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Development and evaluation of the nutrient and antinutrient composition of composite blends produced from wheat (Triticum aestivum), acha (Digitaria exilis), plantain (Musa paradisiaca) and aerial yam (Dioscorea bulbifera) flours

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Abstract-* This study evaluated the nutrient and anti-nutrient composition of composite flour produced from wheat (Triticum aestivum), acha (Digitaria exilis), unripe plantain (Musa paradisiaca), and aerial yam (Dioscorea bulbifera) flour blends. Six flour formulations were prepared by partially substituting wheat flour with varying proportions of acha, unripe plantain, and aerial yam flour. Standard analytical methods were used to determine the proximate, mineral, vitamin, and anti-nutrient composition of the samples. Data obtained were subjected to one-way analysis of variance (ANOVA), and Duncan's Multiple Range Test was used to separate means at $p < 0.05$. The results showed significant differences among the flour blends. Moisture, protein, ash, crude fibre, and fat increased from 10.28–11.83%, 11.86–15.26%, 0.67–1.82%, 0.61–4.26%, and 1.82–2.37%, respectively, while carbohydrate and energy value decreased from 74.76–64.46% and 360.82–341.46 kcal/100 g, respectively. Calcium, iron, potassium, magnesium, and phosphorus increased from 28.61–65.47, 2.84–5.86, 126.74–259.36, 32.51–74.92, and 108.36–181.85 mg/100 g, respectively, whereas sodium decreased from 6.42–5.18 mg/100 g. Vitamins A, C, B_1, B_2, and B_3 increased from 5.82–25.63 µg/100 g, 0.92–10.62 mg/100 g, 0.29–0.47 mg/100 g, 0.12–0.23 mg/100 g, and 2.18–3.64 mg/100 g, respectively. Phytate, oxalate, tannin, and saponin ranged from 24.84–44.13, 8.62–16.63, 0.71–1.86, and 1.18–2.91 mg/100 g, respectively. The study concluded that wheat–acha–plantain–aerial yam composite flour possesses superior nutritional quality with acceptable anti-nutrient levels and has promising potential for functional bakery applications and improved food and nutrition security.

***Keywords:* nutrient, antinutrient composition, composite blends, wheat, acha, plantain, aerial yam, flours**

I. INTRODUCTION

Bread remains one of the most widely consumed staple foods globally because of its convenience, affordability, long shelf life, and substantial contribution to daily dietary energy intake (Noorfarahzilah et al., 2014; Wang & Jian, 2022). It is conventionally produced from refined wheat (Triticum aestivum) flour because the gluten-forming proteins, gliadin and glutenin, impart the viscoelastic properties required for dough development, gas retention, and desirable loaf volume during baking (Barak et al., 2013; Biesiekierski, 2017). However, refined wheat flour contains relatively low amounts of dietary fibre, resistant starch, essential minerals, vitamins, and bioactive compounds compared with many indigenous cereals and tubers (Seal et al., 2021; Udomkun et al., 2022). In many developing countries, including Nigeria, the heavy dependence on imported wheat has increased production costs and foreign exchange expenditure, thereby stimulating interest in composite flour technology as a sustainable strategy for enhancing nutritional quality while reducing reliance on wheat importation (Hasmadi et al., 2020; Wang & Jian, 2022).

Composite flour technology has received increasing global attention because it enables the incorporation of locally available cereals, roots, tubers, legumes, and fruits into wheat flour to improve the nutritional and functional quality of bakery products (Noorfarahzilah et al., 2014; Hasmadi et al., 2020). Numerous studies have demonstrated that appropriate substitution of wheat flour with indigenous crops enhances protein content, dietary fibre, mineral composition, antioxidant activity, and functional characteristics while maintaining acceptable product quality (Adebowale et al., 2012; Olagunju et al., 2020; Wang & Jian, 2022). Beyond nutritional improvement, composite flour technology promotes the utilization of local agricultural resources, supports agricultural diversification, creates value-added opportunities for farmers, and contributes to national food and nutrition security through reduced dependence on imported cereals (Nwanekezi, 2013; Wang & Jian, 2022).

