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Proximate Composition, Mineral Profile, and Functional Properties of Composite Blends of Baobab (Adansonia digitata L.) Pulp and Moringa (Moringa oleifera Lam.) Leaf Powders.

Benjamin Adzokatsey ADZOKATSE

bensenanu1@gmail.com

Kwame Nkrumah University of science and technology , KUMASI https://orcid.org/0009-0003-4711-4937

Newton Kweku Amaglo

Kwame Nkrumah University of Science and Technology

Research Article

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Benjamine Adzokatsey and Newton kweku Amaglo

Department of Horticulture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.

Abstract

Hidden hunger and micronutrient deficiencies remain persistent public health challenges across sub-Saharan Africa, exacerbated by cereal -based diets deficient in essential minerals and high-quality proteins. This study evaluated the proximate composition, mineral profiles and functional properties of composite powders

formulated from baobab pulp (Adansonia digitata) and moringa leaf (Moringa oleifera) powders. Five treatments were arranged in a Completely Randomized Design (CRD) with three replications: T1 (100% Baobab Pulp Powder[BPP]), T2 (75 %BPP: 25% Moringa Leaf Powder[MLP]), T3 (50% BPP: 50% MLP), T4 (25% BPP: 75% MLP), and T5 (100% MLP). Proximate and mineral analyses revealed significant variations (p < = 0.0001) across treatments. Pure moringa leaf powder (T5) recorded the highest values crude ash (6.76%), crude fiber (17.11%), crude fat (7.70%), total phenolic content, and total flavonoid content. Conversely, 100% baobab pulp powder (T1) exhibited the highest moisture content (0.68%) and exceptional vitamin C concentration (287.27 mg/100g). the 75% BPP: 25% MLP blend (T2) achieved an optimal crude protein content of 27.68%, alongside superior calcium (3.02%) and magnesium (0.56%) concentrations. Mineral analysis confirmed strong complementary profiles, where the inclusion of baobab pulp's organic acids enhanced mineral solubility and mitigated the astringent sensory characteristics of moringa. These findings demonstrate that dual food-to-food fortification using baobab and moringa powders provides a nutrient-dense, shelf-stable, climate-resilient solution to combat micronutrients malnutrition in developing regions.

Keywords: Adansonia digitata; Moringa oleifera; Food fortification; Proximate composite; Mineral profile; Functional foods.

Introduction

Despite global advancements in agricultural food production, the contemporary global food system remains gripped by the dual burden of malnutrition and hidden hunger, affecting over two billion people worldwide, predominantly in sub-Saharan Africa (Dad et al., 2013;Popkin et al., 2020). Diets across this region rely heavily on

starchy staples such as maize, sorghum, and cassava, which provide adequate caloric energy but lack essential micronutrients such as iron, zinc, calcium, and high-quality protein (Akinola et al., 2020). This nutrient deficiency leads to adverse health outcomes, including stunted cognitive development, increased child mortality, weakened immune defense, and diminished economic productivity (de Pee & Grede, 2021).

To counteract these nutritional challenges, researchers are increasingly turning to indigenous, drought-resilient African superfoods as sustainable, cost-effective vehicles for food fortification (Akinola et al., 2020). Among these, baobab (Adansonia digitata L.) pulp and moringa (Moringa oleifera Lam.) leaves stands out due to their exceptional nutritional density and adaptability to marginal soil and arid climates (Islam et al., 2021; Dossa et al., 2023).

Moringa (Moringa oleifera), native to Indian subcontinent and widely naturalized across tropical Africa, is renowned for its high-plant protein content (25-30% dry weight), essential amino acids, beta-carotene, calcium, potassium, and iron (Leone et al., 2015; Babalola et al., 2020). Furthermore, moringa leaves are rich in bioactive polyphenols, including quercetin, kaempferol, and chlorogenic acid, which exhibit potent antioxidant and anti-inflammatory properties (Sik et al., 2021). However, the utilization of moringa leaf powder (MLP) in direct human consumption is frequently hindered by sensory barriers, notably an intense grassy bitterness driven by glucosinolates and a deep green chlorophyll coloration that reduces consumer acceptability when inclusion levels exceed 10% (Boateng et al., 2022).

Conversely, the fruit pulp of the baobab tree (Adansonia digitata) offers a rich source of vitamin C (concentrations five to ten times higher than citrus fruits), dietary soluble and insoluble fibers, and essential minerals such as calcium, potassium, and magnesium (Dossa et al., 2023; Abdulwaliyu et al., 2024). Baobab pulp is characterized by a natural tangy flavor profile due to high concentrations of organic acids (citric, malic, and tartaric acids) (Affonfere et al., 2022). In nutritional science, combining baobab pulp with moringa leaf powder establishes an ideal food-food fortification strategy: baobab’s ascorbic acids act as a potent enhancer for the non-heme iron present in moringa, significantly, improving mineral bio-accessibility (Affonfere et al., 2022; Islam et al., 2021). Currently, the organic acids in baobab pulp

function as a natural masking agent, subduing moringa's herbaceous bitterness while improving product pH stability and shelf-life (Boateng et al., 2022; Dossa et al., 2023).

Although the individual nutritional properties of baobab pulp and moringa leaf powders are well documented, limited systemic research has evaluated the physiochemical synergies, proximate dynamic, and mineral interactions of binary composite blends across standardized formulation ratio (Dossa et al., 2023). Therefore, this study aims to assess the proximate composition, mineral profile, and antioxidant characteristics of formulated composite blends of baobab pulp powder and moringa leaf powder, providing a scientific foundation for value- added functional food development.

Literature Review

Protein and Amino Acid Profile

Within Baobab pulp powder and moringa leaf powder leaf powder formulation, Moringa leaf powder contribute a higher level of protein, formulations with a higher Moringa leaf powder concentration ratio of 25% to 75% Baobab pulp powder can achieve protein levels near 10 to 12%, compared to non-significant amounts in pure fruit powders (BaoActive, 2025). Moringa leaf powder is a fully loaded protein, containing all nine vital amino acids, which contribute for the low protein content of Baobab pulp powder (Abdoun et al., 2022).

