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Nutritional and Microbiological Assessment of a Complementary Food from Grain Amaranth (*Amaranthus hypochondriacus*), African Yam Bean (*Sphenostylis stenocarpa*) Seed, and Carrot (*Daucus carota*) Blends

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Abstract

The unbalanced nutrient density and low microbiological quality of many complementary foods are still the primary causes of infant malnutrition in poorer countries. In this study, complementary food was produced using blends of grain amaranth, African yam bean, and carrot flour. The resultant complementary food was analysed for proximate, mineral, antinutrients, antioxidant compositions, vitamin C, beta-carotene, microbial properties, and sensory evaluations. Principal component analysis was also used to assess nutrient clustering and separate the nutrients into components. The samples demonstrated a rich nutritional profile, with protein content ranging from 4.07 to 26.45%, carbohydrates (53.90-87.66%), fibre (0.08-1.92%), moisture (4.94-7.17%), and energy values between 373.85 and 415.47 kcal/100 g. All the samples have a high mineral content and an Na/K ratio of ~1 or below. The antioxidant properties increased with increasing concentration, with values ranging from

62.98 to 73.09% and from 4.74 to 97.10 mg AAE/g for DPPH and FRAP, respectively. No fecal contamination was observed in any of the samples. The samples, except the control, had bacterial growth ranging from 1.41 to 1.60 log_{10} (CFU/g). The sample with higher inclusion of African Yam Bean Seeds and the control were more preferred in terms of sensory properties. The PCA showed that the vectors for sodium, potassium, vitamin C, and β-carotene pointed strongly toward the positive side of PC2. Overall, the formulated blends demonstrate strong potential as affordable, nutrient-dense, and microbiologically safe complementary foods for infant and young child feeding.

Keywords
African yam bean; grain amaranth; carrot; complementary foods; seeds

1. Introduction

Proper feeding of infants right from birth is the most important factor for their healthy growth and full intellectual development during the following years. For the first six months, breast milk is the sole source of essential nutrients and bioactive compounds for infants, which not only sustains the infant but also prevents infections and developmental deficiencies [1]. After six months, however, breast milk alone tends not to meet the infant's increasing energy and nutrient requirements, which is why timely and nutritionally adequate foods are needed [2]. Meanwhile, inadequate nutrition and micronutrient deficiencies in many low- and middle-income countries are primarily attributable to the low nutrient density of complementary foods [3]. Therefore, the development of affordable, nutrient-dense complementary foods using locally available crops, therefore, becomes a public health priority. Underutilised crops not only represent promising avenues to meet such needs but, given their climate resilience, cultural familiarity, and generally high nutrient content, will also be very helpful.

Grain amaranth, also known as *Amaranthus hypochondriacus*, is one such pseudocereal appreciated for its very high protein content, ranging from 13 to 18% [4], a well-balanced amino acid profile, high essential fatty acids, and relatively high micronutrient content [5]. It is an apt gluten-free crop for complementary food formulation and food security because it can withstand extreme climatic conditions.

Another underutilized legume is the African yam bean (*Sphenostylis stenocarpa*), which is highly recognized because of its high protein concentration and potential to enhance amino acid balance in cereal-based complementary foods [6]. Although highly nutritious and appreciated for its nutritional value, it has garnered limited use due to its long cooking time and low consumer awareness [7]. Its protein richness, however, makes it a likely year-round source of plant protein for poor households.

Carrot (*Daucus carota*) is rich in β-carotene, a type of provitamin A, which is necessary for visual development, immune function, and the prevention of night blindness in children [8, 9]. Vitamin C and antioxidant constituents enhance the immune defense system and reduce oxidative stress related to chronic diseases [10]. Oxidative stress is one of the major causes of cancer and inflammation, and antioxidants help cushion its effects [11]. Incorporating vitamin C-rich components, such as carrots, into complementary food formulations tends to enhance micronutrient density and functional properties.

Given the high prevalence of malnutrition in many developing regions, there is a great need for nutrient-dense and microbiologically safe complementary foods. Blending grain amaranth, African yam bean, and carrot represents a feasible way to develop a plant-based product with a balanced nutritional profile. However, limited information exists on the combined nutritional, antioxidant, microbiological, and sensory performance of complementary foods formulated from grain amaranth, African yam bean, and carrot. This study, therefore, assessed the nutritional composition, antioxidant properties, microbiological quality, and the correlation among these parameters in a complementary food formulated from these three underutilized crops, aimed at providing evidence for their potential use in infant and young child feeding.

2. Materials and Methods

2.1 Materials

2.1.1 Sources of Materials

Grain Amaranth and African yam bean seeds were obtained from the National Horticultural Research Institute (NIHORT) and characterised at the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State. At the same time, carrots were purchased from Aleshinloye market, Ibadan. Microbiological media and chemical reagents of analytical grade were sourced from an accredited chemical store in Ibadan.

2.2 Methods

2.2.1 Production of Grain Amaranth Flour

Grain Amaranth (Figure 1) was processed into flour (Figure 2) using the slightly modified method described by Isaac-Bamgboye *et al.* [12] (Figure 3). One kilogram (1 kg) of fresh grain amaranth was weighed using a weighing scale and cleaned to remove dirt, dust, sand, and stones. It was washed manually with potable water until it was free of dirt, and the water was drained off using a plastic sieve. The drained grains were spread thinly in open air for 1 hour 40 mins, toasted in an open and wide pan on a cooking hotplate at 90°C for 10 mins, dry-milled using a Bajaj food processor (Bajaj Maverick, Model No. 410513, Bajaj Electricals Ltd, India) to get the flour, cooled to 29°C, then packaged into a zip-lock polythene bag and stored in an airtight container until further analyses.

Figure 1 Raw grain amaranth.

Figure 2 Grain amaranth flour.

