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Chemical Composition of Flour Blend Biscuits Produced from Acha, Malted Pigeon Pea and Peanut Paste

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Abstract

This study investigated the chemical composition of biscuits formulated from acha (Digitariaexilis), malted pigeon pea (Cajanus cajan), and peanut paste as a functional substitute for conventional baking fat. Eight formulations (Samples A–H) were produced with progressive substitution of peanut paste (0–30%) and analyzed for proximate composition, vitamins, phytochemicals, minerals, antinutrients, and in vitro digestibility.Proximate analysis revealed significant (p ≤ 0.05) improvements in protein (12.13–20.02%), fat (6.36–8.72%), fiber (0.64–1.10%), and ash (6.68–9.79%) with corresponding reductions in carbohydrate (69.25–53.89%). Vitamin assays showed enrichment of vitamin E (0.39–4.94 μg/100 g) and riboflavin (0.25–0.70 mg/100 g), though vitamin B12 was undetected. Phytochemical content increased markedly, with carotenoids, total phenolics, and flavonoids reaching 80.35 μg/100 g, 60.37 mg/100 g, and 37.69 mg/100 g, respectively, in the most enriched formulation. Mineral composition also improved significantly, with magnesium, potassium, calcium, sodium, and zinc levels rising to 178.43, 665.24, 364.91, 94.22, and 10.16 mg/100 g, respectively. Antinutrient concentrations (cyanide, phytates, tannins) increased but remained below established safety thresholds. Importantly, in vitro protein and starch digestibility were significantly enhanced, peaking at 83.72% and 82.97% in biscuits containing 30% peanut paste.The findings demonstrate that acha–pigeon pea–peanut paste composite biscuits represent a nutritionally superior alternative to conventional formulations. By combining local, underutilized crops, these biscuits provide enhanced protein quality, micronutrient density, and bioactive compounds, offering a functional food with strong potential for addressing protein-energy malnutrition and micronutrient deficiencies in resource-limited settings.

Keywords: *Acha flour, Mated pigeon pea, Peanut paste, Composite biscuits.*

1.0 INTRODUCTION

The increasing interest of consumers in functional foods and gluten-free products has encouraged the inclusion of novel plant food materials in food product development. Biscuits can serve as a good vehicle to dispense essential nutrients and health-promoting compounds; in addition to the fact that such snacks are affordable, convenient, and generally accepted by the populace Gluten-free biscuits can be prepared from bioprocessed whole grain cereals or a combination of cereals and legumes that may improve the nutritional and health-promoting characteristics as well as consumer acceptability of the These biscuits typically offer a range of nutritional advantages. (13) Whole grains and legumes contribute valuable nutrients such as dietary fiber, which supports digestive health, and essential minerals like iron, magnesium, and zinc, which play crucial roles in various bodily functions(5).

Biscuit is a baked product primarily made from wheat flour, fat, sugar, and other ingredients, often enriched with various flours such as acha and sweet potato to improve nutritional value (7).They are small, typically flat baked goods made from flour, sugar, and fat, with potential for fortification using non-conventional legumes to boost nutritional value (6). It is a processed snack made from composite flours, including blends like maize-soybean, which offer improved protein and micronutrient profiles (12). Biscuits are crispy or chewy baked goods made from a mixture of flour, sugar, and fat, sometimes including marinated meat flavors for added taste and nutritional benefits (25). It is also a popular snack made from dough composed of flour, sugar, fat, and water, often enhanced with ingredients like grasshopper flour to increase protein content (16).

Acha (*Digitariaexilis*) is a nutrient-rich cereal grain indigenous to Nigeria, valued for its high protein content and adaptability to various agroecological zones(9). Acha, also known as hungry rice, is a drought-tolerant cereal grain grown in Nigeria for its nutritional benefits, including protein and essential amino acids(8). It is a traditional cereal grain in Nigeria, valued for its resilience to harsh environmental conditions and nutritional attributes (15). Acha is an important cereal grain in Nigeria, known for its high protein content, dietary fiber, and essential minerals(15). It is also a nutritious cereal grain grown in Nigeria, contributing to food security and providing essential nutrients like protein and iron, (13) Acha is a gluten-free cereal grain, rich in essential amino acids and minerals, supporting dietary diversity and health in Nigeria. As reported by (26).Acha is a valuable cereal grain in Nigeria, rich in protein and dietary fiber, suitable for enhancing food security and nutrition. Acha, an indigenous cereal grain in Nigeria, is known for its nutritional qualities and cultural significance in local diets; specifically, acha contains approximately 8-10% protein, 3.5-4% fat, 75-80% carbohydrates, 2-3% dietary fiber, 2.5-3% ash, 1.2-1.5% iron, 0.6-0.8% calcium, 0.15-0.25% phosphorus, and 0.1-0.2% thiamine (7).

Pigeon pea, commonly known as *Cajanuscajan*, is are leguminous crop rich in protein and essential amino acids, important for human nutrition and food security (5). It is drought-tolerant legumes cultivated widely in Nigeria for their nutritional value, including high protein content and amino acids According to (5), pigeon beans are a traditional cereal grain in Nigeria, valued for their resilience to harsh environmental conditions and nutritional attributes.It is an important cereal grain in Nigeria, known for its high protein content, dietary fiber, and essential minerals (12).

According to (3) it is observed that pigeon bean is economically and nutritionally an important legume and is a major source of protein for the poor communities of many tropical and subtropical regions of the world. The nutritional composition includes protein (21.7 g per 100 g), dietary fiber (15 g per 100 g), iron (5 mg per 100 g), calcium (130 mg per 100 g), potassium (1,392 mg per 100 g), and folate (456 µg per 100 g)

Malting involves the sprouting (germination) of grain in moist air, under controlled environmental conditions. The malt is generally dried to produce a shelf-stable product. Malting helps to decrease the levels of phytic acid, tannins, and cyanide, which can interfere with mineral absorption. This makes the nutrients in malted pigeon beans more bioavailable. The germination process breaks down complex carbohydrates, making malted pigeon beans easier to digest (6).

Peanuts (*Arachishypogaea L.*) are an essential legume crop in different regions of the world (22). All over the world, it is consumed in the form of nuts, oil, peanut butter, and peanut paste, among other preparations (30). In addition to being an important source of essential micronutrients,

Substituting peanut paste for baking fat could increase the nutritional value of the biscuits made with malted pigeon pea and acha flour blend. This could be particularly beneficial in regions where malnutrition is a concern. Peanut paste may contribute to the dough's structure and texture, potentially improving the overall quality of the baked goods. It might enhance factors like crispness, crumbliness, and mouth feel. Peanuts are generally less expensive than other baking fats like butter or margarine. This substitution could lead to a more affordable biscuit option for consumers. The aim of the research work is to determine the chemical composition of biscuits produced from acha, malted pigeon pea,and peanut paste.

2.0 MATERIAL AND METHODS

2.1 Material Collection

The material used in this study includes Acha grain (*Digitariaexilis*), Peanut (*Arachishypogaea L.*), wheat flour, baking powder (double-acting), salt (palm salt), baking fats, sugar (Dangote), water (portable water), and Pigeon pea (*Cajanuscajan*) were purchased in Wukari New Market, Wukari Local Government Area, Taraba State.

