relatively low with values ranging from 0.00 to 0.20mg/100g. The values obtained showed no significant (P < 0.05) differences among the samples with the highest value observed in sample D (0.20mg/100g) and the least value in sample A (control) (0.00mg/100g). Alkaloids are considered anti-nutrients because of their action on the nervous system, disruption or inappropriately augmenting electrochemical transmission. For instance, consumption of high tropane alkaloids will cause rapid heartbeat, paralysis and in fatal case led to death. The flavone contents in the formulated breakfast cereal samples were relatively low with values ranging 0.00 to 0.06mg/100g. However, the values obtained showed no significant (p<0.05) differences. The tannins content in this study ranges from 0.00 to 0 52mg/100g. The values obtained showed no significant difference (p<0 05) among the samples. The decrease in the tannin content of the samples could be as a result of the low tannin content in wheat and soybean which are 127.8 mg/100 g and 74.78 mg/100 g respectively as reported by Kudake *et al*. (2018). The low content of tannin in the 100% Acha flour (A) is desirable. Food processing like fermentation, sprouting, decanting etc. reduces the anti-nutritional content of food thereby activating the hydrolytic enzyme (α and β amalyses) and proteolytic enzyme (Asouzu and Umerah, 2020). Furthermore, Tannins may decrease protein quality by decreasing digestibility and palatability (Osagie, 1998). The phytate content of the formulated breakfast cereal ranges from 0.30 to 0.40mg/100g. There was no significant difference (p<0.05) in the samples. The highest value of phytate was found in sample C and D. The result obtained in this study was lower than both (0.38 to 1.25mg/100g) and (8.18 to 9.90mg/100g) recorded for a breakfast cereal made from AYB, maize and defatted coconut flour (Usman, 2012) and for breakfast cereal from yellow maize, soybean and unripe banana (Edima-Nyah et al., 2020) respectively. The phytate and tannin levels observed in this study are lower than those reported by Eze et al. (2020), who found that snacks made from a blend of charamenya and sorghum flour had phytate and tannin contents ranging from 22 to 67 and 1 to 87 mg/100 g, respectively. Legume seeds are known to constitute 1-3% of phytate and are dependent on species, cultivar and germination (Sridhar and Seena, 2005). The presence of vitamin C however, counteracts the inhibitory effects of phytate for consumption (Siegenberg *et al.,* 1991). The knowledge of the phytate level in foods is necessary because high concentration can cause adverse effects on the digestibility (Nwokolo and Bragg, 1977). Okaraonye and Ikewuchi (2009) also reported that phytate

Table 6: Mean sensory scores of the formulated flour samples made from fonio millet bambaranut and soybean.

Sample	Colour	Aroma	Taste	Mouth feel	General Acceptability
A	7.30±1.56^{ab}	6.45±2.56^{a}	7.30±1.67^{b}	6.85±1.57^{b}	7.65±1.84^{b}
B	7.10±1.77^{a}	7.05±1.67^{a}	6.15±1.93^{a}	6.45±1.73^{a}	7.15±1.76^{ab}
C	7.90±1.33^{b}	7.15±1.09^{b}	6.40±1.85^{b}	6.85±1.57^{b}	6.95±2.28^{a}
D	7.25±2.00^{ab}	7.15±1.39^{b}	6.30±1.81^{a}	6.40±1.23^{a}	7.20±1.58^{ab}
E	7.00±2.15^{a}	7.15±1.23^{b}	7.10±1.12^{b}	6.90±1.17^{ab}	7.40±1.19^{b}

Values are means ± standard deviation of duplicate determination; Means with different superscript in the same column are significantly different at p<0.05. **Key:**
A = 100 % Fonio millet
B = 50 % Fonio millet 25 % soybean, 25 % Bambaranut
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D = 50 % Fonio millet, 30 % soybean, 20 % Bambaranut
E = 60 % Fonio millet, 20 % soybean, 20 % Bambaranut.

forms stable complexes with Cu2+, Zn^{2+}, Co^{2+}, Mn^{2+} , Fe^{2+}.

Sensory eqvaluation

The mean sensory attributes of the samples were presented in (Table 6). The parameters evaluated include colour, aroma, taste, mouth feel and general acceptability of the formulated samples. The scores for colour ranged from 7.00 (sample E) to 7.90(sample C).There was significant (p<0.05) differences between the samples and the control (sample A) Except for sample D. sample C ranked the highest followed by sample D. hence, the panelist preferred the colour of sample C. The result was as expected because, the inclusion of soybean and bambaranut modified the colour or appearance of fonio millet as it has reported by Desai *et al.* (2010).

The aroma of samples C, D, and E was most preferred by the panelist. There was no significant difference at (p>0.05) among the aforementioned samples, but they differ from sample A and B. This improvement could probably be due to the flavor impacted by the toasted soybean. The taste score of the formulated breakfast cereal ranged from 6.15 of sample B to 7.30 of sample A. which was highly rated and preferred compared to other formulated Samples. The finding disagrees with Babarinde et al. (2020), who stated legume additions enrich taste qualities in breakfast blends. There was significant (p<0.05) difference among the samples. Interestingly, the level of supplementation improved the taste of the breakfast cereal as for previous literature. The mouthfeel of the formulated breakfast cereal ranged from 6.40 to 6.90. There were significant (p<0.05) differences with that of the control (sample A). Sample E was highly rated and preferred relative to other samples. Mouth feel is the prevailing textural characteristics of the product at the point of consumption that usually determine whether food product could be swallowed or chewed (Edet *et al.,* 2017). The result obtained in this study is in agreement with the findings of Chukwu and Abdul-kadir (2008) as well as Mbaeyi-Nwaoha and Uchendu (2016). The mean score for the general acceptability of the formulated breakfast cereals ranged from 6.95 (sample C) to 7.65 (sample A). There was general decreased in the overall acceptability of the breakfast cereal with a decreased in acha flour, and increase in soybean and bambaranut flour. This is similar to the findings of Agu *et al.* (2014) who reported that the overall acceptability of biscuit produced from acha flour, Bambaranut flour and unripe plantain flour decreases with the decrease in acha and increases with the increase in soybean and Bambaranut flour. Sample A has the highest mean score (7.65) and most acceptable to the panelist. However, there was significantly (p>0.05) differences among the samples. Generally, sample A (100%) fonio millet (acha) had the highest mean score in general acceptability, which indicates that the sample (A) was selected as the best blend for further substitution with soybean and bambaranut flour blends.

Conclusion

The inclusion of various proportions of bambaranut and soybean flour to acha flour in breakfast cereal formulation significantly influence the proximate composition, functional, minerals, and sensory properties of the formulated samples.There is improvement in the proximate composition of fonio millet-based breakfast cereals through supplementation with soybean and bambaranut as it offers higher percentages of protein, fats, and ash with a corresponding increase in the mineral content especially in magnesium zinc, sodium and potassium while anti nutrient composition decreased as seen in flavone, tannin and phytate. Functional properties also improved in terms of swelling power, water absorption capacities, reconstitution time and foaming capacity, while the bulk density and dispersibility affected negatively. The production of fonio millet breakfast cereal flours, blended in the ratio 100:00 formulation of fonio millet and 60:20:20 of fonio millet to (soybean, and bambaranut) should be adopted for use on a large scale as it performed the best among others in terms of nutritional, functional and sensory quality attributes, thereby helping the society in hunger reduction and improve nutrition. Further research should focus on the improvement of functional properties of food products involving the inclusion of legumes most especially bulk density and water retention capacity to improve yield and minimize expenditure while improving diversification and nutritional status.

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