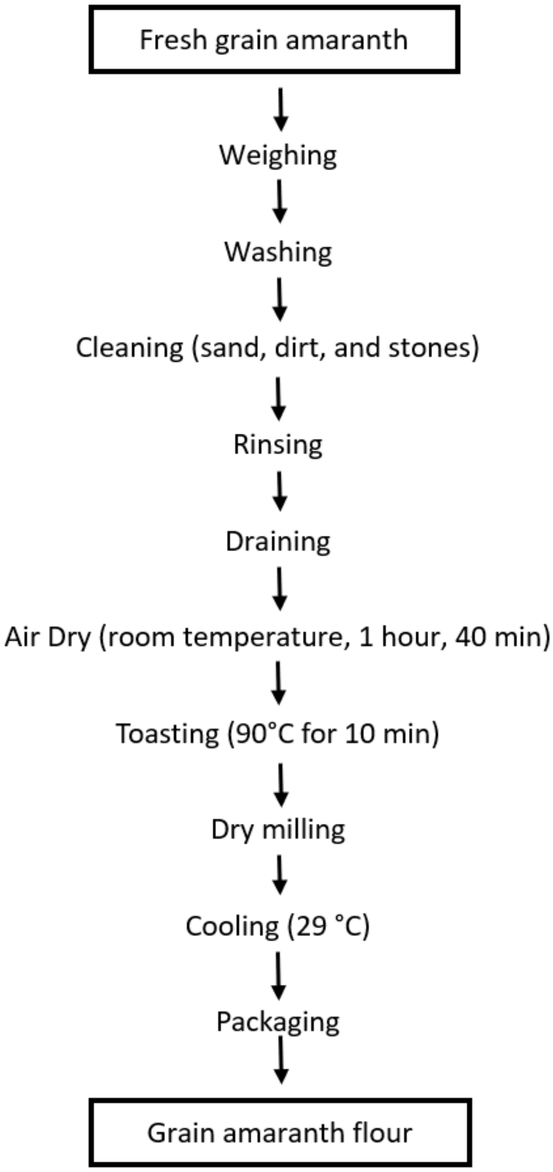


Figure 3 Production of Grain Amaranth flour. Source: Isaac-Bamgboye *et al.* [12].

2.2.2 Production of African Yam Bean Seed (AYBS) Flour

AYBS flour (Figure 4) was processed into flour (Figure 5) using the slightly modified method described by Isaac-Bamgboye *et al.* [6], as presented in Figure 6. African yam bean seeds were weighed into a clean tray and cleaned to remove dirt, stones, sticks, immature, and defective seeds. One kilogram (1 kg) of the cleaned seeds was manually rinsed with potable water to remove dust, then soaked in hot water (80°C) in a covered plastic bowl for 24 h to aid dehulling. The water was decanted, and the seeds rinsed with potable water. The African yam bean seeds were manually dehulled by rubbing between the palms, rinsed with potable water, and drained using a plastic sieve. The clean, dehulled AYBS were spread in a tray and dried in an electric hot air oven (Model: DHG-9030A, Shanghai Yiheng Scientific Instrument Co., Ltd, China) at 60°C for 5 h and toasted in an open and wide pan on a cooking hotplate of the same oven for 30 mins and cooled to 29°C. The cooled seeds were dry-milled into flour using a Bajaj food processor (Bajaj Maverick, Model No. 410513, Bajaj Electricals Ltd, India) and cooled to ambient temperature, packed into a zip-lock polythene bag, and stored in an airtight container for further analyses.

Figure 4 Raw African yam bean seed.

Figure 5 African yam bean seed flour.

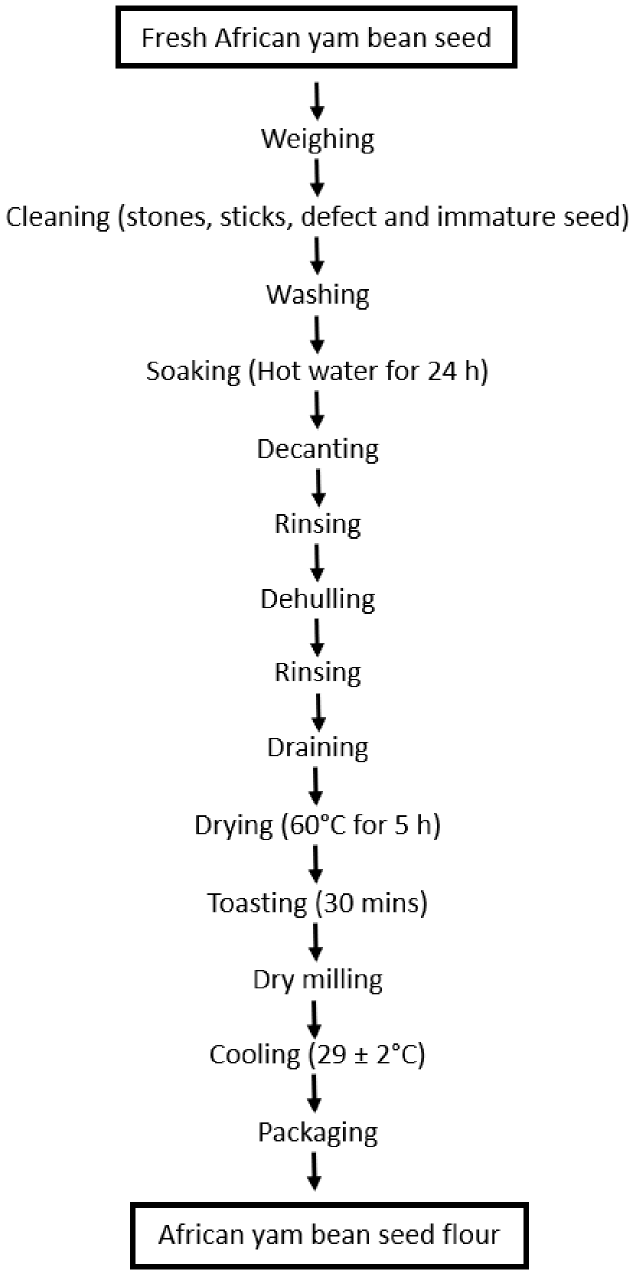


Figure 6 Production of African yam bean seed flour. Source: Isaac-Bamgboye *et al.* [6].

2.2.3 Production of Carrot Flour

Fresh carrots (Figure 7) were processed into flour (Figure 8) using the modified method of Uchegbu *et al.* [13], as presented in Figure 9. Fresh carrots were washed with potable water, and the outer layer was scraped with a manual scraper and rinsed with potable water. Six kilograms (6 kg) of the carrots were weighed, diced, and dried in an electric hot-air oven (Model: DHG-9030A, Shanghai Yiheng Scientific Instrument Co., Ltd, China) at 50°C for 8 h. The dried carrot chips were cooled to ambient temperature, dry-milled using a Bajaj food processor (Bajaj Maverick, Model No. 410513, Bajaj Electricals Ltd, India), further cooled, packaged into a zip-lock polythene bag, and stored in an airtight container for further analysis [13].

Figure 7 Raw fresh carrots.

Figure 8 Carrot flour.

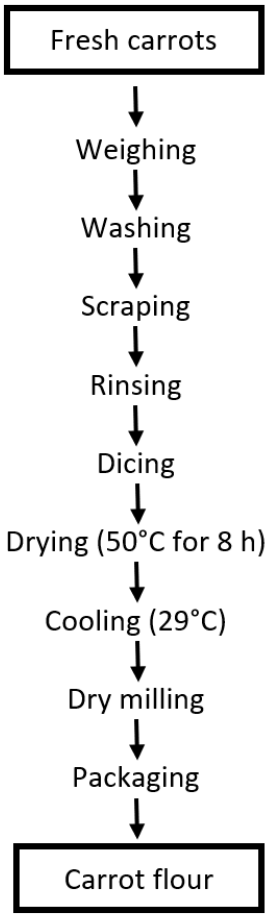


Figure 9 Production of carrot flour. Source: [13] with slight modifications.