2.2 Sample Preparation

2.2.1 Preparation of Acha Flour

Acha flour was prepared according to the procedure in Figure 1. Cream coloredachawas washed with portable water to separate the stones and then dried in the cabinet at 50 °C for 6hours. The resultant dried acha was milled into flour using theattrition mill with a 0.2mm screen size. This method was carried out as described by (11)

2.2.2 Preparation of Peanut Paste

The peanut paste was prepared according to (32).The purchased peanuts were graded and sorted to remove damaged nuts and dirt. 1000g of the sorted peanuts were soaked with 52g of salt for 20minutes. Water was added to cover the peanuts, and the soaked peanuts were dewatered andspread out on a tray to dry. Fine sand was heated in a pan over a burning fire, and the peanuts were added, left to roast for 10minutes with continuous stirring. After roasting, the skin of the peanuts changed from bright red to dull red, and the peanuts from white to light brown. The roasted peanuts were spread on a tray to cool in order to stop the cooking process. The skins on the cooled peanuts were removed by rubbing the roasted peanuts between the two palms,and discolored and spoiled nuts were removed. Cleaned peanuts were subjected to grinding in a roller mill, and the peanut paste was packaged in an airtight glass container and stored at ambient temperature.

2.2.3 Preparation of Malted Pigeon Beans

The pigeon peas were sorted and washed. The peaswere then steeped in water at 29°C for 24 hours. The water was changed at a 6-hour interval during steeping. The resultant steeped peaswere spread on a jute bag and covered with white cotton cloth to germinate for 72 hours. The sprouted seeds were oven dried at a temperature of 50°C for 1 hour, and thereafter, the plumuleswere separated from the seed, and the malted seeds were dried and milled into flour.

2.2.5 Production of Biscuit

The Ingredients used for this biscuit production were flour (200g), sugar (60 g), baking powder (1.5g), salt (1.5g), water (15ml), while 80g of margarine was added to the mixture..Biscuits were prepared according to the method of (20). with some modifications in the recipe. The dry ingredients (flour, sugar, salt, and baking powder, fat etc,) were carefully mixed in a bowl by hand for 3 minutes, and water was added to the mixture and kneaded. The batter was rolled and cut with a biscuit cutter. The cut dough was placed on oil oil-greased baking tray, leaving 25mm space in between, and was baked at 180 ˚C for 25 minutes in the baking oven. After baking, the biscuits were allowed to cool at ambient temperature.

Table 1: Experimental Design for Biscuit Formulation

Sample	A	B	C	D	E	F	G	H
Wheat flour (%)	100	-	-	-	-	-	-	-
Acha/ Malted Pigeon Pea (%)	-	100	100	100	100	100	100	100
Baking fat (%)	30	30	25	20	15	10	5	-
Peanut paste (%)	-	-	5	10	15	20	25	30

KEY;

Sample A = 100% whole wheat Flour, (Control) 30% Baking Fat

Sample B = 100% Acha-malted pigeon pea, 30% Baking Fat, 0% peanut paste

Sample C = 100% Acha-malted pigeon pea, 25% Baking Fat, 5% Peanut Paste
Sample D = 100% Acha-malted pigeon pea, 20% Baking Fat, 10% Peanut Paste
Sample E = 100% Acha-malted pigeon pea, 15% Baking Fat, 15% Peanut Paste
Sample F = 100% Acha-malted pigeon pea, 10% Baking Fat, 20% Peanut Paste
Sample G = 100% Acha-malted pigeon pea, 5% Baking Fat, 25% Peanut Paste
Sample H = 100% Acha-malted pigeon pea, 0% Baking Fat, 30% Peanut Paste
100% Acha-malted pigeon pea =15% malted pigeon pea + 85% acha (preliminary work)

2.3 Determination of Chemical Composition of Biscuit Sample

2.3.1 Proximate Composition analysis

The moisture, ash, protein, fat, fiber, and carbohydrate composition of the food samples were determined in triplicate using the(8) method.

2.4 Micronutrients Analysis of Biscuit Sample

2.4.1 Determination of minerals

2.4.1.1 Calcium

Calcium was determined by the titrimetric method after precipitation as calcium oxalate, as outlined by (16). About 5 mL.ofthe samples will be mixed with 1 mL of ammonium oxalate solution. pH was adjusted to 8 using ammonium hydroxide solution and adjusted again to 5 using dilute acetic acid.

$$\text{Calcium} = \frac{A_s \times C_{ss} \times D_f \times 100}{A_{ss} \times S_v} \quad \text{.......... (6)}$$

Where A_s, is the absorbance of thesample, C_{ss} is the concentration of thestandard solution, $D_f$is the Dilution factor, A_{ss} is the absorbance of the standard solution, and S_v, is thesample volume.

2.4.1.2 Magnesium

Colourimetric method was used to determine magnesium content as outlined by (27)., About 1 mL of magnesium buffer and 2.5 mL of eriochrome blue black tea wereadded to 5 mL of thesample. This was allowed to stand for 10 minutes. Absorbance was taken at 520 nm using a colorimeter. Magnesium was calculated using anequation.

$$\text{Magnesium} = \frac{A_s \times C_{ss} \times D_f \times 100}{A_{ss} \times S_v} \quad \text{..........(7)}$$

Where A_s, is the absorbance of thesample, $C_{ss}$is the concentration of thestandard solution, $D_f$is the Dilution factor, A_{ss} is absorbance of thestandard solution, and S_v, is the sample volume.

2.4.1.3 Potassium

Potassium stock solution and standard dilute potassium solution were prepared with the method for sodium solution as outlined by (23). A calibration graph was prepared from the readings obtained. About 2ml of thesample was mixed with 2Mlof sodium cobaltonitrate and allowed to stand for 45 minutes. About 2 Ml of water was added to the mixture and centrifuged for 15 minutes. The supernatant was obtained and mixed with 2 ml of 99% ethanol. The mixture was centrifuged for 5 minutes, and the supernatant was boiled in a water bath for 10 minutes. About 1 ml of 1% chlorine hydrochloride, 1 ml potassium fericyanide, and 2 ml of distilled water were used for the extract. Absorbance was determined at 620nm using a colorimeter. The sample solution was read,and the potassium, content was calculated using the equation below:

$$\text{Potassium} = \frac{A_s \times C_{ss} \times D_f \times 100}{A_{ss} \times S_v} \quad \text{..........(8)}$$

Where A_s, is absorbance of sample, C_{ss} is concentration of standard solution, $D_f$is Dilution factor, A_{ss} is absorbance of standard solution and S_v, is sample volume.

2.4.1.4Sodium

The colorimeter method was determined by (16). Sodium stock solution was prepared by dissolving 1.271 g of sodium chloride in water and diluting it with 1000 ml and a standard dilute sodium solution was prepared by diluting 10 ml stock solution to 500 ml with water and was kept aside. A calibration graph was prepared from the readings obtained. About 5 ml of sample was mixed with 5 ml of uranyl acetate, shaken and allowed to stand for 5 minutes.

$$\textit{Sodium} = \frac{A_s \times C_{ss} \times D_f \times 100}{A_{ss} \times S_v} \quad \text{.......... (8)}$$

Where A_s, is the absorbance of thesample, C_{ss} is theconcentration of thestandard solution, $D_f$isthe Dilution factor, A_{ss} is theabsorbance of thestandard solution, and S_v, is sample volume.

2.5 Determination of Vitamins Composition of Biscuit Sample

Vitamin B2, E, and B12 were analyzed from the food formulation by the method described by (30) This was performed at the optimum separation condition. High Performance Liquid Chromatography (HPLC) at the optimum separation conditionconsisting of methanol: water (65:35 v/v) with flow rate of Iml.min-1. The pH was measured using pH meter combined with a glass electrode. A 320k Hettich centrifuge and a digital 10P ultrasonic bath was used. A calibration curve was prepared for each vitamin and the correlation coefficient based on the concentration curve obtained.

2.6 Determination of Phytochemicals

2.6.1 Carotenoids content

Carotenoids content was determined according to the method described by (21) A measured weight of thesample was homogenized in methanol using a laboratory blender. A 1:10 (196) mixture was used. The homogenate was filtered to obtain the initial crude extract, 20 ml of ether was added to the filtrate and mixed well, and then treated with 20 ml of distilled water in a separating funnel. The ether layer was recovered and evaporated to dryness at low temperature (35-50°C) in a vacuum desiccator. The dry extract was then saponified with 20 ml of ethanoic potassium hydroxide and left over in a dark cupboard. The next day, the carotenoid was taken up in 20 ml of ether and waswashed with two portions of 29 ml ofdistilled water.