Dietary Fiber and Energy

Baobab pulp powder pulp is a vital source of dissolved and insoluble fiber up to 48%. Blends rich in Baobab pulp powder significantly enhance the crude fiber quantity of the end product, thus is beneficial for gut health but may need careful measurements in children's food complement to ensure energy density is not undermined (Dossa et al., 2023).

Macro minerals profiles

Calcium,(Ca), Phosphorus(P), and Magnesium(Mg) and sodium(Na)

Calcium phosphorus and magnesium are indispensable macro minerals essential for skeletal development, cellular signaling ,enzymatic activation and energy metabolism.

Magnesium (Mg)

Magnesium is an essential micromineral required for over 300 enzymatic reactions ,serving as acritical co factor in adenosine triphosphate (ATP) metabolism ,DNA/DNR synthesis, and neuromuscular transmission [Hakim et., 2022]. In

botanical tissues, magnesium forms the central metallic core of the chlorophyll molecule, making MLP an exceptionally rich plant-based reservoir of this element [Abdulmumin, 2025]. Within human metabolism, magnesium regulates vascular tone, supports insulin sensitivity by acting as a cofactor for tyrosine kinase receptors, and mitigates oxidative stress[Dubey, 2020]. Incorporating MLP into baobab pulp blends substantially elevates dietary magnesium adequacy, assisting in the preventing of metabolic syndrome and hypertension.

Potassium and Sodium

Potassium and sodium constitute the primary electrolyte pair responsible for maintaining cellular osmotic pressure, resisting membrane potentials , and fluid balance [Ali et, 2020].

Potassium both MLP and BPP are exceptionally abundant in potassium, with dry pulp matrices frequently documenting levels exceeding1,000 to 2,100 mg per 100 g [Monteiro et al,. 2022] Physiologically, potassium promotes vasodilation, enhances renal sodium excretion, and lowers systemic blood pressure, counteracting the adverse cardiovascular effect of high-sodium diets.

Sodium (Na)

Natively present in modest quantities within MLP [50-160 mg/kg] and BPP [22-34 mg/100g], sodium functions in conjunction with potassium to propagate action potentials across nerve and muscle cells [Mamman & Yusuf, 2021]. The characteristically low sodium-to-potassium ratio in moringa-baobab composite blends renders them highly advantageous for dietary management of chronic non-communicable disease.

CALCIUM and PHOSPHORUS

Calcium and phosphorus operate synergistically to ensure skeletal integrity, dental mineralize action, and intracellular signaling cascade activation [Magi mix et al.,2020]

CALCIUM (Na)

MLP provides massive concentrations of calcium [ranging from 1,440 to 2,000 mg/100g], which is vital for bone matrix formation, blood coagulation, muscle contraction, and hormone secretion [Abdulmumin, 2025].

PHOSPHORUS(P)

BPP contributes substantial bioavailable phosphorus (up to 775 mg/ 100 g), which is a core component of nucleic acid , cell membrane phospholipids, and high-energy phosphate bonds [ATP] [Ramachandran et al., 2024]. The pairing of calcium -dense moringa leaves with phosphorus- rich baobab pulp optimizes the structural mineral balance necessary for growing children and vulnerable populations .

TRACE ELEMNTS,(ENZYMATIC AND ANTIOXIDANT DEFENSE FUNCTIONS

Manganese (Mn)

Manganese is an essential trace element concentrated primarily in the mitochondria and bones. It serves as an indispensable co-factor for mitochondria superoxide dismutase[MnSOD], a primary antioxidant enzyme responsible for neutralizing superoxide radicals generated during cellular respiration [Dubey, 2020]. Furthermore, manganese plays a key role in amino acid metabolism , gluconeogenesis, and cartilage proteoglycan synthesis. MLP acts as a robust botanical accumulator of manganese[8-86mg/kg], ensuring that composite blends contribute effectively to

cellular protection against oxidation damage [Abdulmumin, 2025].

COPPER(Cu)

Copper is vital for iron homeostasis, red blood cell production , and cellular energy generation. It functions as a catalytic cofactor for cytochrome oxidase in the mitochondrial electron transport chain and ceruloplasmin, an enzyme essential for oxidizing ferrous iron ferric iron for safe transport via transferring [Hakim et al,2022]. Although present in trace amounts in MLP and BPP [approximately1.65 mg/100 g in baobab fractions], the bioavailability of copper is significantly enhanced in these blends due to the co-presence of natural organic acids such as ascorbic acid and citrus acids from baobab pulp ,which prevent luminal precipitation and promote intestinal absorption [Ali et., 2020].

Materials and Methods

Study Area and Sample Preparation

All laboratory analyses were conducted at the Department of Horticulture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. Fresh baobab pulp and tender moringa leaves were harvested from established trees

within the KNUST plantation.

Moringa leaves were carefully sorted to remove damaged tissues, washed thoroughly with clean water, drained, and shade-dried indoors at ambient temperature to preserve heat-sensitive vitamins (A and C) and prevent chlorophyl degradation (Islam et al., 2021). The dried leaves were subsequently milled into a fine powder using a clean mechanical plate miller and passed through a fine-mesh sieve (0.5 mm) to achieve uniform particle size. Baobab fruit pulp was manually separated from seeds and fibrous matrices, pulverized into a fine powder, and sieved following identical protocols.

Experiment Design and Treatment Formulation

A Completely Randomized Design (CRD) was employed, comprising five treatment formulations with three replications per treatment. The blending ratio on a weight-to-weight percentage basis were established as follows:

T1: 100% (BPP) : 0%(MLP)

T2: 75% BPP: 25% MLP

T3: 50% BPP: 50% MLP (Balanced)

T4: 25% BPP: 75% MLP

T5: 0% BPP: 100% MLP

Proximate Analysis

Proximate compositions of the composite powder treatments were determined in triplicate following official analytical standards established by the Association of Official Analytical Chemists (AOAC, 2023):

Moisture Content: determined by drying 5.0g of sample in an electric oven at 105C for 24 hours until constant weight was achieved.