2.2.4 Formulation of Complementary Flour Blends

All flours from Grain amaranth, African yam bean, and Carrots were blended in different proportions to develop varieties of complementary composite mixtures. Before mixing the blends, they were sieved through a 60-mesh sieve to obtain uniform flour. A popular, branded complementary food was purchased from a credible supermarket in Ibadan to serve as the commercial control sample for the formulated flour blends. The formulation ratios for the flour blends are as presented in Table 1:

Table 1 The formulation ratios for Grain amaranth, African yam bean, and Carrot flour blends.

Sample	Formulations
AYC1	90% Grain amaranth flour, 5% African yam bean flour, 5% Carrot flour
AYC2	80% Grain amaranth flour, 15% African yam bean flour, 5% Carrot flour
AYC3	70% Grain amaranth flour, 20% African yam bean flour, 10% Carrot flour
AYC10	Commercial complementary food

2.3 Analysis

2.3.1 Determination of Proximate Composition

The proximate composition (protein, moisture content, fat, ash, crude fiber, and carbohydrate) of the flour blends was determined according to the method described by AOAC [14]. Moisture content was measured using an air oven. Two grams (2 g) of each sample was dried till constant weight in hot air at 105°C for 3 h. Each time, the samples were cooled in a desiccator before weighing and re-dried until constant weight. The percentage of moisture content was calculated as:

$$\%moisture = \frac{Loss\ in\ weight}{Weight\ of\ sample\ before\ drying} \times \frac{100}{1} \quad (1)$$

The Kjeldahl method, as described by AOAC [14], was employed to determine crude protein using a Kjeldahl apparatus. The Soxhlet extraction method was used for the determination of crude fat, and crude fiber content was analyzed using AOAC [14]. The ash content was determined through dry ashing according to AOAC [14]. The total carbohydrate content of the samples was calculated by difference using equation 2, while the energy was determined using the Atwater ratio ((Protein × 4) + (Fat × 9) + (Carbohydrate × 4))

$$\%Carbohydrate = 100\% - (\%Fat + \%Ash + \%Fiber + \%Protein) \quad (2)$$

2.3.2 Determination of Mineral Content

The Calcium and iron content of the samples was evaluated using the method adopted by Adewole *et al*. [15]. The readings were taken using an atomic absorption spectrophotometer (model 205, Buck Scientific, USA). On the other hand, the monovalent elements, sodium and potassium, were assessed using a flame photometer (Sherwood Flame Photometer 410; Sherwood Scientific Ltd., Cambridge, UK) [16].

2.3.3 Determination of Anti-Nutritional Constituents

Determination of Phytate Content.

Phytate content was assayed by AOAC [14]. Four grams of the sample were extracted in 100 mL of 2% HCl for 3 h and filtered through Whatman No. 1 paper. An aliquot (25 mL) of the filtrate was transferred to a 250 mL conical flask, combined with 5 mL of 0.3% ammonium thiocyanate indicator and made up to 53.5 mL with distilled water. The mixture was titrated against standard $FeCl_3$ solution (0.00195 g Fe/mL) to a stable brownish-yellow end point maintained for 5 min.

Determination of Tannin Content.

The tannin content was determined according to the modified Folin-Ciocalteu method by Singh *et al*. [17]. To 0.1 mL of sample extract was added 7.5 mL distilled water, 0.5 mL Folin-Ciocalteu reagent, and 1 mL of 35% Na_2CO_3, and made up to 10 mL. After incubation at room temperature for 30 min, absorbance was measured at 725 nm (SpectraLab 752s). Gallic acid standards (20-100 µg/mL) were used for calibration, and results were expressed as mg gallic acid equivalents (GAE) per g extract.

Determination of Oxalate Content.

The oxalate was determined according to the described method by Joslyn [18]. One gram of the sample was added to 75 mL of 1.5 N H_2SO_4, and the solution was carefully stirred using a magnetic stirrer for 1 h before being filtered using Whatman No. II filter paper. 25 milliliters of the extract were collected and titrated when hot against 0.1 N $KMnO_4$ solution to a faint pink color endpoint.

$$Oxalate = (titre\ value \times 0.9004)\ mg/g \tag{3}$$

2.3.4 Determination of Qualitative Phytochemical Composition

Determination of Reducing Power Activity (FRAP).

Reducing power was evaluated according to Yen and Duh [19]. Different concentrations of the extracts were combined with 2.5 mL of each phosphate buffer, 200 mM at pH 6.6, and 1% potassium ferricyanide, incubated at 50°C for 20 minutes. 2.5 mL of 10% trichloroacetic acid was then added and the mixtures centrifuged at 650 ×g for 10 minutes. Supernatant (5 mL) was combined with 5 mL distilled water and 1 mL of 0.1% ferric chloride. Absorbance was measured at 700 nm for reducing power.

Determination of DPPH Radical Scavenging Ability.

The DPPH free radical scavenging activity was determined according to the method of Gyamfi *et al*. [20]. One milliliter of the extract at various concentrations (25-400 µg/mL) was added to 1 mL of 0.4 mM methanolic DPPH solution, and incubation was done in the dark for 30 min. Absorbance was read at 517 nm. The radical-scavenging activity was calculated in relation to the control using the formula:

$$\%Inhibition = \frac{(AC - AS)}{AC} \times 100 \tag{4}$$

2.3.5 Determination of Vitamin C

Vitamin C was assessed by iodimetric titration. One hundred milliliters of 0.005 M iodine solution were prepared by dissolving 2 g KI and 1.3 g iodine in distilled water. Starch indicator (0.5% w/v) was made by heating 0.25 g soluble starch in 50 mL. The samples (5 g) were made up to 100 mL, left standing for 2 h, and then filtered. A 25 mL aliquot of the filtrate was then titrated with 0.005 M iodine after adding 1 mL starch solution to the endpoint of persistent blue-black coloration. Triplicate analyses were made. Vitamin C concentration was computed using the factor: 1 mL of 0.005 M iodine = 0.008806 g ascorbic acid.

2.3.6 Determination of Beta-Carotene

β-Carotene was estimated following the method of Ranganna [21]. One gram of the sample was extracted with 5 mL of methanol at room temperature for 2 h in the dark. Extracts were partitioned with hexane in a separatory funnel, and the hexane phase was diluted to a final volume of 10 mL. The solution was dried over sodium sulphate, and the absorbance was measured at 436 nm using hexane as a blank. β-Carotene content was calculated as:

$$\beta\text{-}Carotene(\mu g/100\ g) = \frac{Abs(436\ nm) \times V \times D \times 100}{W \times Y} \quad (5)$$

Where: *V* = Total volume of extract; *D* = Dilution factor; *W* = sample weight; *Y* = percentage dry matter content of the sample.