The carotenoid extract (ether layer) was dried in a desiccator and then weighed with light petroleum (petroleum spirit) and allowed to stand overnight in a freezer (- 10°C). The precipitated steroid was removed by centrifugation after 12 h, and the carotenoid extract was evaporated to dryness in a weighed evaporation dish, cooled in a desiccator, and weighed. The weight of carotenoid was determined and expressed as a percentage of the sample weight.

$$\text{Carotenoids content} = \frac{\textit{weight of sample} \times 100}{\textit{Weight of sample taken}} \quad \ldots\ldots\ldots\ldots (10)$$

2.6.2 Total phenolic content (TPC)

Total polyphenols were determined following the Folin-Ciocalteu's method using gallic acid standard as described by (18). Folin-Ciocalteu's reagent (12.5 µl), along with 7% sodium carbonate (125 µl),was added to the samples. Samples werethen incubated for 90 min at room temperature. The absorbance was measured at 750 nm using a microplate reader (Synergy HT, BioTek Instruments, and Winooski, VT, USA).

2.6.3 Determination of flavonoids content

The flavonoid content was determined as described by (20). 10g of flour sample was extracted respectively with 100 ml of 80% aqueous methanol at room temperature (30+20°C). The mixture was then filtered through a Whatman No. 42 grade filter paper into a weighed 250 ml beaker. The filtrate was transferred into a water bath, evaporated to dryness and weighed. The percentage of flavonoid was calculated as:

$$\textit{\% flavonoids content} = \frac{\textit{weight of sample} \times 100}{\textit{Weight of sample taken}} \quad \ldots\ldots\ldots\ldots (11)$$

2.7 Statistical Analysis

All the analyses were carried out in duplicate. Data obtained was subjected to Analysis of Variance (ANOVA); differences between means were evaluated using Tukey's multiple comparison tests with a-95% confidence level. The statistical package in Minitab software version 16 was used. Means-were separated with Duncan Multiple Range Test (DMRT) at 95% confidence level (p=0.05).

3.0 Results and Discussion

3.1Proximate Composition of Raw Materials

The proximate composition of the raw materials used for biscuit production, namely unmalted acha, pigeon pea, and peanut paste isshown in Table 2. The protein, fat, fiber and ash contents increased from 6.80 – 27.50%, 1.20 – 48.20%, 1.30 – 2.60%, and 2.20 – 3.00%, respectively, while the moisture, carbohydrate, and energy values decreased from 10.40 – 5.60%, 79.40 – 13.70% and 567.20 – 352.80 kcal/100 g, respectively. The proximate composition of the three raw materials,unmaltedacha, pigeon pea, and peanut paste, revealed marked nutritional differences that highlight their complementary roles in food formulations. Acha, being a cereal, was characterized by a high carbohydrate content (79.40%), moderate energy value (367.20 kcal/100 g), and low protein (6.80 %). This confirms its primary role as an energy-yielding food with limited protein contribution, a trend consistent with earlier reports on cereals. In contrast, pigeon pea, a legume, contained higher protein (19.02%) and ash (3.00%), with lower fat (1.20 %) and carbohydrate (64.48 %).

The elevated protein level supports its use as a plant-based protein fortifier, while its higher ash content indicates a richer mineral profile compared to acha.

Peanut paste showed the most distinct profile, being exceptionally rich in fat (48.20 %) and protein (27.50 %), with the lowest carbohydrate content (13.70 %). Its energy value (567.20 kcal/100 g) was substantially higher than thatof acha and pigeon pea, reflecting the caloric contribution of its fat content. The relatively high - fibervalue (2.60 %) in peanut paste, compared with acha (1.30 ± 0.01%) and pigeon pea (1.90 %), also suggests its potential role in promoting gastrointestinal health. Moisture levels varied, with pigeon pea recording the highest (10.40 %) and peanut paste the lowest (5.60 %), implying that pigeon pea may be more prone to microbial spoilage if not properly stored, whereas peanut paste would have greater shelf stability.

Table 2: Proximate Composition of Raw Materials

Component (%)	Unmalted Acha	Pigeon Pea	Peanut Paste
Protein	6.80 ± 0.02	19.02 ± 0.03	27.50 ± 0.02
Fat	2.10 ± 0.01	1.20 ± 0.01	48.20 ± 0.03
Fiber	1.30 ± 0.01	1.90 ± 0.01	2.60 ± 0.01
Ash	2.20 ± 0.01	3.00 ± 0.02	2.40 ± 0.01
Moisture	8.20 ± 0.02	10.40 ± 0.02	5.60 ± 0.02
Carbohydrate	79.40 ± 0.03	64.48 ± 0.04	13.70 ± 0.01
Energy (kcal/100 g)	367.20 ± 0.01	352.80 ± 0.02	567.20 ± 0.02

The proximate composition of unmalted acha, pigeon pea, and peanut paste revealed marked nutritional differences that highlight their complementary potential in composite food products. Acha was characterized by a very high carbohydrate content (79.40%) with relatively low protein (6.80%) and fat (2.10%), which reflects its primary role as an energy-rich cereal. This observation is consistent with the report of (14).Who described fonio (acha) as a gluten-free cereal with high starch and energy but limited protein quality.

Pigeon pea, on the other hand, contained considerably higher protein (19.02%) and ash (3.00%) than acha, while its fat content remained low (1.20%). This suggests its value as a protein and mineral fortifier in cereal-based formulations. (25)Similarly reported that blending fonio with pigeon pea significantly improved the protein and mineral profile of the composite flour, thereby enhancing its nutritional adequacy. The high ash content observed here indicates a richer mineral contribution, supporting its potential role in combating mineral deficiencies in cereal-based diets.

Peanut paste was distinct, with exceptionally high fat (48.20%) and protein (27.50%) contents, coupled with the highest energy value (567.20 kcal/100 g). These values align with the findings of 27) who reported fat levels of 40–50% in peanut flour and emphasized its use in energy-dense food formulations. The higher protein content of peanut paste also makes it an effective supplement for enhancing protein density in cereal–legume blends. However, its high fat content poses storage challenges, as lipid oxidation could compromise quality and shelf life (10)

Moisture values varied across the samples, with pigeon pea showing the highest (10.40%) and peanut paste the lowest (5.60%). Higher moisture in pigeon pea suggests greater susceptibility to microbial spoilage if not adequately processed and stored, while the lower moisture of peanut paste supports better microbial stability but increases the risk of rancidity during storage (26).

Fiber values were modest across the samples (1.30–2.60%), with peanut paste contributing slightly more, which may provide dietary benefits such as improved gastrointestinal function.

3.2 Chemical composition of biscuits produced from acha, malted pigeon pea, and peanut paste

3.2.1 Proximate composition of biscuits produced from acha, malted pigeon pea, and peanut paste

The proximate composition of the biscuit produced from acha-malted pigeon pea, baking fat and peanut paste are shown in Table 3 The protein, fat, fiber and ash content increased from 15,80- 20.20, 6.86 – 7.72, 0.95 – 1.10, and 7.79 – 9.79%, respectively, while the moisture carbohydrate and energy content decreased from 5.37 - 5.12, 63.30-53.81% and 378.4 -374.12 cal/g, with increase in the added peanut paste(0 - 30%). The nutritional makeup of the biscuit samples showed significant ($p \leq 0.05$) differences across formulations, with clear trends in macronutrients. Protein content increased steadily from Sample A (12.13%) to Sample H (20.02%). This indicates a growing use of protein-rich ingredients, with Sample H providing the highest amount and potential benefits for those focused on protein intake. In contrast, carbohydrate content decreased from 69.25% in Sample A to 53.89% in Sample H. This suggests that the rising amounts of protein, fat, and fiber caused adecrease in the carbohydrate levels in later samples. Fat content also increased from 6.36% in Sample A to 8.72% in Sample H. This increase may improve flavor, texture, and energy density. Fiber content increased from 0.64% to 1.10%, which may enhance digestive health benefits in the higher-fiber samples. Ash content, which represents total mineral presence, increased from 6.68% to 9.79%. Moisture content varied slightly, peaking in Sample E (6.23%) and showing lower values in Samples A and H. This variation may affect shelf life and texture. Energy values ranged from 374.12 to 388.00 kcal/100 g, with the highest energy found in Sample E, likely due to its combined higher fat and carbohydrate levels. Overall, these results indicate that the later samples, especially F to H, had improved nutrition in terms of protein, fat, fiber, and minerals, while earlier samples like A were richer in carbohydrates (26).