Crude protection: Estimated using the kjeldahl digestion, distillation, and titration method. Total nitrogen (N) was multiplied by a conversion factor of 6.25 (% Protein =

% N*6.25).

Crude Fat: Extracted from 2.0g of sample using petroleum ether (40-60C) in a Soxhlet continuous extraction apparatus for 20 hours.

Crude Fiber: Determined by successive acid(1.25% H_2SO_4) and alkaline (1.25% NaOH) digestion of fat-free sample residues, followed by incineration in muffle furnace at 550C for 30 minutes.

Crude Ash: Determined by incinerating 2.0g of sample in muffle furnace at 550C for 4 hours.

Crude Carbohydrate: calculated by difference: Carbohydrate (%) = 100 – (% Protein + % Fat + % Fiber + % Ash +% Moisture)

Mineral Element Analysis

Mineral composition was determined by following dry-ash digestion of 1.0g of sample incinerated at 500C for 4 hours, dissolved in regia, filtered, and diluted to 100ml with distilled water.

Phosphoros (P): Determined calorimetrically using the vanadomolybdate yellow method on a Spectronic 20 spectrophotometer at 420mm.

Potassium (K) and Sodium (Na): quantified using a digital flame photometer against analytical-grade KCl and NaCl standard curves.

Calcium (Ca) and Magnesium (Mg): Determined via EDTA complexometric titration using EBT indicator.

Copper (Cu) and Manganese (Mn): Analyzed using an Atomic Absorption spectrophotometer (AAS) (Buck Scientific) equipped with air-acetylene flame.

Statistical Analysis

All data were subjected to one-way Analysis of Variance (ANOVA) using SPSS statistical software (Version 26.0). significant differences among treatment means were separated using Turkey's Honestly Significant Differences (HDF) post-hoc test

at a significance threshold of $p < 0.05$.

Results and Discussion

Proximate Composition Dynamics

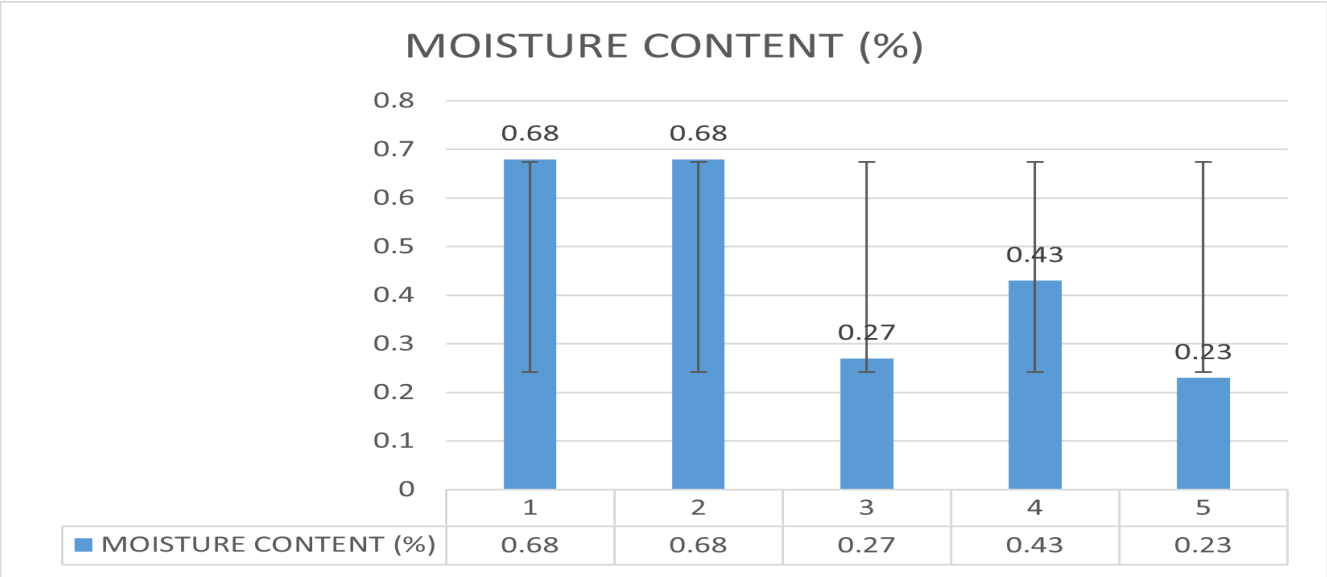
The proximate composition of the composite baobab-moringa powder formulations exhibited highly significant variations ($p <= 0.01$) across treatments, reflecting distinct botanical contributions and synergistic matrix interactions (Table 1).

Parameter	T1(100:0)	T2 (75:25)	T3 (50:50)	T4 (25:75)	T5 (0:100)
Moisture(%)	0.68 + 0.02a	0.67 + 0.02a	0.27 + 0.01b	0.43 + 0.01b	0.23 + 0.00c
Crude Protein (%)	24.17 + 0.35b	27.68 + 1.11a	23.47 + 0.38b	24.56 + 0.80b	23.29 + 1.49b
Crude Fat (%)	5.71 + 0.22c	5.58 + 0.19c	5.66 + 0.20c	6.52 + 0.06b	7.70 + 0.17a
Crude Fiber (%)	9.33 + 0.19d	10.43 + 0.49c	10.72 + 0.26c	14.42 + 0.28b	17.11 + 0.26a
Crude Ash (%)	6.06 + 0.08c	4.04 + 0.12d	6.11 + 0.19c	7.97 + 0.14a	6.76 +0.25b
Carbohydrate (%)	53.95 + 0.92ab	50.64 + 1.74b	54.54 + 1.62a	45.95 + 1.27c	44.31 + 0.74c

Table 1. proximate composition (g/100g dry weight) of baobab pulp and moringa leaf powder composite blends.