Among the indigenous cereals with considerable nutritional potential, acha (Digitaria exilis) has attracted increasing scientific interest because of its excellent nutritional composition and adaptability to marginal environmental conditions. Acha is particularly rich in sulphur-containing amino acids, dietary fibre, iron, calcium, and B-complex vitamins, making it nutritionally superior to many conventional cereal grains. In addition, its favourable functional properties make it suitable for incorporation into composite flour for bakery applications (Deriu et al., 2022; Hasmadi et al., 2020). Previous investigations have reported improvements in the nutritional composition, functional properties, and consumer acceptability of wheat–acha composite bread and other baked products, highlighting the potential of acha as a valuable ingredient in functional food development (Dabels et al., 2016; Olagunju et al., 2020; Deriu et al., 2022).

Unripe plantain (Musa paradisiaca) is another important raw material for composite flour production because it is rich in resistant starch, dietary fibre, potassium, magnesium, vitamin C, provitamin A carotenoids, and antioxidant compounds that have been associated with improved gastrointestinal health and glycaemic regulation (Adeola & Ohizua, 2018; Seal et al., 2021; Udomkun et al., 2022). Similarly, aerial yam (Dioscorea bulbifera) is an underutilized tuber containing appreciable amounts of carbohydrates, dietary fibre, minerals, and phenolic compounds with antioxidant properties. The incorporation of plantain and yam flours into wheat flour has been reported to improve dietary fibre, mineral composition, water absorption capacity, and overall nutritional quality of composite bakery products while maintaining acceptable sensory characteristics (Asif-Ul-Alam et al., 2014; Udomkun et al., 2022).

The nutritional quality of composite flour depends on the complementary characteristics of its constituent ingredients. Wheat contributes gluten, which is indispensable for dough structure and bread-making performance, whereas acha supplies high-quality protein and essential amino acids. Unripe plantain contributes resistant starch, dietary fibre, vitamins, and antioxidant compounds, while aerial yam provides additional carbohydrates, minerals, dietary fibre, and phytochemicals. Consequently, blending these raw materials offers the potential to produce nutritionally superior flour with improved functional properties suitable for bakery applications (Barak et al., 2013; Deriu et al., 2022; Udomkun et al., 2022). Furthermore, evaluating anti-nutritional factors such as phytates, oxalates, tannins, and saponins remains essential because these compounds influence mineral bioavailability, although conventional processing operations including soaking, drying, milling, fermentation, and baking substantially reduce their concentrations to nutritionally safe levels (Benincasa et al., 2019; Tamiru, 2018).

Despite the increasing volume of research on composite flour technology, most published studies have focused on binary or ternary blends involving wheat and one or two locally available crops. Comparatively little information is available on composite flour simultaneously formulated from wheat (Triticum aestivum), acha (Digitaria exilis), unripe plantain (Musa paradisiaca), and aerial yam (Dioscorea bulbifera), particularly with respect to their combined nutrient and anti-nutrient composition. Therefore, this study aimed to formulate composite flour from these four complementary raw materials and evaluate its nutrient and anti-nutrient composition. The findings are expected to provide scientific evidence supporting the development of nutritionally enhanced bakery products, encourage greater utilization of indigenous crops, reduce dependence on imported wheat, and contribute to improved food and nutrition security in Nigeria.

II. MATERIAL AND METHODS

Raw materials

Market branded wheat flour (Triticum aestivum), mature unripe plantain (horn-type) and all other baking ingredients including granulated sugar (Dangote Group Nigeria), baking fat (topper margarine), instant dry yeast (STK Royal brand) and salt (Dangote Group, Nigeria) were procured from Swali market Yenagoa, Bayelsa State, while acha grains was obtained Dawanau market, Kano State, while aerial yam was obtained Ugbawka community in Nkanu-East LGA of Enugu State, Nigeria.

Preparation of Sample flours

Preparation of Acha flour

Acha flour was prepared according to the procedure reported by Olagunju et al. (2020) with slight modification. The Acha grains were washed with tap water to separate stones and sand, then, they were dried in the cabinet dryer at 50 0C for 6 hours. The resultant dried Acha was milled and sieved into flour using the hammer mill with 0.5 mm screen size.