2.3.7 Microbiological Analysis

The enumeration of microorganisms was carried out on each flour blend two hours after preparation. Total bacteria count, total coliform, and total fungal count were conducted using Nutrient agar (37°C for 48 hours under aerobic conditions) to assess bacterial contamination, and Coliform Count was conducted using MacConkey Agar (37°C for 24 hours under aerobic conditions) to detect potential faecal contamination; these tests were carried out under aseptic conditions [22].

Three different dilution factors (10^{-4}, 10^{-5}, and 10^{-6}) were used. The total number of colonies observed was multiplied by the dilution factor to calculate the total bacterial count (TBC). Total coliform, mold, and total viable count were expressed as colony-forming units per gram (CFU/g) of the sample. The total bacteria count was calculated as follows:

$$\frac{Number\ of\ colony \times Dilution\ factor}{Volume\ of\ inoculum} \quad (6)$$

2.3.8 Sensory Evaluation

The sensory evaluation of the complementary flour blends was carried out in the laboratory. All the samples were prepared into sample bottles (ketchup cup) based on the formulation proportions of Grain amaranth, African yam bean, and carrot flour blends. The samples were prepared as a paste at a ratio of 1 part flour blend to 5 parts clean boiled water, and stirred until a consistent paste was obtained. The organoleptic properties of the samples from the flour blends were evaluated by thirty (30) semi-trained panellists, randomly chosen from the staff and students of the Abiola Ajimobi Technical University who are nursing mothers or have infants and are familiar with ogi as described by Alabi *et al*. [23]. The panelists were briefed before the evaluation process commenced. Sensory attributes evaluated were: Appearance, taste, flavor, mouthfeel, consistency, and overall acceptability. The rating was on a 9- point hedonic scale ranging from 1 = dislike extremely to 9 = like extremely [24].

2.3.9 Principal Component Analysis

PCA was implemented with Minitab Statistical Software (Version 21, Minitab LLC, USA) to explore the multivariate relationships and patterns among the complementary flour blends from grain amaranth, African yam bean, and carrot. The data analysis gave us a clearer understanding of the samples (AYC1, AYC2, AYC3, AYC10) in terms of proximate composition, mineral content, vitamin C, beta-carotene, and microbiological counts. The quantitative data were input into Excel and then imported into Minitab. Only quantitative variables were considered.

Variables had different units (%; mg/100 g; μg/100 g; CFU/g); therefore, all variables were standardized to a mean of zero and a standard deviation of one to avoid disproportionate influence. PCA was performed using the correlation matrix, generating eigenvalues, variance explained, scree plot, biplot, and component scores. The Kaiser criterion (eigenvalue > 1) and inspection of the scree plot were used to retain components. Biplot interpretation provided indications about the influence of each variable on the components and locations of the samples according to their clusters and differences between the blends.

2.3.10 Statistical Analysis

Data obtained from the proximate, antinutritional, phytochemical, antioxidant, mineral, microbiological, and sensory evaluations were statistically analyzed using SPSS (version 2021) to determine significant differences among the different formulations. Duncan's Multiple Range Test (DMRT) was employed to compare means and establish statistically significant variations. A confidence level of 95% ($p < 0.05$) will be used for all analyses to determine statistical significance.

2.4 Ethics Statement

Sensory testing followed the official protocols of the Ethical Committee, School of Agriculture and Agricultural Technology, Federal University of Technology, Akure, Nigeria (FUTA/SAAT/2022/036), adopted by the Ethical Committee at Abiola Ajimobi Technical University. Caregivers serving on the panel were briefed on the study's objectives and provided verbal consent before their participation.

3. Results and Discussions

3.1 Proximate Composition of the Complementary Flour

The proximate composition of the complementary blends produced from grain amaranth, African yam bean, and carrot flour is shown in Table 2. The moisture content ranged from 4.94% to 7.16%, with the commercial samples exhibiting the lowest. There is no significant difference ($p \geq 0.05$) between AYC1 and AYC2 with 90% and 80% amaranth. All moisture values were below the recommended 10% threshold for dry infant foods, indicating good storage stability and reduced microbial risk [25]. This is consistent with previous reports on cereal-legume complementary blends [26].

Table 2 Percentage Proximate Composition of Grain Amaranth (*Amaranthus hypochondriacus*), African Yam Bean (*Sphenostylis stenocarpa*) Seed Flour.

Sample	Moisture	Protein	Fat	Crude Fibre	Ash	Carbohydrate	Energy (kcal)
AYC1	7.16 ± 0.02^{a}	17.45 ± 0.04^{c}	8.43 ± 0.03^{c}	1.44 ± 0.05^{c}	2.73 ± 0.03^{c}	62.79 ± 0.07^{b}	396.83^{c}
AYC2	7.16 ± 0.03^{a}	23.68 ± 0.01^{b}	10.56 ± 0.01^{b}	1.76 ± 0.06^{b}	2.94 ± 0.01^{b}	53.90 ± 0.03^{c}	405.36^{b}
AYC3	6.97 ± 0.03^{b}	26.45 ± 0.03^{a}	12.59 ± 0.03^{a}	1.92 ± 0.02^{a}	2.98 ± 0.02^{a}	49.09 ± 0.06^{d}	415.47^{a}
AYC10	4.94 ± 0.04^{c}	4.07 ± 0.02^{d}	0.77 ± 0.02^{d}	0.08 ± 0.02^{d}	2.48 ± 0.02^{d}	87.66 ± 0.02^{a}	373.85^{d}

Values represent the means of three replicates ± standard deviation. Mean values followed by different superscripts within columns are significantly different according to Duncan's Multiple Range Test ($p < 0.05$), represented with a-d. Repeated superscript letters indicate that the means were not significantly different ($p > 0.05$).

KEY: AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control.

Protein content varied significantly among the samples, ranging from 4.07% to 26.45%. The nutritional value of protein in all the formulated blends met the requirements set by FAO/WHO for complementary foods [27], while that of the commercial control did not. The increased protein levels were indicative of the addition of African yam bean and grain amaranth, known sources of quality plant proteins. Similar protein fortification has been achieved in other blends made using legumes and pseudocereals [28, 29]. These findings indicate the potential for significantly enhanced nutritional adequacy of these ingredients for infant growth and tissue development, especially when used as a replacement for low-nutrient complementary foods available to nursing mothers.

The fat content ranged between 0.77 and 12.59%. The highest value was observed in AYC3. These values fall within and, in some instances, exceed the ranges reported for similar cereal-legume-vegetable blends [28]. Indeed, this variation reflects the various contributions of grain amaranth and African yam bean to lipids; carrot added very little. More importantly, all formulations met the minimum requirement set by FAO/WHO for fat, hence supporting energy density and absorption of fat-soluble vitamins.

Crude fiber ranged from 0.08 to 1.92%, below the recommended upper limit of 4% for infant foods. Low fiber content is desirable because high fiber intake can decrease energy density and displace nutrients in infants under 24 months. Values agree with previously reported low-fiber complementary blends [28]. Slight differences in the studies are most likely due to ingredient ratios and milling intensities, both of which affect the degree of fiber reduction in composite flours.