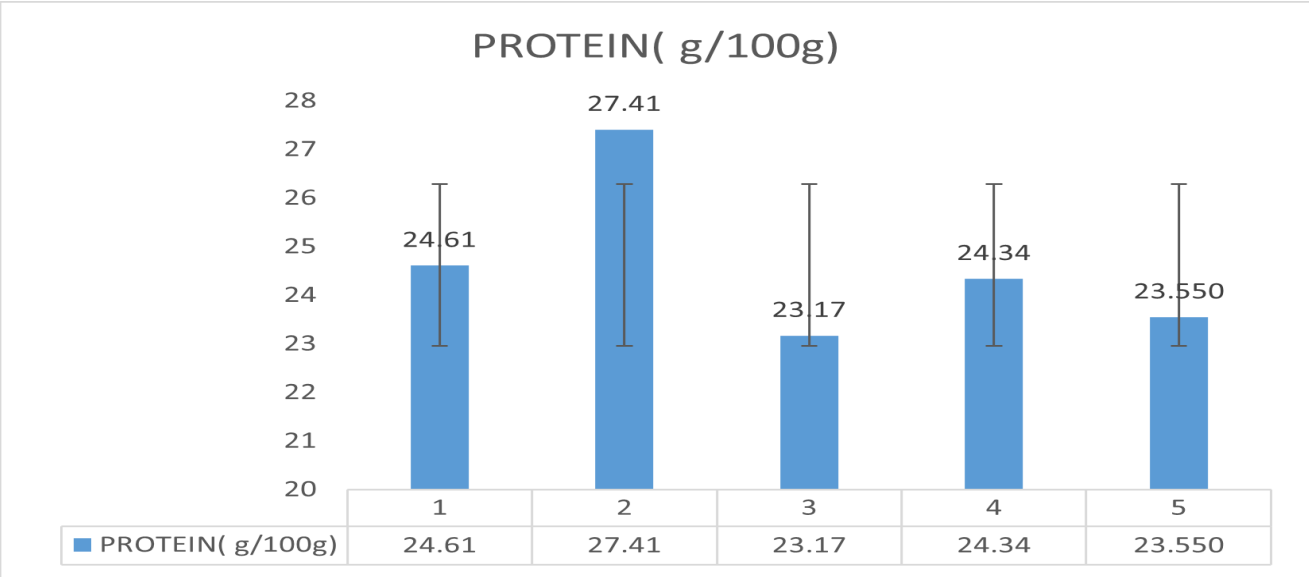
Moisture content ranged from 0.23% in pure moringa (T5) to 0.68% in pure baobab pulp (T1). The sharp decline in moisture observed in treatments containing higher moringa proportions (T3 and T5) is attributed to strong intermolecular hydrogen bonding between plant proteins and complex polysaccharides (Ndabikunze et al., 2022). All formulations-maintained moisture levels well below the 10.0% safety threshold recommended for dried functional powders, ensuring robust resistant against microbial proliferation and hydrolytic rancidity during storage (FAO, 2022).

Figure 1: Distribution on Moisture Content



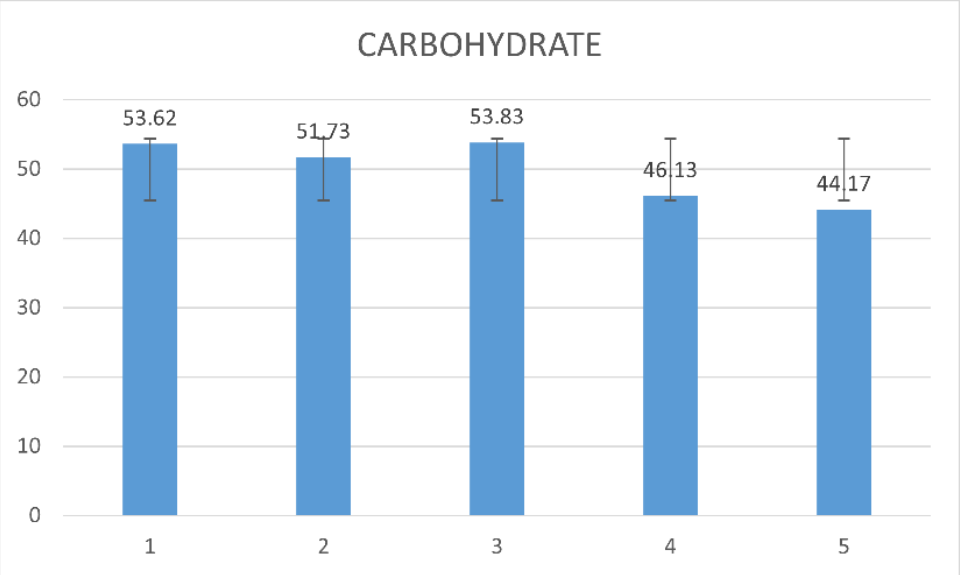
Crude protein varied significantly ($p = 0.0011$), with T2 (75% BPP: 25% MLP) recording the highest protein concentration of 27.68%. This synergistic peak exceeds the protein content of individual constituents, driven by favorable protein-polysaccharide complexation between baobab pectic substances and moringa globulin proteins (Kambabazi et al., 2023).

Figure 2: Distribution on Protein content



Total carbohydrate content peaked in T3 (54.54%), reflecting the rich soluble sugar and polysaccharide reserve characteristics of baobab fruit pulp (Chadare et al., 2009).