Production of Plantain flour

The unripe plantain flour was prepared according to the method of Chinmah et al. (2004). Five kilograms (5kg) of matured unripe plantain fruits was thoroughly cleaned and peeled manually with a kitchen knife. The peeled plantain fruits were cut into smaller sizes with a knife. The slices were rinsed, placed in a stainless pot and blanched with 3 liters of potable water at 85 0C for 20 min on a hot plate. The blanched slices were drained, rinsed and spread on the trays and dried in a hot air oven (Model DHG 9101 ISA) at 60 0C for 10 h with occasional stirring of slices at intervals of 30 min to ensure uniform drying. The dried slices were milled in the attrition mill and sieved through a 40μm mesh sieve. The flour produced was packaged in an airtight plastic container, labeled and kept in a refrigerator until needed for further use.

Preparation of Raw Aerial Yam Flour

Raw aerial yam flour was prepared using the method described by Okechukwu et al. (2025). One kilogram (1 Kg) of the aerial yams which were free from dirt and other extraneous materials were weighed, cleaned, peeled and sliced into chips manually (using knife) and rewashed using tap water. The chips were rinsed and dried in a hot air oven (Model DHG 9101 ISA) at 60 0C for 24 h with occasional stirring of the chips at intervals of 30 min to ensure uniform drying. The dried chips were milled into flour using the attrition mill and sieved using a China-made mechanical sieve shaker with 500micron mesh sieve. The flour produced was packaged in an airtight plastic container, labeled and kept in a refrigerator until needed for analysis.

Formulation of flour blends

The wheat, acha, plantain and aerial yam flours were blended to fit into the experimental design as shown in Table 1. The flours were thoroughly mixed at predetermined ratios; 101= (100:0:0:0), 202 = (80:7.5:7.5:5), 303 = (70:15:7.5:7.5), 404 = (60:17.5:12.5:10), 505 = (50:20:17.5:12.5) and 606 = (40:25:17.5:12.5) to give samples A-F using a Panasonic MX-AC 2105 blending machine to obtain homogenous blends. The composite flour blends produced were separately packaged in lidded plastic containers labeled and stored in a refrigerator until needed for analysis. The whole wheat flour without any substitution (Sample A) served as control.

Table 1: Composition of the different formulations based on experimental design.

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Experimental Run	Wheat flour	Acha flour	Plantain flour	Aerial yam flour
101	100	0	0	0
202	80	7.5	7.5	5
303	70	15	7.5	7.5
404	60	17.5	12.5	10
505	50	20	17.5	12.5
606	40	25	20	15

Proximate Analysis

The moisture, crude protein, fat, ash and crude fibre contents of the samples were determined on dry weight according to the methods of AOAC (2010). Carbohydrate was determined by difference (AOAC, 2010). The energy content of the flours was calculated from the proximate composition using the At-water factor 4×protein, 9×fat, and 4×carbohydrate respectively (Shumaila and Mahpara, 2009). All determinants were carried out in triplicate samples.

Micronutrients Analyses

The calcium, potassium, iron, phosphorus, magnesium, sodium, vitamins (B-complexes, A, C) contents of the samples were determined on dry weight basis according to the methods of AOAC (2010). The ascorbic acid and niacin contents of the samples were determined according to the methods of AOAC (2010). The thiamine and riboflavin contents of the flours were determined according to the flourimetric methods described by Onwuka (2005). All determinations were carried out in duplicate.

Antinutrient Analysis

The levels of trypsin inhibitor, tannin, phytate, oxalate, saponin and haemagglutinin of the samples were determined on dry weight basis according to the spectrophotometric methods described by Onwuka (2005). All determinations were carried out in triplicate samples.

Statistical Analysis

The data generated after the analysis were subjected to Analysis of Variance (ANOVA) using Special Package for Social Sciences (SPSS version 20, 2013). Significant means were separated using Turkey's least significant difference (LSD) test at $p<0.05$.

III. RESULTS AND DISCUSSION

3.1 Proximate Composition of Composite Flour Produced from Wheat, Acha, Plantain and Aerial Yam Flour Blends

Table 3.1: Proximate composition (%) and energy value (kcal/100 g) of composite flour blends produced from wheat, acha, plantain and aerial yam flour.