Table 3: Proximate composition of biscuits produced from acha, malted pigeon pea and peanut paste

Component/ Sample	A	B	C	D	E	F	G	H
Protein (%)	12.13 ± 0.01^{h}	15.80 ± 0.03^{f}	14.34 ± 0.01^{g}	16.12 ± 0.02^{e}	17.32 ± 0.03^{d}	18.88 ± 0.01^{c}	19.22 ± 0.03^{b}	20.02 ± 0.03^{a}
Fat (%)	6.36 ± 0.03^{h}	6.86 ± 0.00^{f}	6.78 ± 0.02^{g}	7.22 ± 0.03^{e}	7.92 ± 0.02^{d}	8.18 ± 0.01^{c}	8.47 ± 0.03^{b}	8.72 ± 0.03^{a}
Fibre(%)	0.64 ± 0.02^{f}	0.95 ± 0.02^{cd}	0.86 ± 0.02^{e}	0.90 ± 0.02d^{e}	0.93 ± 0.02^{cd}	0.98 ± 0.01^{c}	1.04 ± 0.01^{b}	1.10 ± 0.02^{a}
Ash (%)	6.68 ± 0.03^{g}	7.79 ± 0.02^{d}	7.38 ± 0.02^{f}	7.57 ± 0.02^{e}	7.77 ± 0.02^{d}	8.91 ± 0.03^{c}	9.34 ± 0.02^{b}	9.79 ± 0.02^{a}
Moisture (%)	5.04 ± 0.03^{g}	5.37 ± 0.02^{e}	5.97 ± 0.02^{c}	6.11 ± 0.02^{b}	6.23 ± 0.02^{a}	5.50 ± 0.02^{d}	5.31 ± 0.02^{e}	5.12 ± 0.02^{f}
Carbohydrate (%)	69.25 ± 0.04a	63.30 ± 0.02^{c}	64.54 ± 0.03^{b}	63.20 ± 0.02^{d}	61.86 ± 0.03^{e}	58.61 ± 0.03^{f}	56.24 ± 0.03^{g}	53.89 ± 0.03^{f}
Energy (kcal/100 g)	382.76	378.14	376.54	382.26	388.00	383.58	378.07	374.12

KEY:
Sample A = 100% Whole wheat Flour, 30% Baking Fat
Sample B = 100% Acha-malted pigeon pea, 30% Baking Fat, 0 % peanut paste
Sample C = 100% Acha-malted pigeon pea, 25% Baking Fat, 5% Peanut Paste
Sample D = 100% Acha-malted pigeon pea, 20% Baking Fat, 10% Peanut Paste
Sample E = 100% Acha-malted pigeon pea, 15% Baking Fat, 15% Peanut Paste
Sample F = 100% Acha-malted pigeon pea, 10% Baking Fat, 20% Peanut Paste
Sample G = 100% Acha-malted pigeon pea, 5% Baking Fat, 25% Peanut Paste
Sample H = 100% Acha-malted pigeon pea, 0% Baking Fat, 30% Peanut Paste
100% Acha-malted pigeon pea =15% malted pigeon pea + 85% acha (preliminary work)

Protein content rose steadily from 12.13% in Sample A to 20.02% in Sample H, while carbohydrate decreased from 69.25% to 53.89%. This inverse relationship is expected when a protein-rich, oil-bearing ingredient such as peanut paste progressively replaces conventional baking fat and when the proportion of legume flour rises. Peanuts typically contain approximately 25–36% protein and 47–53% oil, so increasing their share boosts protein (and fat) while diluting starch, thereby lowering calculated carbohydrate (16). Similar protein increase and carbohydrate reductions have been consistently reported when biscuits or cookies are fortified with legumes, nut flours, or seed-derived ingredients, including chickpea, pigeon pea, and groundnut composites (13). This nutrient trade-off is also in line with findings that legume-based enrichment often enhances protein quality indices while slightly lowering available carbohydrate fractions in baked goods (1)

The fat increased from 6.36% in Sample A to 8.72% in Sample H agreed with higher peanut paste levels, given its high oil content. This trend is consistent with other studies showing an increase in lipid content when nut or legume fractions are added, as well as fat-mimicking fruit or seed purees, replacing part of the shortening in biscuit formulations (24). Despite higher fat levels, metabolizable energy values remained within a narrow band of 374–388 kcal/100 g. This stability reflects compensatory decreases in carbohydrate content and modest increases in fiber and minerals patterns also observed in other composite biscuits where macronutrient trade-offs maintain energy density within a narrow range (29). These findings suggest that strategic fat,carbohydrate substitution can enhance nutritional quality without substantially altering caloric value.

Fiber content increased from 0.64% to 1.10% and ash from 6.68% to 9.79% across the formulations. The addition of malted pigeon pea flour and the presence of peanut cell-wall material are key contributors to these increases, as legumes are rich in both dietary fiber and minerals. This is in agreement with reports that germination or malting of pigeon pea increases total ash, improves mineral bioavailability, and enhances functional properties suitable for bakery applications (9).Acha (fonio) is also naturally mineral-dense for certain elements and widely used in gluten-free bakery products; blending with legume flours has been shown to increase ash content and improve protein quality compared to cereal only (2).These results suggest that the observed ash and fiber gains are a predictable outcome of the composite flour approach, which leverages the complementary nutrient strengths of legumes and ancient grains.

Moisture content ranged from 5.04% to 6.23%, peaking at Sample E. Even small moisture variations (~1%) can significantly influence crispness and shelf life in low moisture baked goods because water activity directly impacts texture softening, microbial stability, and lipid oxidation rates (18). Higher fat in later samples raises the parallel risk of lipid oxidation, which can be accelerated by oxygen exposure during storage. Studies have shown that packaging with stronger oxygen and water-vapor barriers, such as metallized films, significantly slows peroxide and hexanal formation and limits moisture gain compared with low-density polyethylene (LDPE) or polypropylene (PP) alone (19). Therefore, Samples F–H, while nutritionally superior due to higher protein, fiber, and ash, would particularly benefit from high-barrier laminate packaging to maintain storability and preserve sensory quality under tropical ambient conditions.

The progression from Sample A to H reflects the classic legume/nut enrichment signature in biscuits: increased protein, minerals, fiber, and fat, with a compensatory decline in carbohydrate, and only minor shifts in energy density. From a product development perspective, Samples F–H present the most attractive nutrient profile for protein-forward marketing claims, while Sample E delivers the peak energy value. For optimal shelf stability, particularly in warm and humid climates, pairing higher-fat formulations with metallized oriented polypropylene (OPP) or vacuum-metalized polyethylene terephthalate (VM-PET) laminates and maintaining moisture content below 6% is advisable to mitigate texture loss and rancidity (32)

3.3 Vitamin composition of biscuits produced from acha, malted pigeon pea and peanut paste

The vitamin composition of the biscuit produced from acha-malted pigeon pea, baking fat, and peanut paste is shown in Table 4. The vitamin E content increased from 0.39 – 4.94 µg/100 g, while vitamin B2 increased from 0.25 – 0.70 mg/100 g with an increase in the added peanut paste (0 – 30%). Vitamin B12 was not detected in any of the samples, indicating its absence or presence below detection limits.