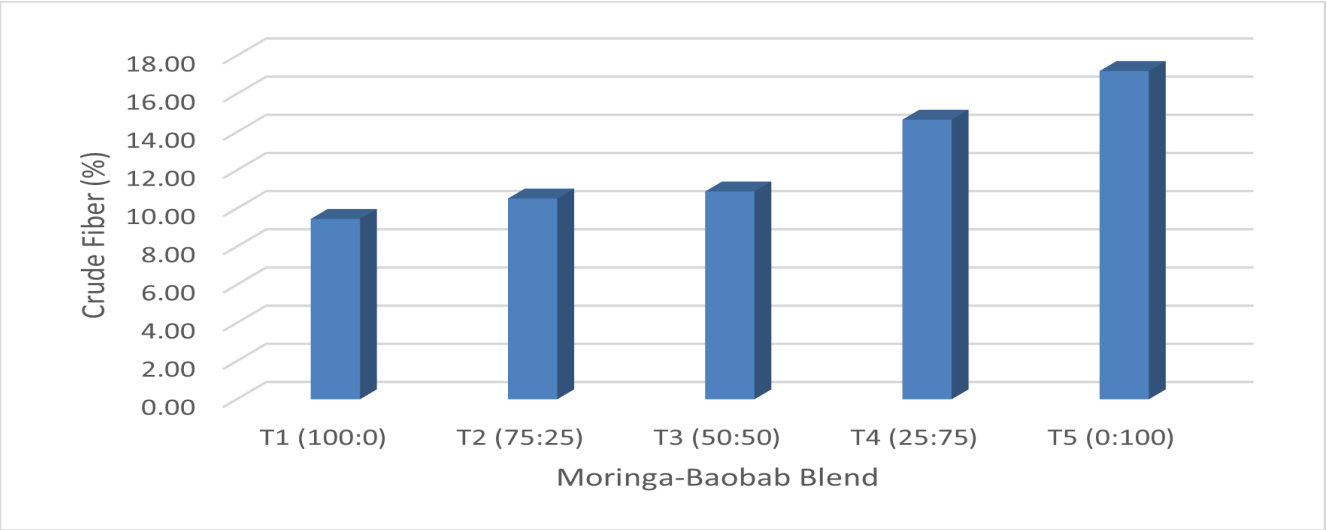
Figure 3: Distribution on carbohydrates Content



Crude fiber increased progressively with rising moringa proportions, ranging from 9.33% (T1) to 17.11% (T5). This high fiber content underscores moringa's potential in modulating glycemic response and supporting gut health (Barber et al., 2020).

Figure Crude fat content was highest in pure moringa (7,70%), supplying essential polyunsaturated fatty acids (Stadlmayr,B et al., 2025). Ash content, indicative of total mineral reserve, fluctuated significantly, recording a maximum of 7.97% in T4 (25% BPP: 75% MLP).

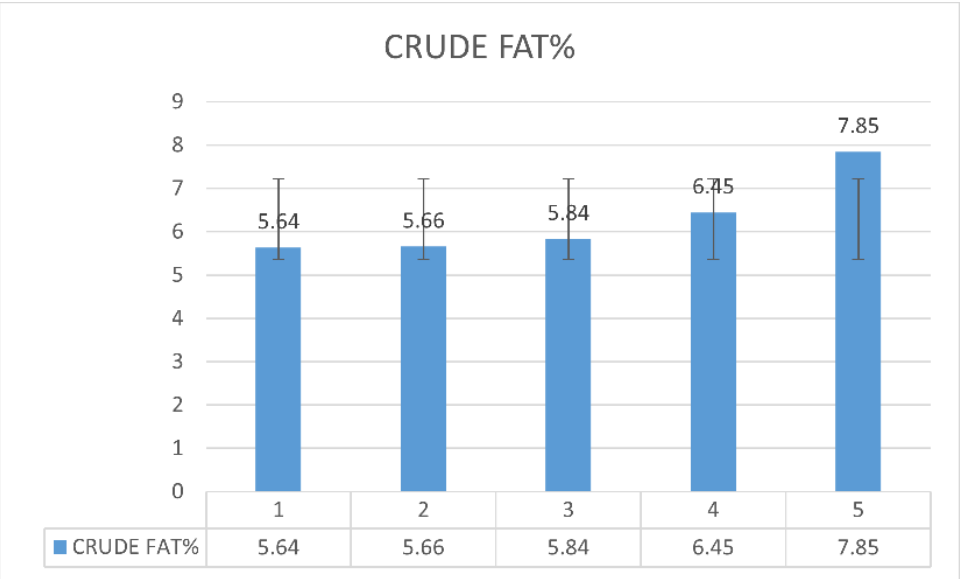
Figure 4: Distribution on Crude fibre



Lipid Stability

The monounsaturated fatty acids present in Moringa leaf powder, together with the flavonoid antioxidants found in both powders, help extend the shelf life of the blended product (Abdoun et al., 2022).

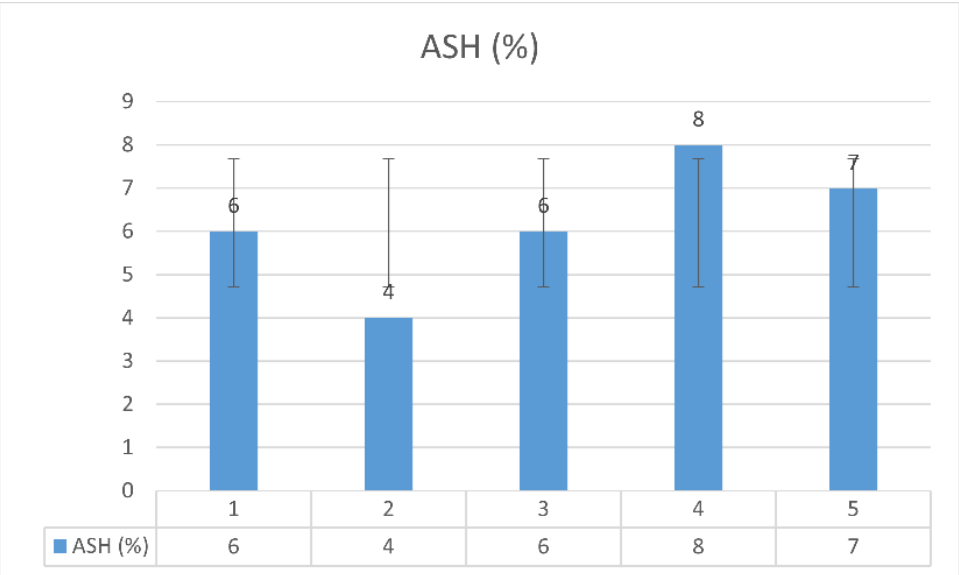
Figure 5: Distribution Crude fat Content