Sample	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude Fibre (%)	Carbohydrate (%)	Energy (kcal/100 g)
A (100:0:0:0)	10.28 ± 0.12^a	11.86 ± 0.21^a	1.82 ± 0.05^a	0.67 ± 0.03^a	0.61 ± 0.02^a	74.76 ± 0.41^f	360.82 ± 1.34^f
B (80:7.5:7.5:5)	10.54 ± 0.14^b	12.43 ± 0.18^b	1.91 ± 0.04^b	0.89 ± 0.04^b	1.37 ± 0.06^b	72.86 ± 0.37^e	357.51 ± 1.16^e
C (70:15:7.5:7.5)	10.87 ± 0.09^c	13.15 ± 0.17^c	2.03 ± 0.06^c	1.12 ± 0.05^c	2.08 ± 0.04^c	70.75 ± 0.43^d	353.76 ± 1.42^d
D (60:17.5:12.5:10)	11.14 ± 0.15^d	13.82 ± 0.15^d	2.14 ± 0.05^d	1.35 ± 0.04^d	2.84 ± 0.08^d	68.71 ± 0.36^c	349.92 ± 1.25^c
E (50:20:17.5:12.5)	11.48 ± 0.18^e	14.51 ± 0.19^e	2.26 ± 0.07^e	1.59 ± 0.06^e	3.57 ± 0.09^e	66.59 ± 0.44^b	345.83 ± 1.38^b

F (40:25:20:15)	11.83 ± 0.13[f]	15.26 ± 0.22[f]	2.37 ± 0.08[f]	1.82 ± 0.05[f]	4.26 ± 0.07[f]	64.46 ± 0.52[a]	341.46 ± 1.47[a]

Values are expressed as mean ± standard deviation of triplicate determinations. Means within the same column bearing different superscripts differ significantly ($p < 0.05$).

3.1 Proximate Composition of Composite Flour Produced from Wheat, Acha, Plantain and Aerial Yam Flour Blends

The proximate composition of wheat–acha–plantain–aerial yam composite flour is presented in Table 4.1. Significant ($p < 0.05$) differences were observed among all the flour blends, indicating that substitution of wheat flour with acha, plantain, and aerial yam markedly influenced the nutritional composition of the composite flour. Moisture content increased progressively from 10.28% in the control flour (Sample A) to 11.83% in Sample F containing the highest substitution level. Nevertheless, the moisture values remained below the recommended maximum level for flour storage, suggesting satisfactory keeping quality. The gradual increase may be attributed to the higher water-binding capacity of dietary fibre and non-starch polysaccharides present in plantain and yam flours. Similar increases in moisture content following composite flour substitution have been reported by Hasmadi et al. (2020), Deriu et al. (2022), and Udomkun et al. (2022).

Crude protein increased significantly from 11.86% in the control flour to 15.26% in Sample F. This improvement is primarily attributable to the nutritional contribution of acha, which is recognized for its relatively high-quality protein and favourable amino acid profile, particularly its sulphur-containing amino acids. The findings indicate that progressive substitution with indigenous crops enhanced the protein density of the flour blends. Similar increases in protein content have been reported in wheat–fonio composite flour by Olagunju et al. (2020), Deriu et al. (2022), and Hasmadi et al. (2020).

Fat content increased slightly from 1.82% to 2.37% across the flour blends. Although statistically significant, the increase remained relatively small, indicating that the composite flour retained its low-fat characteristic. Low lipid content is desirable because it minimizes oxidative rancidity during storage and contributes to prolonged shelf stability. Similar observations have been documented in wheat–plantain composite flour by Adeola and Ohizua (2018) and Udomkun et al. (2022).

Ash content increased from 0.67% in the control flour to 1.82% in Sample F, reflecting the greater mineral contribution of acha, plantain, and aerial yam. Ash content is widely accepted as an indicator of total mineral matter; therefore, the increasing trend suggests enhanced micronutrient density in the composite flour. Comparable increases have been reported in composite flour studies involving wheat blended with indigenous cereals and tubers (Deriu et al., 2022; Udomkun et al., 2022).

Crude fibre exhibited the greatest proportional increase, rising from 0.61% in the control flour to 4.26% in Sample F. This improvement may largely be attributed to the resistant starch and dietary fibre supplied by unripe plantain together with the fibre-rich characteristics of aerial yam. Increased dietary fibre is nutritionally beneficial because it improves gastrointestinal health, promotes satiety, assists glycaemic regulation, and reduces the risk of cardiovascular disease (Seal et al., 2021). Similar improvements in dietary fibre have also been reported by Adeola and Ohizua (2018), Deriu et al. (2022), and Udomkun et al. (2022).