Table 4: Vitamin composition of biscuits produced from acha, malted pigeon pea, and peanut paste

Sample	Vitamin E (µg/100g)	Vitamin B2 (mg/100g)	Vitamin B12 mg/100g
A	0.39 ± 0.02^{h}	0.25 ± 0.01^{f}	ND
B	2.04 ± 0.02^{g}	0.36 ± 0.02^{d}	ND
C	0.68 ± 0.01^{f}	0.29 ± 0.02^{e}	ND
D	1.18 ± 0.01^{e}	0.35 ± 0.01^{d}	ND
E	1.70 ± 0.02^{d}	0.42 ± 0.01^{c}	ND
F	4.38 ± 0.01^{c}	0.64 ± 0.01^{b}	ND
G	4.66 ± 0.01^{b}	0.67 ± 0.01^{ab}	ND
H	4.94 ± 0.01^{a}	0.70 ± 0.01^{a}	ND

Results are means ± SD. Mean results along the column with different superscript are significantly different ($p< 0.05$).
ND= Not determined

KEY:
Sample A = 100% Whole wheat Flour, 30% Baking Fat
Sample B = 100% Acha-malted pigeon pea, 30% Baking Fat, 0 % peanut paste
Sample C = 100% Acha-malted pigeon pea, 25% Baking Fat, 5% Peanut Paste
Sample D = 100% Acha-malted pigeon pea, 20% Baking Fat, 10% Peanut Paste
Sample E = 100% Acha-malted pigeon pea, 15% Baking Fat, 15% Peanut Paste
Sample F = 100% Acha-malted pigeon pea, 10% Baking Fat, 20% Peanut Paste
Sample G = 100% Acha-malted pigeon pea, 5% Baking Fat, 25% Peanut Paste
Sample H = 10 % Acha-malted pigeon pea, 0% Baking Fat, 30% Peanut Paste
100% Acha-malted pigeon pea =15% malted pigeon pea + 85% acha (preliminary work)

3.4 phytochemical composition of biscuits produced from acha, malted pigeon pea and peanut paste

The phytochemical composition of the biscuit produced from acha-malted pigeon pea, baking fat and peanut paste are shown in Table 5. The carotenoid, total phenol and flavonoid contents increased from **11.25 – 80.35 µg/100 g, 34.58 – 60.37 mg/100 g and 16.24 – 37.69 mg/100 g**, respectively, with increase in the added peanut paste (0 – 30%).

Table 5: Phytochemical Contents of Biscuit Samples

Sample	Carotenoids (µg/100g)	Total Phenol (mg/100g)	Flavonoids (mg/100g)
A	11.25 ± 0.01^{h}	34.58 ± 0.02^{h}	16.24 ± 0.01^{i}
B	45.54 ± 0.01^{d}	52.33 ± 0.01^{d}	31.67 ± 0.01^{d}
C	18.76 ± 0.02^{g}	38.26 ± 0.01^{g}	30.00 ± 0.02^{h}
D	31.30 ± 0.02^{f}	43.02 ± 0.01^{f}	30.55 ± 0.01^{f}
E	43.85 ± 0.02^{e}	47.77 ± 0.01^{e}	31.12 ± 0.02^{e}
F	69.93 ± 0.01^{c}	56.30 ± 0.02^{c}	35.23 ± 0.01^{c}
G	75.14 ± 0.01^{b}	58.33 ± 0.01^{b}	36.46 ± 0.01^{b}
H	80.35 ± 0.01^{a}	60.37 ± 0.01^{a}	37.69 ± 0.01^{a}

KEY:
Sample A = 100% Whole wheat Flour, 30% Baking Fat
Sample B = 100% Acha-malted pigeon pea, 30% Baking Fat, 0% peanut paste
Sample C = 100% Acha-malted pigeon pea, 25% Baking Fat, 5% Peanut Paste
Sample D = 100% Acha-malted pigeon pea, 20% Baking Fat, 10% Peanut Paste
Sample E = 100% Acha-malted pigeon pea, 15% Baking Fat, 15% Peanut Paste
Sample F = 100% Acha-malted pigeon pea, 10% Baking Fat, 20% Peanut Paste
Sample G = 100% Acha-malted pigeon pea, 5% Baking Fat, 25% Peanut Paste
Sample H = 100% Acha-malted pigeon pea, 0% Baking Fat, 30% Peanut Paste
100% Acha-malted pigeon pea =15% malted pigeon pea + 85% acha (preliminary work)

The results from Tables 4 and 5 show the vitamins and phytochemical profiles of the biscuit samples, which revealed marked variations attributable to the differences in formulation and ingredient composition ($p < 0.05$). Vitamin E, a fat-soluble antioxidant essential for protecting cell membranes from oxidative damage, exhibited a progressive increase from 0.39 µg/100 g in Sample A to 4.94 µg/100 g in Sample H. This significant rise in the later samples may be linked to the inclusion of plant oils, nuts, or whole grains rich in tocopherols, which have been documented as potent sources of vitamin E (28). Increased vitamin E content is particularly important because it can enhance the oxidative stability of food products and contribute to the prevention of chronic diseases associated with oxidative stress (12).

Vitamin B2 (riboflavin) levels also increased steadily from 0.25 mg/100 g in Sample A to 0.70 mg/100 g in Sample H. Riboflavin is crucial for energy metabolism and acts as a coenzyme in oxidation–reduction reactions (13). The observed increase suggests the use of riboflavin-rich ingredients such as milk powder, eggs, or certain cereals in the later formulations (30). The absence of Vitamin B12 across all samples indicates that the formulations lacked animal-derived ingredients such as meat, fish, or dairy in sufficient amounts, as B12 is predominantly found in animal products (31).

Carotenoid content, which contributes to pro-vitamin A activity and acts as a potent antioxidant, rose from 11.25 µg/100 g in Sample A to 80.35 µg/100 g in Sample H. This may be due to the incorporation of yellow/orange plant materials such as maize, carrots, or pumpkin, which are naturally rich in β-carotene (16). Increased carotenoid levels can improve eye health, immune function, and skin protection against UV damage (17).

Total phenolic content followed a similar upward trend, from 34.58 mg/100 g in Sample A to 60.37 mg/100 g in Sample H. Phenolic compounds are known for their antioxidant, anti-inflammatory, and antimicrobial activities (3). Their increase suggests the use of whole grains, legumes, or plant extracts, which are phenolic-rich and can enhance the functional quality of baked products (28).

Flavonoid content also increased markedly, from 16.24 mg/100 g in Sample A to 37.69 mg/100 g in Sample H. Flavonoids, a subgroup of polyphenols, are associated with reduced risk of cardiovascular diseases, certain cancers, and neurodegenerative disorders due to their ability to scavenge free radicals and modulate cell signalling pathways (17). The higher levels in Samples F–H further reinforce the idea that strategic ingredient selection, particularly from plant-based sources, can significantly boost the health-promoting potential of biscuits.

The results strongly suggest that the gradual changes in formulation, potentially involving the replacement of refined flours with whole grains, incorporation of legumes, and addition of plant-based bioactive-rich ingredients led to significant improvements in vitamin and phytochemical contents. These compositional enhancements not only improve the nutritional value but also contribute to the potential of such biscuit formulations as functional foods capable of providing antioxidant protection and reducing the risk of oxidative stress related disorders (22).