Ash content (2.48-2.89%) was within expected ranges for cereal-legume-vegetable blends and similar to values reported earlier for millet-legume and sorghum-legume complementary foods [30, 31]. The relatively small variations suggest that African yam bean, grain amaranth, and carrot have comparable mineral compositions with conventional raw materials commonly used in formulations of complementary foods.

Carbohydrate content ranged from 49.09 to 87.66% and increased with increasing levels of substitution of African yam bean and carrot. These values were in agreement with carbohydrate-rich mixtures established in related works by Jenfa *et al*. [32] on sorghum-orange-fleshed sweet potato composite flour. They exceeded the >60% recommendation of FAO/WHO [33] and the 51.23-54.23% reported by Akinola *et al*. [34]. The control samples outperformed all other samples in this regard. Sample AYC1 possesses the highest CHO value (62.78%) among the composites. This can be attributed to a higher level of grain amaranth in this sample and a much higher level of carrot in the other samples.

There was a significant difference ($p \leq 0.05$) in the energy contributions of the flour mixtures that were used as the complements. AYC3 was the highest scorer with a terrific 415.47 kcal/100 g, while AYC10 was the lowest at the other end of the range with 373.85 kcal/100 g. While the control sample exhibited a higher carbohydrate (CHO) content, it possessed the lowest energy value. This is likely due to the lower crude fat content in the control, as fat provides a higher caloric contribution per gram according to the Atwater formula (9 kcal/g for fat; 4 kcal/g for protein and carbohydrate). Additionally, the considerable caloric content of AYC3 and AYC2 could be due to their high fat and protein contents, as together they are the main sources of metabolic energy [35]. The very low caloric density of the AYC10 blend, however, is due to its low fat and protein content, despite its high carbohydrate content. Hence, the AYC3 and AYC2 blends may provide a higher caloric intake for complementary feeding, while the AYC10 blend will be suitable in situations where a lower energy density is required.

3.2 Mineral Content of the Complementary Flour

The mineral content of grain amaranth (*Amaranthus hypochondriacus*), African yam bean (*Sphenostylis stenocarpa*) seed, and carrot (*Daucus carota*) flour blends is presented in Table 3. Calcium is vital for the optimal growth and development of newborns and young children [36]. The calcium content of the complementary flour blends ranged from 902.45 to 1604.84 mg/100 g, with sample AYC1 having the lowest and sample AYC3 the highest. The sample flour blends contained significant amounts of the element, hence making them suitable meals for children. Previous researchers, Arukwe *et al.* [37] and Adepeju *et al.* [38], reported lower calcium values ranging between 41.10-340.82 mg/100 g and 156.50-500 mg/100 g, respectively, for their samples with about 70% pearl millet flour, 20% African yam bean seed flour, and 10% carrot flour. The increase in calcium content observed in this study could be due to inclusions in grain amaranth, which is completely absent in those studies; hence, all the samples exceeded the recommended calcium intake (295 mg/100 g) in infants.

Table 3 Mineral content of grain amaranth, African yam bean seed, and carrot flour blends (mg/100 g).

Sample	Ca	K	Na	Fe	Na/K
AYC1	502.45	217.4	100	9.053	0.459982
AYC2	406.473	172.4	85.175	6.755	0.494055
AYC3	386.838	221.2	229.95	7.025	1.039557
AYC10	1068.73	230.075	128.275	13.82	0.557536

KEY: AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control.

The potassium content of the flour blends ranged from 217.40 to 239.27 mg/100 g, with sample AYC1 having the lowest value and AYC3 having the highest value. These results showed obvious differences in the potassium content of the flour blends and the commercial control. Similar to the observations of the present study, Adepeju *et al.* [38] reported a potassium content in the range of 195.00-570.00 mg/100 g in the complementary food. However, Arukwe *et al.* [37] reported a higher value. From a nutritional standpoint, these potassium levels contribute significantly to the Adequate Intake (AI) for infants, playing a vital role in maintaining intracellular osmotic pressure and supporting neuromuscular function during early development [39-41].

The sodium content of the test samples varied significantly ($p < 0.05$) between 85.175 and 128.28 mg/100 g, with sample AYC2 having the lowest value and commercial control (AYC10) having the highest value. Adepeju *et al.* [38] also reported a reduced sodium content ranging between 33.00 mg/100 g and 180.00 mg/100 g of the complementary foods prepared using Maize, sorghum, soybean, crayfish, and date palm fruits. Among the formulated flour blends, the highest sodium content was observed in the complementary foods prepared with 90% grain amaranth, 5% African yam bean seed, and 5% carrot flours (AYC1). The relatively higher sodium content in AYC1 (90% Grain Amaranth, 5% African Yam Bean, 5% Carrot) may be attributed to the superior mineral profile of grain amaranth compared to conventional cereals. Importantly, the low sodium levels observed across all blends are nutritionally advantageous, as they minimize the renal solute load on the developing infant kidneys and contribute to a favorable Sodium-to-Potassium (Na/K) ratio, which is critical for cardiovascular health [42]. Additionally, Akinyede and Ajewole [43] reported that high intake of sodium can elevate blood pressure, while potassium opposes this effect.

The iron content of all the samples ranged significantly ($p < 0.05$) from 9.05-17.03 mg/100 g, with sample AYC1 having the lowest value and AYC3 having the highest value, which were higher than that of AYC10 (13.82 mg/100 g). Iron is essential for the transportation of oxygen, healthy bone growth, and overall metabolic activities in infants [44]. Given that iron deficiency remains a leading cause of anemia in weaning infants [45], the high iron density of AYC3 suggests it could serve as an effective dietary intervention to meet the high iron requirements (11 mg/day for infants 7-12 months) during the complementary feeding period [46].

3.3 Antinutritional Constituents of the Complementary Flour

Table 4 presents the antinutritional composition of the grain amaranth-African yam bean-carrot flour blends and the commercial control. There were significant ($p < 0.05$) variations in the phytate, oxalate, and tannin among the complementary food samples.

Table 4 Antinutrient Content of the Complementary Flour.

Sample	Phytate (mg/g)	Oxalate (mg/g)	Tannin (mg GAE/g)
AYC1	4.02 ± 0.09^{a}	3.66 ± 0.05^{a}	0.35 ± 0.01^{c}
AYC2	2.96 ± 0.10^{b}	1.44 ± 0.00^{c}	0.45 ± 0.01^{b}
AYC3	2.53 ± 0.10^{c}	1.63 ± 0.01^{b}	0.71 ± 0.01^{a}
AYC10	1.31 ± 0.01^{d}	0.28 ± 0.02^{d}	0.45 ± 0.00^{b}

Values represent the means of three replicates ± standard deviation. Mean values followed by different superscripts within columns are significantly different according to Duncan's Multiple Range Test ($p < 0.05$), represented with a-d. Repeated superscript letters indicate that the means were not significantly different ($p > 0.05$).

KEY: AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control.