Carbohydrate content decreased significantly from 74.76% to 64.46% as substitution levels increased. The reduction reflects the replacement of refined wheat starch with flour components containing relatively higher amounts of protein, fibre, and mineral matter. Similar inverse relationships between carbohydrate concentration and nutrient enrichment have been reported by Olagunju et al. (2020) and Deriu et al. (2022).

Consequently, the calculated energy value declined from 360.82 kcal/100 g in the control flour to 341.46 kcal/100 g in Sample F. The decrease resulted mainly from reduced digestible carbohydrate despite the slight increase in fat content. Lower caloric density, together with higher dietary fibre, may make the composite flour more suitable for consumers requiring controlled energy intake, including individuals with obesity and type 2 diabetes. Comparable reductions have been reported by Adeola and Ohizua (2018), Olagunju et al. (2020), and Udomkun et al. (2022).

Overall, the results demonstrate that progressive incorporation of acha, plantain, and aerial yam substantially improved the nutritional quality of the flour by increasing protein, ash, and dietary fibre while reducing carbohydrate concentration and energy density. Among the formulations evaluated, Sample F (40% wheat, 25% acha, 20% plantain, and 15% aerial yam) exhibited the most nutritionally desirable proximate composition, suggesting that higher substitution levels can enhance nutritional quality without adversely affecting the suitability of the flour for bakery applications.

3.2 Mineral Composition of Composite Flour Produced from Wheat, Acha, Plantain and Aerial Yam Flour Blends

Table 3.2: Mineral composition (mg/100 g) of composite flour blends produced from wheat, acha, plantain and aerial yam flour.

Sample	Calcium	Iron	Potassium	Magnesium	Phosphorus	Sodium
A (100:0:0:0)	28.61 ± 0.81^a	2.84 ± 0.05^a	126.74 ± 2.15^a	32.51 ± 0.74^a	108.36 ± 1.85^a	6.42 ± 0.12^f
B (80:7.5:7.5:5)	35.84 ± 0.92^b	3.31 ± 0.07^b	151.62 ± 2.28^b	40.65 ± 0.81^b	121.44 ± 2.03^b	6.18 ± 0.11^e
C (70:15:7.5:7.5)	42.78 ± 1.04^c	3.88 ± 0.08^c	178.25 ± 2.36^c	48.91 ± 0.86^c	136.72 ± 2.11^c	5.93 ± 0.10^d
D (60:17.5:12.5:10)	50.63 ± 1.11^d	4.46 ± 0.09^d	204.87 ± 2.48^d	57.83 ± 0.94^d	151.85 ± 2.24^d	5.66 ± 0.09^c
E (50:20:17.5:12.5)	57.91 ± 1.18^e	5.12 ± 0.11^e	232.44 ± 2.57^e	66.74 ± 1.02^e	166.93 ± 2.36^e	5.43 ± 0.08^b
F (40:25:20:15)	65.47 ± 1.26^f	5.86 ± 0.12^f	259.36 ± 2.71^f	74.92 ± 1.11^f	181.85 ± 2.45^f	5.18 ± 0.07^a

Values are presented as mean ± standard deviation of duplicate determinations. Means bearing different superscripts within the same column differ significantly ($p < 0.05$).

Discussion of Mineral Composition of Composite Flour Produced from Wheat, Acha, Plantain and Aerial Yam Flour Blends

Table 3.2 presents the mineral composition of wheat–acha–plantain–aerial yam composite flour. Significant ($p < 0.05$) differences were observed among all flour samples, indicating that increasing the substitution of wheat flour with indigenous crops markedly improved the mineral composition of the flour blends.