3.5 Mineral composition of biscuits produced from acha, malted pigeon pea, and peanut paste

The mineral composition of the biscuit produced from acha-malted pigeon pea, baking fat, and peanut paste is shown in Table 6. The magnesium, potassium, calcium, sodium, and zinc contents increased from 125.44 – 178.43 mg/100 g, 377.35 – 665.24 mg/100 g, 175.87 – 364.91 mg/100 g, 63.35 – 94.22 mg/100 g and 2.56 – 10.16 mg/100 g, respectively, with increase in the added peanut paste (0 – 30%). The mineral composition of the biscuit samples varied significantly ($p \leq 0.05$) across different formulations. There was a noticeable upward trend from Sample A to Sample H. Magnesium (Mg) levels increased from 125.44 mg/100 g in Sample A to 178.43 mg/100 g in Sample H. This suggests a gradual addition of Mg-rich ingredients like whole grains or legumes. Potassium (K) also saw a significant rise, jumping from 377.35 mg/100 g in Sample A to 665.24 mg/100 g in Sample H. This increase may improve cardiovascular health and electrolyte balance in the latter samples. Calcium (Ca) content improved as well, increasing from 175.87 mg/100 g in Sample A to 364.91 mg/100 g in Sample H. This change indicates better potential for bone health.

Sodium (Na) levels grew moderately, increasing from 63.35 mg/100 g to 94.22 mg/100 g, which remains within acceptable limits for most baked goods. Zinc (Zn) content surged more than fourfold, rising from 2.56 mg/100 g in Sample A to 10.16 mg/100 g in Sample H, which may enhance immune and metabolic health. Samples F to H, marked with superscript "a" or "b," were the most mineral-rich. In contrast, Sample A, marked with superscript "h," consistently had the lowest mineral values across all parameters. This pattern suggests that changes in ingredient formulation, likely including mineral-rich flours, seeds, or fortificants, significantly improved the nutritional quality of the later samples, making them more beneficial in terms of micronutrients.

Table 6: Mineral Composition of Biscuit Samples (mg/100g)

Sample	Mg	K	Ca	Na	Zn
A	125.44 ± 0.02^{h}	377.35 ± 0.01^{h}	175.87 ± 0.02^{h}	63.35 ± 0.01^{g}	2.56 ± 0.01^{h}
B	151.57 ± 0.01^{e}	575.89 ± 0.02^{d}	235.23 ± 0.01^{e}	87.34 ± 0.01^{d}	4.67 ± 0.01^{e}
C	137.46 ± 0.01^{g}	494.33 ± 0.01^{g}	180.03 ± 0.01^{g}	76.78 ± 0.01^{f}	3.19 ± 0.02^{g}
D	144.74 ± 0.02^{f}	529.27 ± 0.02^{f}	221.11 ± 0.02^{f}	82.06 ± 0.01^{e}	3.97 ± 0.01^{f}
E	152.01 ± 0.01^{d}	564.19 ± 0.01^{e}	262.17 ± 0.01^{d}	87.34 ± 0.01^{d}	4.76 ± 0.01^{d}
F	167.59 ± 0.02^{c}	615.16 ± 0.01^{c}	325.35 ± 0.01^{c}	89.64 ± 0.02^{c}	8.36 ± 0.01^{c}
G	173.01 ± 0.01^{b}	640.19 ± 0.01^{b}	345.13 ± 0.01^{b}	91.92 ± 0.01^{b}	9.27 ± 0.02^{b}
H	178.43 ± 0.01^{a}	665.24 ± 0.02^{a}	364.91 ± 0.01^{a}	94.22 ± 0.02^{a}	10.16 ± 0.01^{a}

KEY:
Sample A = 100% Whole wheat Flour, 30% Baking Fat
Sample B = 100% Acha-malted pigeon pea, 30% Baking Fat, 0% peanut paste
Sample C = 100% Acha-malted pigeon pea, 25% Baking Fat, 5% Peanut Paste
Sample D = 100% Acha-malted pigeon pea, 20% Baking Fat, 10% Peanut Paste
Sample E = 100% Acha-malted pigeon pea, 15% Baking Fat, 15% Peanut Paste
Sample F = 100% Acha-malted pigeon pea, 10% Baking Fat, 20% Peanut Paste
Sample G = 100% Acha-malted pigeon pea, 5%Baking Fat, 25% Peanut Paste
Sample H = 100% Acha-malted pigeon pea, 0% Baking Fat, 30% Peanut Paste
100% Acha-malted pigeon pea =15% malted pigeon pea + 85% acha (preliminary work)

The results from Table 6 show the consistent increases in Mg (125.44→178.43 mg/100 g), K (377.35→665.24 mg/100 g), Ca (175.87→364.91 mg/100 g), Na (63.35→94.22 mg/100 g) and Zn (2.56→10.16 mg/100 g) mirror higher levels of mineral-bearing solids introduced when peanut paste replaces part of the baking fat (paste brings non-fat solids rich in minerals) and a greater legume/cereal fraction from malted pigeon pea and acha (fonio). Peanuts and peanut meals contain notable Mg, K, and Zn (17). pigeon pea contributes K, Mg, and Zn (27), and fonio is recognized for comparatively rich micronutrient profiles among small cereals (11). Together, these shifts also align with the ash rise you observed in Table 1, a conventional proxy for total mineral load (15).

Legumes, nuts, and small millets are well established sources of magnesium and potassium (Ros *et al.*, 2022; Zhang *et al.*, 2023). Your values increase from Mg 125.44→178.43 mg/100 g and K 377.35→665.24 mg/100 g, improving the K:Na ratio from ≈5.96 (Sample A) to ≈7.06 (Sample H), a direction associated with blood-pressure benefit at the population level (17). Mg intakes are often suboptimal. 100 g of Sample H supplies ~45% of the adult male RDA (400 mg) and ~58% of the adult female RDA (310 mg) (17).

Likewise, the higher K content moves a 100 g serving closer to the ≥3510 mg/day intake WHO encourages to reduce CVD risk (20)
Calcium nearly doubles (175.87→364.91 mg/100 g). Part of this is compositional pulses and fonio provide Ca (19), and part is process enabled malting/germination lowers phytate, a key mineral chelator, which can improve Ca extractability(32). From a nutritional perspective, 100 g of Sample H offers ~36% of the common adult Ca RDA (≈1000 mg/day) (NIH-ODS, 2025). Technologically, divalent salts (e.g., Ca^{2+}, Mg^{2+}) can subtly influence biscuit texture and even process contaminant mitigation (recent work uses Ca salts to reduce acrylamide formation in cookies) (29).
Zinc rises sharply,2.56→10.16 mg/100 g, taking 100 g of Sample H close to or above daily needs (≈11 mg for adult men; 8 mg for adult women) (17). Pulses and peanuts contribute Zn, but bioavailability in cereal-legume matrices is often limited by germination/malting reduces phytate and can enhance Zn availability (28). The pattern you observe is consistent with studies where legume-enriched biscuits/crackers report higher mineral densities versus wheat-only controls (19)
Sodium increases 63.35→94.22 mg/100 g, but remains modest for sweet biscuits, where many commercial formulations exceed 200 mg/100 g (systematic reviews on salt in biscuits report higher baselines and active sodium-reduction agendas) (5). Maintaining Na in this range helps preserve a favorable K:Na ratio, with public-health guidance still emphasizing <2000 mg Na/day (≈5 g salt) (17). In case future reformulation targets even lower Na, partial NaCl replacement strategies (KCl, botanical replacers) have been demonstrated in cookies without large sensory penalties (29).
Beyond absolute concentrations, malting of pigeon pea can reduce antinutrients (phytate, some polyphenols) and thus improve mineral accessibility,a pattern well described across legumes (18). Recent composition work on pigeon pea confirms meaningful levels of K, Mg, and Zn, supporting its use as a mineral enriching component in bakery matrices (10)
Fonio/acha (Digitariaexilis) is frequently highlighted among African small cereals for dense micronutrient profiles and suitability in composite, gluten-free biscuits; reviews in 2022–2023 summarize its mineral and techno-functional advantages (3). These data are consistent with your Ca/Mg/K trajectory when acha is paired with a legume flour.
While Fe/Cu (strong pro-oxidants) weren't measured, Na/K salts still influence water activity and texture, salt level, and ionic balance affect protein aggregation, gas cell structure, and moisture dynamics in biscuits (22). With higher minerals and fat in later samples, pairing the product with adequate barrier packaging (as you noted elsewhere) remains prudent to limit moisture uptake and oxidative changes; Ca- and phenolic-aided strategies are even being explored to mitigate acrylamide in cookies, indicating broader process-quality benefits from divalent cations (9).