The phytate levels in the samples ranged from 1.31 to 4.02 mg/g, with AYC1 recording the highest at 4.02 mg/g, and the commercial control, AYC10, having the lowest, 1.31 mg/g. AYC2 and AYC3 are statistically the same at 2.53%, indicating that increasing African yam bean and carrot inclusion beyond 15 mg/g did not further elevate the phytate concentration. The higher phytate level observed in AYC1 may be attributed to its higher grain amaranth proportion, since the cereal and pseudo-cereals are known phytic acid contributors. However, the overall phytate values reported in this study are substantially lower than those previously reported for unprocessed or minimally processed African yam bean and cereal-based complementary food blends. For example, phytate contents in the range of 2.95-7.08 mg/g were reported by [7] for processed African yam bean seeds. In contrast, higher ranges were reported in limitedly processed complementary food formulations by Wasihun *et al*. [47]. The relatively low phytate levels recorded in the present study suggest that applied processing steps were effective in reducing the levels of phytic acid, probably as a result of partial activation of endogenous phytase enzymes. This is nutritionally important because phytate strongly chelates essential minerals like iron, zinc, and calcium, thereby reducing their intestinal absorption [48]. Even though the formulated blends contain valuable sources of minerals, residual phytate, more so in AYC1, shows that further strategies to reduce phytate, such as extended fermentation or malting, would improve mineral bioavailability, especially for infants who have a very high demand for micronutrients.

The oxalate values ranged from 0.279 to 3.662 mg/g among the samples. AYC1 had the highest value of 3.662 mg/g, followed by AYC3, which had 1.633 mg/g, and AYC2 with 1.441 mg/g, while the commercial control, AYC10, had the lowest value. The markedly lower oxalate contents of AYC2 and AYC3 compared with AYC1 suggest that increasing African yam bean and carrot inclusion contributed to oxalate dilution or enhanced oxalate reduction during processing. The values obtained for the formulated blends are considered low and nutritionally acceptable, considering the reported levels of oxalate for raw or inadequately processed plant-based foods [49].

The complementary foods should ideally have lower levels of oxalate since it forms insoluble complexes with calcium and, therefore, reduces the bioavailability of calcium; this, in turn, may lead to the risk of mineral imbalance [50]. The reduced levels of oxalate in the AYC formulations agree with those reported by Njoki *et al*. [51], who found that soaking and similar pre-treatment methods were effective ways of leaching water-soluble oxalates from legumes and grains. This suggests that the formulated blends will have a minimal risk of oxalate-related inhibition of minerals during infant feeding.

The tannin content ranged from 0.354 to 0.713 mg GAE/g, and among the formulated samples, AYC3 recorded the highest tannin, while AYC1 represented the least. The tannin content for the commercial control was comparable to that of AYC2. The relatively low tannin values observed across all samples suggest that tannins were effectively reduced in processing. Tannins are well-known to bind dietary proteins and inhibit digestive enzymes, thus markedly reducing protein digestibility along with mineral absorption [52]. According to Cirkovic-Velickovic and Stanic-Vucinic [53], the low tannin levels recorded in this study, especially for AYC1 and AYC2, suggest improved nutrient utilization, hence enhanced nutritional quality of the formulated complementary foods. Although AYC3 has slightly higher content, the value remains within nutritionally acceptable limits and is unlikely to inhibit protein digestibility. Instead, moderate tannin levels may contribute antioxidant benefits that complement the antioxidant profile previously observed in the same formulation [54].

Although the enriched formulations had significant amounts of calcium, potassium, sodium, and iron, the nutritive importance of these minerals can only be achieved if these are absorbed and available for use. Several antinutritional factors can interfere with the availability of these minerals. Phytate, oxalate, and tannins are known to decrease nutrient bioavailability, particularly of minerals, by forming insoluble complexes with mineral ions, thereby reducing mineral solubility and intestinal absorption [55]. Phytate is the most powerful mineral bioavailability inhibitor since it forms stable complexes with divalent minerals such as calcium and iron due to the presence of phosphate groups [56]. Therefore, even though AYC1 is rich in calcium and iron, its higher phytate content will reduce mineral availability. The reduced content of phytates in the successive samples (AYC2 to AYC10) indicates better mineral availability. In addition, oxalate inhibits calcium absorption through the formation of insoluble calcium oxalate; hence, higher oxalate content in AYC1 is likely to have inhibited more calcium absorption than other formulations. Tannins inhibit mineral absorption through the formation of insoluble complexes; however, the higher tannin content of AYC3 may slightly reduce iron bioavailability, although the tannin levels in all samples were relatively low.

3.4 Qualitative Phytochemical Composition of the Complementary Flour

The qualitative phytochemical composition of grain amaranth (*Amaranthus hypochondriacus*), African yam bean (*Sphenostylis stenocarpa*) seed, and carrot (*Daucus carota*) flour blends is presented in Table 5. The saponin content of the flour blends ranged in moderate amounts (+ve), which could not be found in the commercial control (AYC10). Tannin, terpenoid, coumarin, alkaloid, and phenols are present in minimal quantities (+ve) in all the samples of the test. All the complementary flour blends and the commercial control flavonoid, steroid, quinones, diterpenes, anthocyanins, and cardiac glycosides could not be detected. Saponins are found in various plants, roots, and legumes, where they possess a steroid aglycone structure bonded to a carbohydrate moiety. Their presence in food products has been considered harmful, to the extent that they may impair absorption when consumed regularly [6]. According to Eze *et al.* [57], reported that absence of flavonoids, steroids, quinones, di-terpenes, anthocyanins, and cardiac glycosides could be due to processing methods such as boiling, fermentation, cooking, and soaking.

Table 5 Qualitative Phytochemical Composition of the Complementary Flour.

SN	Phytochemicals	AYC1	AYC2	AYC3	AYC10
1	Saponin (Foam Test)	+ve	+ve	+ve	-ve
2	Tannin	+ve	+ve	+ve	+ve
3	Flavonoid (Lead Acetate' Test)	-ve	-ve	-ve	-ve
4	Steroid (Salkowaski Test)	-ve	-ve	-ve	-ve
5	Quinones (Hcl)	-ve	-ve	-ve	-ve
6	Terpenoid (Salkowaski's test)	+ve	+ve	+ve	+ve
7	Coumarin (Reaction with 10% NaOH)	+ve	+ve	+ve	+ve
8	Di-terpenes (Cupric Acetate's Test)	-ve	-ve	-ve	-ve
9	Anthocyanins (Reaction with Acid and NH3)	-ve	-ve	-ve	-ve
10	Alkaloid (Hager's Test)	+ve	+ve	+ve	+ve
11	Cardiac Glycosides (Legal's Test)	-ve	-ve	-ve	-ve
12	Phenols	+ve	+ve	+ve	+ve

+ve means that the compound is present in the sample, while -ve means that the compound is absent in the sample.

KEY: AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds, and 10% Carrot; AYC10 = Commercial Control.