Calcium content increased steadily from 28.61 mg/100 g in the control sample to 65.47 mg/100 g in Sample F. This progressive increase may be attributed to the naturally higher calcium contents of acha, unripe plantain, and aerial yam compared with refined wheat flour. Calcium plays indispensable roles in bone mineralization, muscle contraction, nerve impulse transmission, blood coagulation, and cellular signalling. Therefore, the increased calcium concentration observed in the composite flour indicates improved nutritional quality and suggests that the flour may contribute to meeting dietary calcium requirements. Similar improvements in calcium content following incorporation of indigenous cereals and tubers into wheat flour have been reported by Deriu et al. (2022), Udomkun et al. (2022), and Hasmadi et al. (2020).

Iron content also increased significantly from 2.84 mg/100 g in the control flour to 5.86 mg/100 g in Sample F. Iron is an essential micronutrient required for haemoglobin synthesis, oxygen transport, immune competence, and cognitive development. Iron deficiency remains one of the leading causes of nutritional anaemia globally, particularly among women and children. The higher iron concentration observed in the present study is therefore

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nutritionally important and may be attributed to the relatively high iron content of acha and aerial yam. Comparable increases in iron concentration have been reported in wheat-based composite flour enriched with indigenous cereals and tubers by Olagunju et al. (2020), Deriu et al. (2022), and Udomkun et al. (2022).

Potassium exhibited one of the greatest increases, rising from 126.74 mg/100 g in the control flour to 259.36 mg/100 g in Sample F. This finding is expected because unripe plantain is recognized as an excellent natural source of potassium. Potassium is essential for maintaining intracellular fluid balance, nerve impulse transmission, muscle contraction, and regulation of blood pressure. Increased potassium intake has also been associated with reduced risk of hypertension and cardiovascular diseases. Similar increases in potassium concentration have been reported by Adeola and Ohizua (2018), Udomkun et al. (2022), and Seal et al. (2021).

Magnesium content increased significantly from 32.51 mg/100 g in Sample A to 74.92 mg/100 g in Sample F. Magnesium functions as a cofactor for more than 300 enzymatic reactions involved in carbohydrate metabolism, protein synthesis, nucleic acid metabolism, and energy production. The progressive increase observed in this study demonstrates that substitution with acha and aerial yam substantially enhanced the magnesium density of the flour blends. Similar findings have been documented by Deriu et al. (2022) and Udomkun et al. (2022).

Phosphorus content increased from 108.36 mg/100 g in the control flour to 181.85 mg/100 g in Sample F. Phosphorus is an essential component of bones, teeth, phospholipids, nucleic acids, and adenosine triphosphate (ATP), making it indispensable for growth, cellular metabolism, and energy transfer. The steady increase recorded across the flour blends suggests that incorporation of indigenous crops significantly improved the phosphorus content of the composite flour. Similar observations have been reported by Olagunju et al. (2020), Hasmadi et al. (2020), and Deriu et al. (2022).

Conversely, sodium content decreased slightly from 6.42 mg/100 g in the control sample to 5.18 mg/100 g in Sample F. Although the reduction was relatively modest, lower sodium concentrations may be nutritionally advantageous because excessive sodium intake has been linked to hypertension and cardiovascular disorders. The decrease observed may be explained by dilution of refined wheat flour with plantain and aerial yam flours, which naturally contain lower sodium concentrations. Similar reductions have been reported in wheat–plantain composite flour by Adeola and Ohizua (2018) and Udomkun et al. (2022).

Overall, the mineral analysis demonstrated that increasing substitution of wheat flour with acha, plantain, and aerial yam significantly enhanced the micronutrient composition of the flour blends. Sample F exhibited the highest concentrations of calcium, iron, potassium, magnesium, and phosphorus while maintaining the lowest sodium content. These findings indicate that composite flour formulated from indigenous crops possesses superior mineral density and may contribute to improved dietary intake of essential minerals while supporting the production of nutritionally enhanced bakery products.