Ash and Mineral Density

The total ash content, which are evidence of mineral richness, remains high in the formulation. Moringa leaf powder attributes substantially Calcium up to 2003 mg/100g and Iron, whilst Baobab pulp powder contributes Potassium and Magnesium (RJPT, 2025; Dossa et al., 2023). Working as an enhancer, Baobab pulp powder's ascorbic and citric acid content helps offset the anti-nutritional phytates present in Moringa leaf powder, increasing the bio accessibility of both iron and zinc in the process (Akinola et al., 2020; Dossa et al., 2023).

Figure 6:Distribution on Crude Ash Content



Mineral Composition Dynamics

The mineral profile of the composite powders demonstrated extensive macro- and micro- element enrichment, with highly significant differences ($p < 0.01$) across treatments

(Table 2).

Treatment	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cu (mg/kg)	Mn (mg/ kg)
T1(100:0)	0.17 + 0.07b	2.88 + 0.02a	1.46 + 0.02e	0.24 + 0.01c	0.051 + 0.001a	4.52 + 0.36c	53.26 + 0.78c
T2(75:25)	0.44 + 0.01a	2.21 + 0.01b	3.02 + 0.02b	0.56 + 0.01a	0.044 + 0.000c	6.32 + 0.23b	62.91 + 0.65b
T3(50:50)	0.43 + 0.01a	2.91 + +0.03a	2.35 + 0.03d	0.45 + 0.02b	0.049 + 0.001b	5.90 + 0.13b	79.21 + 1.53a
T4(25:75)	0.37 + 0.00a	2.21 + 0.03b	2.47 + 0.02c	0.43 + 0.01b	0.041 + 0.000d	6.18 + 0.16b	67.11 + 1.69b
T5(0:100)	0.40 + 0.00a	2.09 + 0.02c	3.09 + 0.02a	0.56 + 0.01a	0.039 + 0.000e	7.61 + 0.51a	57.35 + 2.71c

T 2. Mineral composition of baobab pulp and moringa leaf powder composite blends. able

Pure moringa leaf powder (T5) contributed exceptional concentrations of calcium (3.09%), magnesium (0.05%), and copper (7.61mg/kg), reinforcing its status as a premier botanical source of bone-building minerals and hematopoietic co-factors (Babalola etal.,2020; Burkhead & Collins, 2022). Baobab pulp (T1) exhibited robust potassium (2.88%) and sodium (0.05%) levels, essential for electrolyte balance and osmotic regulation (Osman, 2004). the binary blend T2 (75% BPP: 25% MLP) exhibited strong synergistic mineral accumulation, particularly in calcium (3.02%) and phosphorus (0.44%), establishing an optical Ca: P ratio for childhood

complementary foods. Furthermore, baobab's abundant ascorbic and citric acid matrix effectively lowers local pH, chelating phytates and significantly enhancing the bio-accessibility of moringa's non-heme iron and zinc (Affonfere et al., 2022; Dossa et al., 2023).