3.5 Antioxidant Composition of the Complementary Flour

The quantitative phytochemical composition of grain amaranth (*Amaranthus hypochondriacus*), African yam bean (*Sphenostylis stenocarpa*) seed, and carrot (*Daucus carota*) flour blends are illustrated in Figure 10 and Figure 11. The total phenolic contents are AYC3 > AYC10 > AYC2 > AYC1, with AYC3 having the maximum total phenolic content. This indicates that AYC3 has one of the best abilities to reduce radicals, thus emphasizing the importance of total phenolic content in increasing reduction capacity. Consequently, AYC1, with one of the highest DPPH radical-scavenging activities, despite its lower total phenolic content, reveals that total phenolics play a rather less significant role compared to their efficiency.

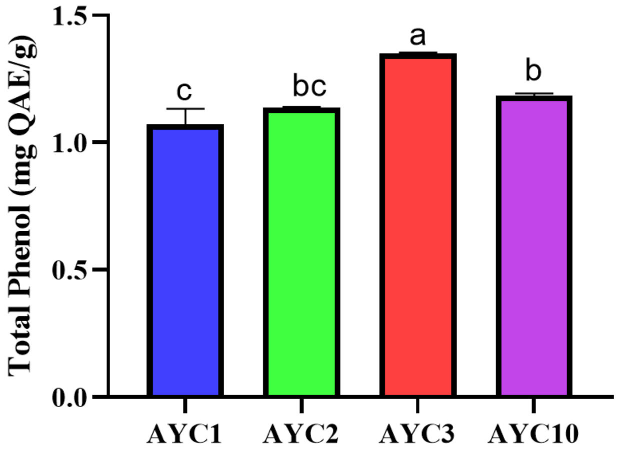


Figure 10 Total Phenol Content of grain amaranth, African yam bean seed, and carrot flour blends. Each bar represents the mean of three replicates ± standard deviation. Mean values followed by different superscripts on each bar are significantly different according to Duncan's Multiple Range Test ($p < 0.05$), represented with a-d. Repeated letters indicate that the means were not significantly different ($p > 0.05$). **KEY:** AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control.

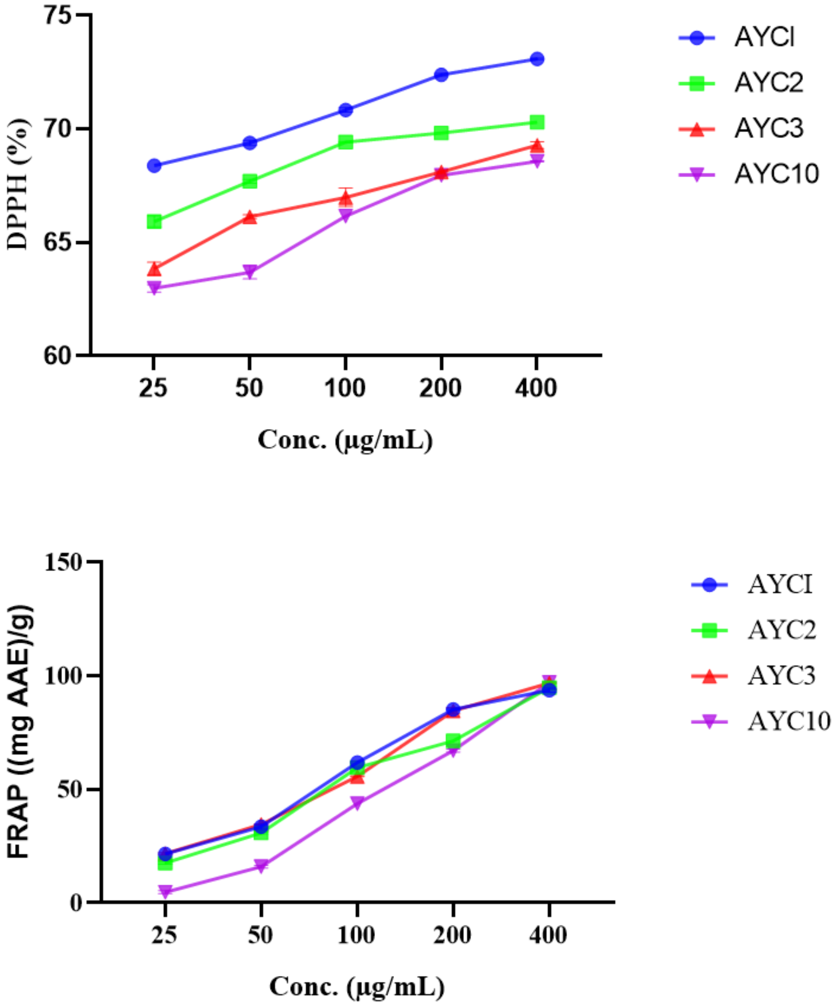


Figure 11 *In-vitro* antioxidative activities of grain amaranth, African yam bean seed, and carrot flour blends. **KEY:** AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control.

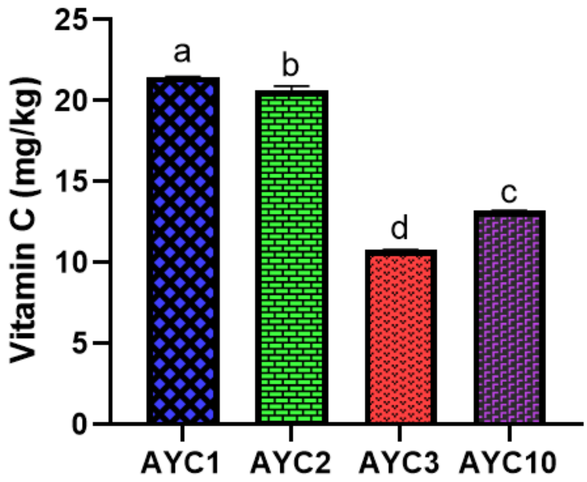
The DPPH radical scavenging capacity of the complementary food formulations of AYC (AYC1 to AYC3) and the commercial control (AYC10) showed a gradual increase with an increase in the concentration of extracts from 25 to 400 µg/mL, and this indicates that there is a concentration-dependent activity of scavenging of free radicals.

Amongst the formulations, AYC1 (90% grain amaranth, 5% African yam bean, 5% carrot) showed maximum DPPH radical-scavenging capacity across all concentrations. This indicates that grain amaranth contains compounds with strong radical-scavenging ability [58], which may be attributed to phenolic acids or flavonoids. When considered from the complementary aspect, it can be inferred that those diets that have high grain amaranth content can scavenge free radicals even at low concentrations, which is an effective measure, considering that portion sizes are small in infants. However, the activity reduced gradually as the inclusion levels of African yam bean and carrot were increased. Although African yam bean and carrot have good nutritional value, increasing inclusion levels could reduce the concentration of highly active radical-scavenging compounds or their accessibility due to interactions within the mixture. This also emphasizes the significance of formulation optimization in combining nutrient enhancement with functional antioxidant activity [59].