3.3 Vitamin Composition of Composite Flour Produced from Wheat, Acha, Plantain and Aerial Yam Flour Blends

Table 3.3: Vitamin composition of composite flour blends

Sample	Vitamin A (µg/100 g)	Vitamin C (mg/100 g)	Thiamine (B_1) (mg/100 g)	Riboflavin (B_2) (mg/100 g)	Niacin (B_3) (mg/100 g)
A	5.82 ± 0.18^a	0.92 ± 0.03^a	0.29 ± 0.01^a	0.12 ± 0.01^a	2.18 ± 0.05^a
B	8.94 ± 0.20^b	2.44 ± 0.06^b	0.33 ± 0.01^b	0.14 ± 0.01^b	2.41 ± 0.04^b
C	12.67 ± 0.24^c	4.26 ± 0.08^c	0.36 ± 0.01^c	0.16 ± 0.01^c	2.71 ± 0.06^c
D	16.85 ± 0.28^d	6.37 ± 0.10^d	0.40 ± 0.01^d	0.18 ± 0.01^d	3.02 ± 0.05^d

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E	20.94 ± 0.32^{e}	8.41 ± 0.12^{e}	0.43 ± 0.02^{e}	0.20 ± 0.01^{e}	3.31 ± 0.07^{e}
F	25.63 ± 0.35^{f}	10.62 ± 0.15^{f}	0.47 ± 0.02^{f}	0.23 ± 0.01^{f}	3.64 ± 0.08^{f}

Values are expressed as mean ± standard deviation. Means with different superscripts within a column are significantly different ($p < 0.05$).

Discussion of Vitamin Composition of Composite Flour Produced from Wheat, Acha, Plantain and Aerial Yam Flour Blends

Table 3.3 presents the vitamin composition of composite flour produced from wheat, acha, unripe plantain, and aerial yam flour blends. Significant ($p < 0.05$) differences were observed among all the flour samples, indicating that progressive substitution of wheat flour with indigenous crops significantly enhanced the vitamin composition of the composite flour.

Vitamin A content increased significantly from 5.82 µg/100 g in the control sample to 25.63 µg/100 g in Sample F. This progressive increase may be attributed primarily to the inclusion of unripe plantain, which contains appreciable quantities of provitamin A carotenoids, together with the contribution of aerial yam. Vitamin A is essential for normal vision, immune function, epithelial tissue integrity, cellular differentiation, and growth. Therefore, the increased vitamin A concentration observed in the composite flour indicates an improvement in its nutritional quality compared with conventional wheat flour. Similar improvements in provitamin A content have been reported in composite bread and flour enriched with plantain and other indigenous crops by Udomkun et al. (2022), Deriu et al. (2022), and Hasmadi et al. (2020), who observed that substitution with nutrient-rich local crops significantly enhanced the micronutrient composition of bakery products.

Vitamin C content also increased significantly from 0.92 mg/100 g in the control sample to 10.62 mg/100 g in Sample F. Although partial losses of ascorbic acid normally occur during drying and milling, the composite flour retained appreciable quantities of vitamin C owing to the incorporation of unripe plantain. Vitamin C functions as an important antioxidant that protects cells against oxidative damage, promotes collagen synthesis, enhances immune function, and improves the intestinal absorption of non-haem iron. Consequently, the higher vitamin C concentration recorded in Samples D, E, and F may further improve the bioavailability of the increased iron content observed in the present study. Similar findings have been reported by Seal et al. (2021), Udomkun et al. (2022), and Wang and Jian (2022), who reported that plant-based composite flours improve antioxidant vitamin content and nutritional functionality of bakery products.

Thiamine (Vitamin B_1) increased progressively from 0.29 mg/100 g in the control flour to 0.47 mg/100 g in Sample F. Thiamine serves as an essential coenzyme in carbohydrate metabolism and supports normal nervous system function and energy production. The observed increase suggests that acha and aerial yam contributed additional B-complex vitamins to the flour blends. Similar improvements in thiamine concentration have been reported by Hasmadi et al. (2020), Deriu et al. (2022), and Olagunju et al. (2020), who demonstrated that incorporation of indigenous cereals into wheat flour significantly enhanced the vitamin profile of composite flour.

A similar trend was observed for riboflavin (Vitamin B_2), which increased significantly from 0.12 mg/100 g in the control sample to 0.23 mg/100 g in Sample F. Riboflavin participates in numerous oxidation–reduction reactions through its role in flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN), thereby supporting energy metabolism, tissue growth, and maintenance of healthy skin and vision. The increase observed across the flour blends indicates that substitution with indigenous crops contributed additional micronutrients beyond their carbohydrate content. Comparable increases in riboflavin have been documented in composite flour formulations incorporating cereals and tubers by Hasmadi et al. (2020), Deriu et al. (2022), and Udomkun et al. (2022).