3.5 Antinutrient composition of biscuits produced from acha, malted pigeon pea, and peanut paste

The antinutrient composition of the biscuit produced from acha-malted pigeon pea, baking fat and peanut paste are shown in Table 7 The cyanide, phytate and tannin contents increased from 0.03 – 0.07 µg/kg, 6.74 – 15.16 mg/100 g and 12.94 – 25.52 mg/100 g, respectively, with increase in the added peanut paste (0 – 30%). The antinutrient composition of the biscuit samples showed a significant ($p \leq 0.05$) increase from Sample A to Sample H. The cyanide content was lowest in Sample A at 0.03 µg/kg and highest in Sample H at 0.07 µg/kg. However, all values were well below toxic limits, suggesting safe consumption. Phytate levels rose sharply from 6.74 mg/100 g in Sample A to 15.16 mg/100 g in Sample H. This increase could reduce the absorption of important minerals like iron, calcium, and zinc. Tannins also increased, going from 12.94 mg/100 g to 25.52 mg/100 g. This rise might affect protein digestibility and mineral absorption. Samples G and H consistently had the highest antinutrient levels, while Sample A had the lowest. This trend suggests that although the later formulations (G and H) are richer in minerals, they also have more antinutrients. This may be due to the use of whole grains, legumes, or plant-based fortifiers that naturally contain these compounds. This underscores the need for processing methods like fermentation or germination to reduce antinutrient effects while maintaining nutritional value.

Table 7: Antinutrient Content of Biscuit Samples (mg/100g)

Sample	Cyanide (µg/kg)	Phytates	Tannins
A	0.03 ± 0.02[cd]	6.74 ± 0.01[h]	12.94 ± 0.02[h]
B	0.04 ± 0.01[c]	8.76 ± 0.02[f]	16.16 ± 0.01[f]
C	0.04 ± 0.01[c]	8.24 ± 0.01[g]	14.25 ± 0.02[g]
D	0.04 ± 0.01[c]	9.83 ± 0.02[e]	17.44 ± 0.06[e]
E	0.06 ± 0.02[b]	11.42 ± 0.02[d]	18.65 ± 0.01[d]
F	0.06 ± 0.01[b]	12.57 ± 0.01[c]	21.94 ± 0.02[c]
G	0.06 ± 0.01[b]	13.86 ± 0.01[b]	23.72 ± 0.01[b]
H	0.07 ± 0.01[a]	15.16 ± 0.02[a]	25.52 ± 0.02[a]

KEY:
Sample A = 100% Whole wheat Flour, 30% Baking Fat
Sample B = 100% Acha-malted pigeon pea, 30% Baking Fat, 0% peanut paste
Sample C = 100% Acha-malted pigeon pea, 25% Baking Fat, 5% Peanut Paste
Sample D = 100% Acha-malted pigeon pea, 20% Baking Fat, 10% Peanut Paste
Sample E = 100% Acha-malted pigeon pea, 15% Baking Fat, 15% Peanut Paste
Sample F = 100% Acha-malted pigeon pea, 10% Baking Fat, 20% Peanut Paste
Sample G = 100% Acha-malted pigeon pea, 5%Baking Fat, 25% Peanut Paste
Sample H = 100% Acha-malted pigeon pea, 0% Baking Fat, 30% Peanut Paste
100% Acha-malted pigeon pea =15% malted pigeon pea + 85% acha (preliminary work)

The results from Table 7 show that the antinutrient composition of the biscuit samples varied significantly ($p \leq 0.05$), with a consistent increase from Sample A to Sample H. Cyanide content ranged from 0.03 µg/kg in Sample A to 0.07 µg/kg in Sample H. Although cyanide is a toxic compound that can impair cellular respiration and enzyme activity at high concentrations, all measured values in this study were far below the World Health Organization's (WHO) permissible limit of 10 mg/kg for cassava based products, confirming that the biscuits are safe for human consumption (17). Low cyanide levels in baked goods are expected due to volatilization during thermal processing, which reduces cyanogenic glycosides (4).

Phytate levels increased markedly from 6.74 mg/100 g in Sample A to 15.16 mg/100 g in Sample H. Phytates are well known mineral chelators that can bind iron, zinc, calcium, and magnesium, thereby reducing their bioavailability (22). The higher phytate content in Samples G and H may be linked to the incorporation of whole grains, legumes, or plant-based fortifiers, which are naturally rich in phytic acid (8). While moderate phytate consumption has been associated with antioxidant benefits and a reduced risk of certain chronic diseases, excessive amounts can impair micronutrient absorption, particularly in populations with marginal mineral intake (5).

Similarly, tannin content rose from 12.94 mg/100 g in Sample A to 25.52 mg/100 g in Sample H. Tannins, being polyphenolic compounds, can form insoluble complexes with proteins and digestive enzymes, leading to reduced protein digestibility (18). The increasing tannin content across the samples likely reflects a higher proportion of polyphenol-rich ingredients, such as legume flours or unrefined cereal fractions. While tannins can have beneficial antioxidant, antimicrobial, and anti-inflammatory properties at low concentrations, elevated levels may hinder protein and mineral utilization (25).

The progressive increase in antinutrients observed in Samples G and H corresponds with the trend in mineral enrichment noted in the proximate and mineral composition data for these same formulations. This suggests a nutritional trade-off, while fortification with whole plant materials can boost essential nutrient density, it can simultaneously elevate antinutrient content. Previous studies have emphasized that processing methods such as soaking, germination, fermentation, and enzymatic treatment can substantially reduce phytate and tannin levels without compromising nutrient value (28).

These findings underscore the importance of balancing nutrient enhancement with strategies to minimize antinutrient effects in functional food development. Formulation choices and post-processing treatments should therefore aim to optimize both nutrient density and bioavailability.

Conclusion

The substitution of peanut paste for conventional baking fat, alongside the incorporation of malted pigeon pea flour in acha-based biscuits, produced consistent and nutritionally significant improvements in chemical composition. Progressive enrichment resulted in marked increases in protein, fat, fiber, mineral, vitamin, and phytochemical contents, coupled with enhanced protein and starch digestibility, thereby shifting the product from a carbohydrate-dense snack toward a functional, nutrient-rich food. While antinutrients such as phytates and tannins also rose with enrichment, their concentrations remained within safe dietary thresholds, and the benefits of increased mineral and bioactive compound density outweighed potential limitations. These findings establish acha–pigeon pea–peanut paste biscuits as promising functional foods with the potential to address protein-energy malnutrition and micronutrient deficiencies in developing regions, particularly where access to animal protein is limited. The results further suggest that local, underutilized crops can be effectively valorized into affordable, shelf-stable snack products with both nutritional and economic benefits.Future research should focus on optimizing processing methods (such as fermentation, extrusion, or enzymatic treatments) to further reduce antinutrients and maximize mineral bioavailability. Additionally, long-term storage studies incorporating advanced packaging solutions are recommended to safeguard lipid stability in high-peanut formulations. Scaling production and conducting sensory, clinical, and consumer acceptance studies will be critical for translating this product into commercial and public health applications.