Figure 7. Distribution on phosphorus content

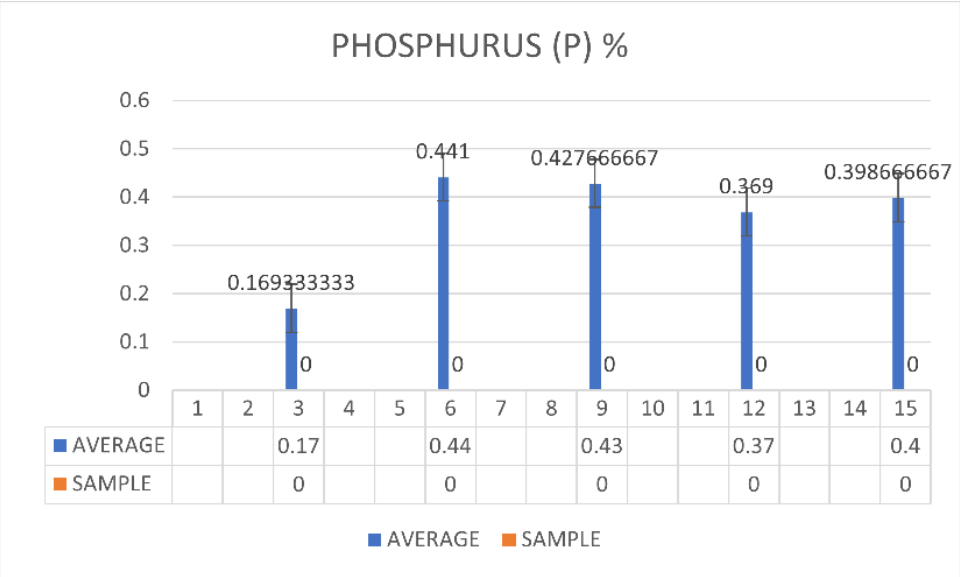


Figure 8 : distribution on potassium content

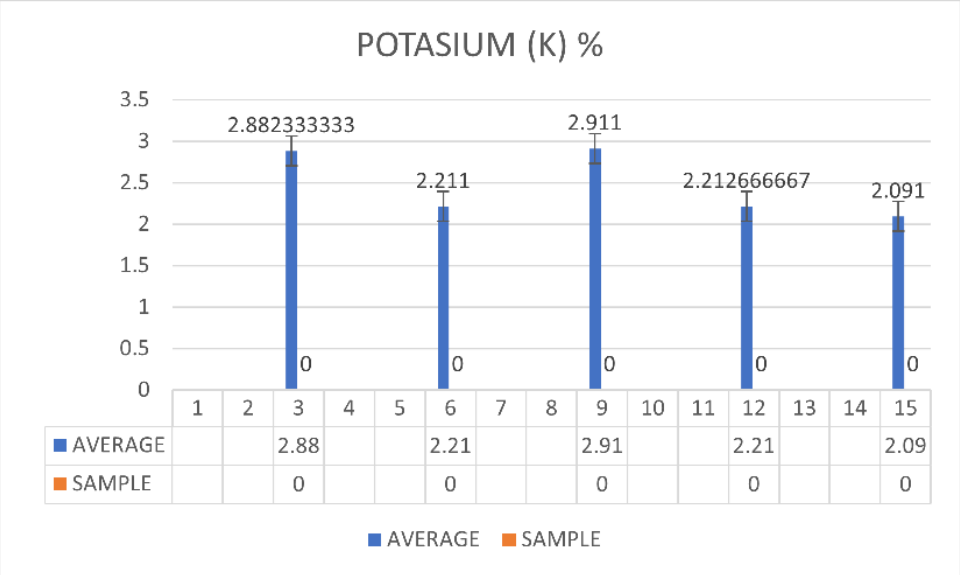


Figure 9 : Distribution on Calcium Content

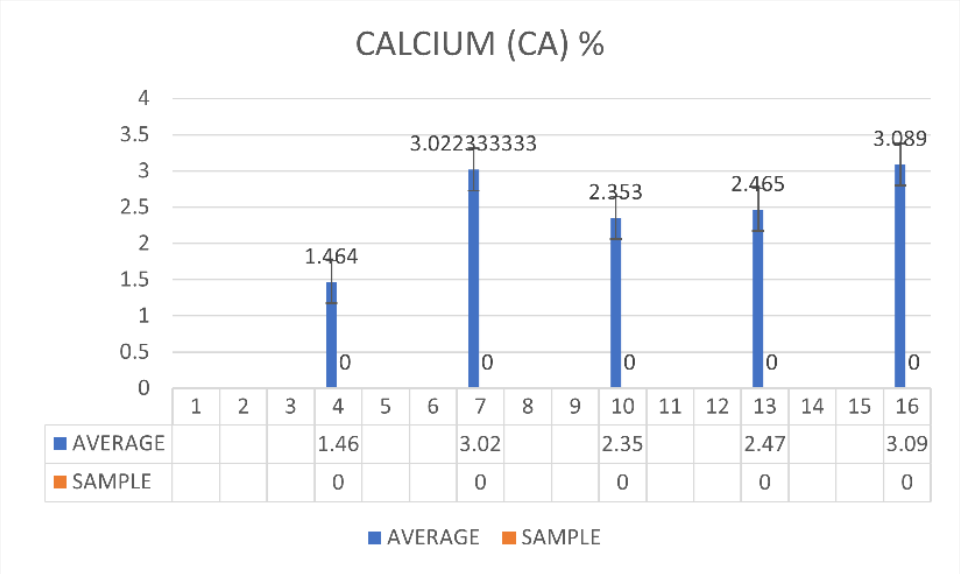


Figure 10: Distribution on Magnésium Content

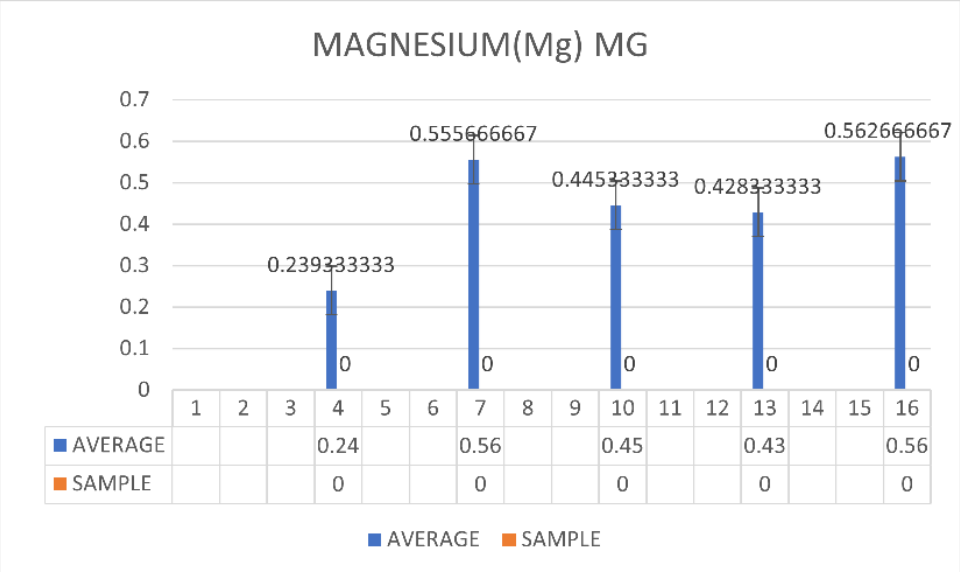


Figure 11 : Distribution on Sodium Content

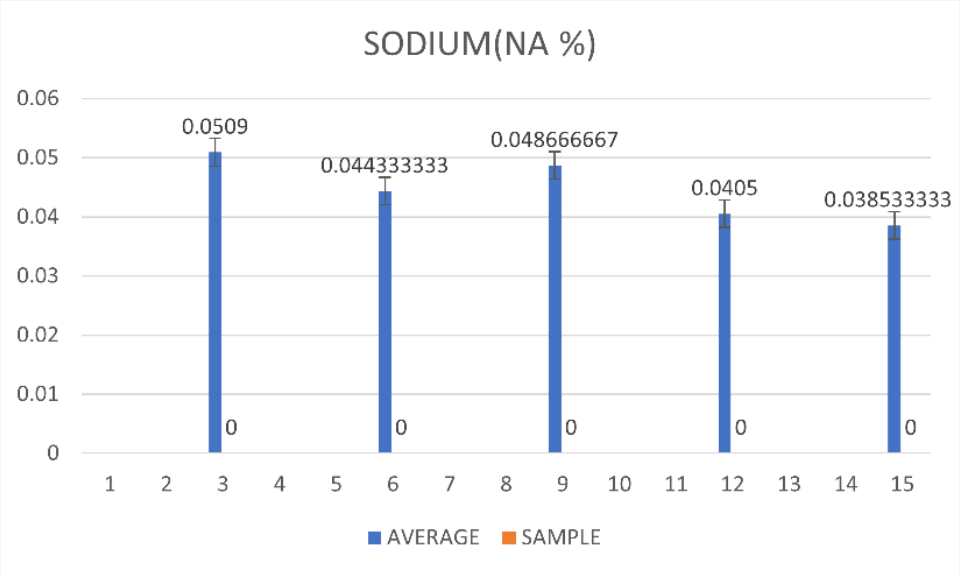


Figure 12: Distribution on Copper Content

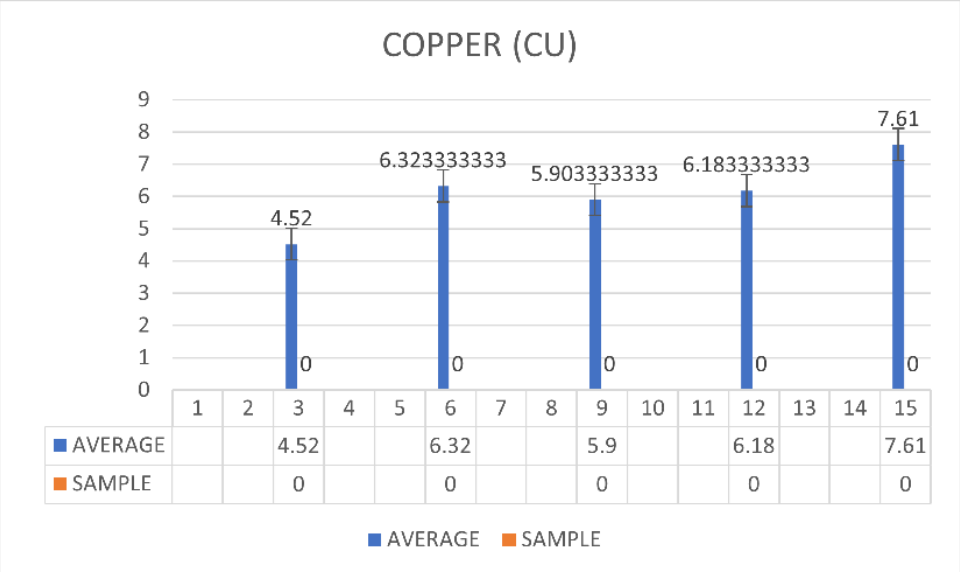
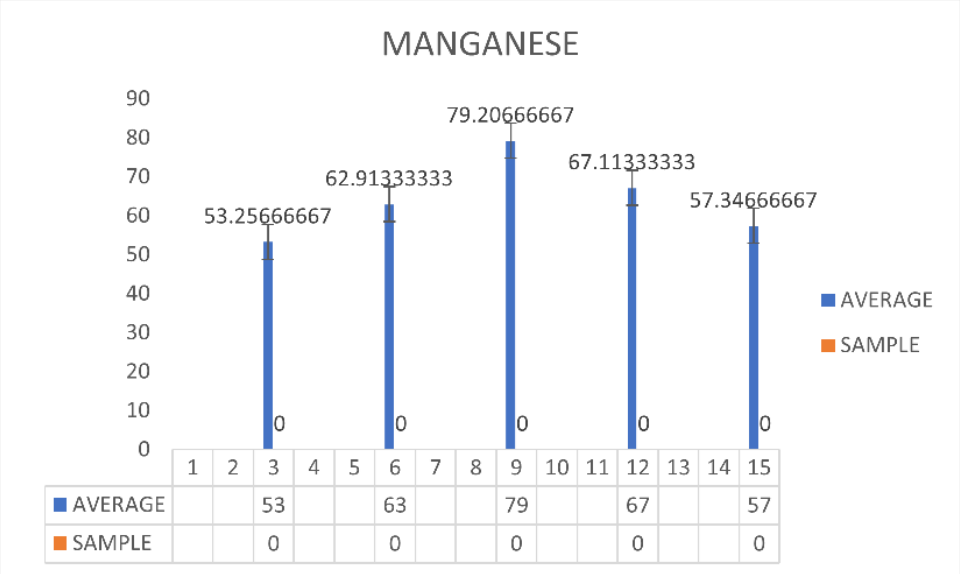


Figure 13 Distribution on Manganes Content



Recommendations

1.further studies should focus microbial load and shelf life at different storage facilities of the blended moringa powder and baobab powder.

2. research should be conducted on additional functional food that result a particular ratio of maximum mineral level

3. it recommended that 75% :25% baobab pulp powder moringa leaf powder is the best to consumers to improve taste

Conclusion

This study successfully evaluated the proximate composition and mineral profile of composite powder formulations derived from baobab pulp and moringa leaf powders. The empirical findings confirm that binary blending successfully merges

the high protein, lipid, and mineral density of moringa leaves with the rich carbohydrate, dietary fiber, and vitamin C matrix of baobab pulp. Specifically, the 75% baobab pulp to 25% moringa leaf blend (T2) demonstrated superior protein and calcium concentrations, while effectively utilizing baobab's organic acids to mask sensory astringency and enhance mineral bioavailability. Thus, dual food-to-food fortification using these climate-resilient indigenous crops offers available, sustainable, and scalable dietary strategy to combat hidden hunger and protein energy malnutrition in sub-Saharan Africa.

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