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Niacin (Vitamin B_3) also increased significantly from 2.18 mg/100 g in the control flour to 3.64 mg/100 g in Sample F. Niacin is an essential component of nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP), which are indispensable coenzymes involved in carbohydrate, lipid, and protein metabolism. The progressive increase observed therefore reflects an overall enhancement in the nutritional density of the composite flour. Similar improvements in niacin concentration following enrichment of wheat flour with indigenous cereals and tubers have been reported by Olagunju et al. (2020), Deriu et al. (2022), and Hasmadi et al. (2020).

Overall, the vitamin composition improved consistently with increasing substitution of wheat flour by acha, unripe plantain, and aerial yam. Sample F exhibited the highest concentrations of all the vitamins evaluated, indicating that greater incorporation of indigenous crops substantially enhanced the micronutrient density of the flour. These findings support the growing body of evidence that composite flour technology provides an effective strategy for developing nutrient-dense bakery raw materials capable of improving dietary quality, reducing micronutrient deficiencies, promoting the utilization of indigenous food resources, and contributing to sustainable food and nutrition security.

3.4 Anti-nutrient Composition of Composite Flour Produced from Wheat, Acha, Plantain and Aerial Yam Flour Blends

Table 3.4: Anti-nutrient composition (mg/100 g) of composite flour blends produced from wheat, acha, plantain and aerial yam flour

Sample	Phytate	Oxalate	Tannin	Saponin
A (100:0:0:0)	24.84 ± 0.41^a	8.62 ± 0.18^a	0.71 ± 0.03^a	1.18 ± 0.05^a
B (80:7.5:7.5:5)	28.43 ± 0.46^b	10.11 ± 0.21^b	0.92 ± 0.04^b	1.54 ± 0.06^b
C (70:15:7.5:7.5)	32.65 ± 0.52^c	11.74 ± 0.23^c	1.14 ± 0.05^c	1.88 ± 0.07^c
D (60:17.5:12.5:10)	36.58 ± 0.56^d	13.42 ± 0.26^d	1.37 ± 0.05^d	2.23 ± 0.08^d
E (50:20:17.5:12.5)	40.26 ± 0.61^e	14.95 ± 0.28^e	1.61 ± 0.06^e	2.56 ± 0.09^e
F (40:25:20:15)	44.13 ± 0.67^f	16.63 ± 0.31^f	1.86 ± 0.07^f	2.91 ± 0.10^f

Values are expressed as mean ± standard deviation of triplicate determinations. Means bearing different superscripts within the same column differ significantly ($p < 0.05$).

IV. CONCLUSION

This study established that composite flour produced from wheat, acha, unripe plantain, and aerial yam possessed superior nutritional quality compared with conventional wheat flour, as evidenced by significant improvements in protein, dietary fibre, mineral, and vitamin contents. The findings further demonstrated that increasing the proportion of acha, unripe plantain, and aerial yam enhanced the micronutrient density of the flour blends while maintaining anti-nutrient concentrations within acceptable limits for safe consumption. Among the formulations evaluated, the blend containing 40% wheat, 25% acha, 20% unripe plantain, and 15% aerial yam exhibited the most favourable nutritional profile, indicating its suitability for functional bakery applications. The study therefore confirms that the strategic utilization of indigenous cereal and tuber crops can reduce dependence on imported wheat while supporting the development of nutrient-dense bakery products. Overall, the adoption of this composite flour technology offers a sustainable approach to improving food and nutrition security, promoting value addition to local agricultural resources, and enhancing consumer health.

V. RECOMMENDATIONS

1. The composite flour formulation containing 40% wheat, 25% acha, 20% unripe plantain, and 15% aerial yam should be considered for the

production of bread and other bakery products because it exhibited the highest protein, dietary fibre, mineral, and vitamin contents among all the formulations evaluated.
2. The incorporation of acha, unripe plantain, and aerial yam into wheat flour should be encouraged in composite flour production to improve the nutritional quality of bakery products through increased protein, dietary fibre, and essential micronutrients.
3. Conventional processing methods such as drying, milling, and baking should continue to be applied during the production of composite flour and bakery products to maintain the anti-nutrient contents within acceptable limits while preserving the enhanced nutritional quality of the flour.

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