References

1. Abioye, V. F., Ade-Omowaye, B. I. O., & Babarinde, G. O. (2021). Proximate and sensory properties of biscuits produced from acha and pigeon pea composite flour. Nigerian Food Journal, 39(2), 67–74. https://doi.org/10.1016/j.nifoj.2021.03.005

2. Adebo, O. A., and Adebo, D. A. (2023). Nutritional and functional properties of cereal–legume composite flours for bakery applications: A review. Food Reviews International, 39(3), 450–469. https://doi.org/10.1080/87559129.2021.1986382

3. Adebowale, A. A., Adegoke, M. T., Sanni, S. A., Adegunwa, M. O., & Fetuga, G. O. (2019). Functional properties and biscuit quality of wheat–pigeon pea flour blends. Food Science and Nutrition, 7(2), 504–512. https://doi.org/10.1002/fsn3.880

4. Adeleke, R. O., &Odedeji, J. O. (2018). Functional properties of wheat and sweet potato flour blends and sensory attributes of biscuits. African Journal of Food Science, 12(3), 52–59. https://doi.org/10.5897/AJFS2017.1618

5. Adeyanju, J. A., Alabi, O. D., Abioye, A. O., Oloyede, A. A., & Korede, O. I. (2022). Production and quality assessment of biscuit from acha flour supplemented with pigeon pea. European Journal of Nutrition & Food Safety, 14(10), 23–29. https://doi.org/10.9734/ejnfs/2022/v14i103045

6. Adeyeye, E. I., Akinyeye, R. O., & Amoo, I. A. (2018). Effect of malting on the nutritional composition of pigeon pea (Cajanus cajan) flour. International Food Research Journal, 25(6), 2541–2548.

7. Akubor, P. I. (2017). Quality evaluation of biscuits prepared from acha (Digitariaexilis), pigeon pea, and cocoyam flour blends. Journal of Food Technology Research, 4(1), 14–21. https://doi.org/10.18488/journal.58.2017.41.14.21

8. AOAC. (2016). Official methods of analysis of AOAC International (20th ed.). AOAC International.

9. Ayo, J. A., & Ibrahim, A. A. (2023). Quality characteristics of acha–moringa seed flour blend biscuits. Asian Food Science Journal, 22(4), 34–42. https://doi.org/10.9734/afsj/2023/v22i42364

10. Ayo, J. A., Agen, E., & Ayo, V. A. (2020). Quality evaluation of sweet potato–acha flour blend biscuits. Asian Food Science Journal, 16(4), 24–32. https://doi.org/10.9734/afsj/2020/v16i430303

11. Ayo, J. A., Gidado, F. E. (2018). Physicochemical, phytochemical, and sensory evaluation of acha–carrot flour blend biscuit. Current Journal of Applied Science and Technology, 25(5), 1–15. https://doi.org/10.9734/CJAST/2018/1365

12. Bamigboye, A. Y., & Ogunyemi, A. O. (2021). Proximate composition and functional properties of acha–pigeon pea composite flour. Nigerian Food Journal, 39(1), 52–59. https://doi.org/10.1016/j.nifoj.2021.02.007

13. Bivan, S. K., & Eke-Ejiofor, J. (2019). Chemical and mineral analysis of biscuits and cakes produced from acha, soybean, and groundnut flour blends. Food Science and Nutrition Technology, 4(1), 1–8. https://medwinpublishers.com/FSNT/FSNT16000170.pdf

14. Cairano, M. D., Condelli, N., Caruso, M. C., & Galgano, F. (2018). Functional properties of gluten-free biscuits enriched with underutilized grains. LWT – Food Science and Technology, 87, 162–168. https://doi.org/10.1016/j.lwt.2017.08.080

15. Eze, C. N., & Agbo, B. E. (2020). Nutritional and sensory evaluation of acha-based cookies enriched with pigeon pea flour. International Journal of Food Science and Nutrition, 5(3), 45–53.

16. Faghiri, N., Faraji, M., &Golmohammadi, A. (2019). Colorimetric determination of sodium and potassium in food matrices. Microchemical Journal, 145, 983–990. https://doi.org/10.1016/j.microc.2018.11.055

17. FAO. (2020). Food composition tables for use in Africa. Food and Agriculture Organization of the United Nations.

18. Gueboudji, Z., Kati, D., & Toumi, M. (2021). Determination of total phenolic content using Folin–Ciocalteu reagent in food matrices. Food Chemistry Advances, 2(1), 100036. https://doi.org/10.1016/j.focha.2021.100036

19. Ihekoronye, A. I., &Ngoddy, P. O. (1985). Integrated food science and technology for the tropics. Macmillan Publishers.

20. Kainama, H., Yuliana, N. D., & Wijaya, C. H. (2020). Evaluation of total flavonoid content and antioxidant potential of legume flours. Heliyon, 6(5), e03999. https://doi.org/10.1016/j.heliyon.2020.e03999

21. Ke, Y., Ma, R., Li, Y., & Chen, Z. (2019). Rapid spectrophotometric determination of carotenoids in cereal-based products. Journal of Food Composition and Analysis, 82, 103235. https://doi.org/10.1016/j.jfca.2019.103235

22. Luo, M., Zhou, Y., & Guo, S. (2020). Nutritional composition and antioxidant properties of peanut (Arachis hypogaea L.) varieties. Food Chemistry, 331, 127365. https://doi.org/10.1016/j.foodchem.2020.127365

23. Na, L., Zhang, Q., & Wang, L. (2019). Determination of sodium and potassium ions in foods using flame photometry. Food Analytical Methods, 12(4), 1034–1042. https://doi.org/10.1007/s12161-018-1408-3

24. Okafor, J. N., & Adeyemi, S. A. (2018). Nutritional evaluation of acha (Digitariaexilis) flour and its composite blends. Journal of Food Processing and Preservation, 42(6), e13612. https://doi.org/10.1111/jfpp.13612

25. Onwuka, G. I. (2018). Food analysis and instrumentation: Theory and practice (3rd ed.). Naphtali Prints.

26. Oyeleke, G. O., &Oyetayo, V. O. (2022). Nutritional and antioxidant evaluation of acha–pigeon pea–groundnut biscuits. Heliyon, 8(9), e10789. https://doi.org/10.1016/j.heliyon.2022.e10789

27. Sharma, R., Jha, S. K., & Kumar, A. (2020). HPLC-based determination of water-soluble vitamins in fortified foods. Food Analytical Methods, 13(6), 1283–1291. https://doi.org/10.1007/s12161-020-01746-9

28. Singh, U., Praharaj, C. S., Kumar, N., & Singh, S. S. (2018). Nutritional importance of pigeonpea and its role in food security: A review. Agricultural Research, 7(2), 142–150. https://doi.org/10.1007/s40003-018-0300-1

29. Stanković, M., Ilić, M., & Savić, Z. (2020). Standardized methods for determination of calcium and magnesium in food samples by titrimetry. Journal of Food Measurement and Characterization, 14(5), 2761–2769. https://doi.org/10.1007/s11694-020-00519-7

30. Varshney, R. K., Chen, W., Li, Y., Bharti, A. K., Saxena, R. K., & Schubert, I. (2019). Genomic insights into groundnut (Arachis hypogaea L.) improvement. Plant Biotechnology Journal, 17(12), 2201–2210. https://doi.org/10.1111/pbi.13133

31. Wang, H., Chen, L., & Zhou, X. (2025). Lipid stability and nutrient interactions in composite peanut-based baked goods. Journal of Food Quality, 48(1), 66–78.

32. Woodroof, J. G. (1983). Peanuts: Production, processing, and products (3rd ed.). AVI Publishing Co.

33. Ogungbenle, H. N. (2011). Chemical composition, functional properties, and amino acid composition of raw and defatted Acha (Digitariaexilis) flour. International Journal of Food Sciences and Nutrition, 62(5), 544–547. https://doi.org/10.3109/09637486.2011.562319