The Fe^{3+} reducing activity of the samples increased with concentration, with all samples tested exhibiting potential in reducing Fe^{3+} to Fe^{2+}. At concentrations of 400 µg/mL, AYC3 had the highest FRAP value of 96.81 mg AAE/g, followed closely by the commercial control and then the other samples. The better Fe^{3+} reducing activity of AYC3 can be attributed to the combined effects of African yam bean and carrot, both of which possess phenolic compounds and carotenoids. At lower concentrations, the formulated blends recorded higher values for FRAP than the commercial product, indicating that the antioxidants in the formulated blends work even at low concentrations. This is an essential aspect in preparing infant complementary foods; efficiency and not quantity matter [60]. The difference in both DPPH and FRAP data suggests that there are differing mechanisms of antioxidant action [61]. Although AYC1 has a stronger radical scavenging capacity based on DPPH, AYC3 has a stronger overall reducing capacity based on FRAP. This suggests that the antioxidant properties of these preparations depend not only on the amount but also on the type of phenolics [62].

3.6 Vitamin C and Beta Carotene Content of the Complementary Flour

The vitamin C and β-carotene content of grain amaranth (*Amaranthus hypochondriacus*), African yam bean (*Sphenostylis stenocarpa*) seed, and carrot (*Daucus carota*) flour blends is illustrated in Figure 12. The vitamin C content of the flour blends ranged from 10.77 to 21.48 mg/g, with sample AYC1 having the lowest and AYC3 the highest. The high vitamin C content in the formulation from AYC3 was expected, as that could be because of the increase in carrot flour among the flour blends, while the commercial control (13.214 mg/g) contained more than some of the formulated complementary food samples; it may be as a result of possible ascorbic acid-dense raw materials. Okoronkwo *et al*. [36] reported that vitamin C contributes to rebuilding bones and tissues, forms red blood cells, helps heal wounds and cuts, and prevents infections. This shows that the samples may help to build the tissues when consumed by the infants.



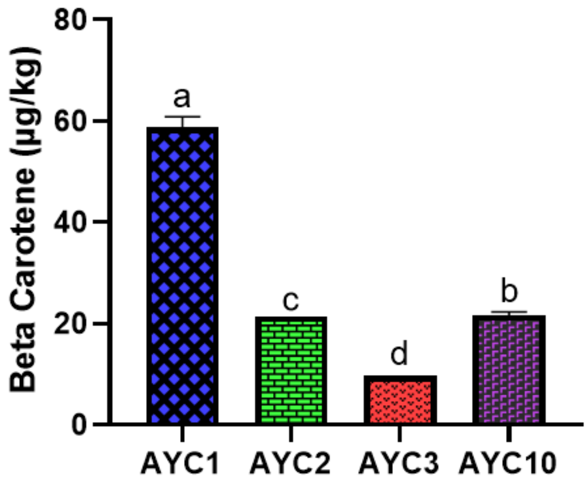


Figure 12 Vitamin C and Beta-carotene content of grain amaranth, African yam bean seed, and carrot flour blends. Each bar represents the mean of three replicates ± standard deviation. Mean values followed by different superscripts on each bar are significantly different according to Duncan's Multiple Range Test ($p < 0.05$), represented with a-d. Repeated letters indicate that the means were not significantly different ($p > 0.05$). **KEY:** AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds, and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds, and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds, and 10% Carrot; AYC10 = Commercial Control.

The beta-carotene content of the complementary food blends ranged from 9.62 to 58.75 (µg/100 g), with sample AYC1 having the lowest and sample AYC3 the highest. There was a significant difference ($p < 0.05$) among the test samples. The high value of beta-carotene obtained in this present study was lower compared to the values of beta-carotene reported by Arukwe *et al*. [37], which ranged from 5010.10 to 8022.50 µg/100 g of formulated complementary food prepared with fermented pearl millet, fermented African yam bean, and carrot flours. This reflects the higher contribution of carrot content used in the study. Ebabhamiegbebho *et al*. [63] also observed a higher value of beta-carotene, which ranged from 320 to 760 µg/100 g in pearl millet, African yam bean, and tiger nut-based complementary blends. Okoronkwo *et al*. [36] reported that the easiest way to introduce more beta-carotene into infants' food was by enriching such foods with carotene-rich constituents, which is an important nutrient that helps to develop the immune system of infants, and also against several infections.

3.7 Total Bacterial, Mold, and Coliform Counts for the Complementary Flour

The total bacterial count, total coliform count, and total fungal count of grain amaranth (*Amaranthus hypochondriacus*), African yam bean (*Sphenostylis stenocarpa*) seed, and carrot (*Daucus carota*) flour blends are presented in Table 6. Initially, the bacteria count in the range of 1.41-1.60 log_{10} (CFU/g) was observed on the nutrient agar medium of the complementary flour blends. There were significant differences ($p < 0.05$), with an increase in the total bacterial count in the test samples, with AYC3 having the lowest and AYC2 the highest. In contrast, bacterial count was not detected in the commercial control. Mekuria *et al.* [27] reported a slightly higher total bacterial count of 3.04-3.46 CFU/g in the complementary food prepared with red teff, soybean, and maize. These growths obtained could be due to the water and processing materials used in the preparation of the food products, however, all values remained within permissible limits for complementary foods, especially when compared to the study of Uchegbu *et al.* [13], which detected higher levels of total bacteria count of 5.29×10^3 CFU/g at 24 hours of fermentation, which gradually decreased to 5.02×10^3 CFU/g at 72 hours of fermentation, in the formulated samples from sorghum, pumpkin seed, and carrot flour blends.

Table 6 Microbiological Status for the Complementary Flour.

SAMPLE	TBC log_{10} (CFU/g)	TMC log_{10} (CFU/g)	TCC log_{10} (SFU/g)
AYC1	1.48 ± 0.46^{b}	1.50 ± 0.70^{a}	ND
AYC2	1.60 ± 0.56^{a}	1.20 ± 0.70^{b}	ND
AYC3	1.41 ± 0.61^{bc}	1.03 ± 2.46^{c}	ND
AYC10	ND	5.56 ± 0.42	ND

Values represent the means of three replicates ± standard deviation. Mean values followed by different superscripts within columns are significantly different according to Duncan's Multiple Range Test ($p < 0.05$), represented with a-c. Repeated superscript letters indicate that the means were not significantly different ($p > 0.05$).

KEY: AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control. ND = not detected (below detection limit).

The mold count of the complementary food ranged from 1.03 to 5.56 log_{10} (CFU/g), with the minimum value being AYC3, while the maximum value was AYC10. Significant differences ($p < 0.05$) were observed in the total mold counts of the complementary food samples. These variations are likely attributable to the differing inclusion levels of grain amaranth flour, which may have introduced varying initial microbial loads or altered the moisture/nutrient availability for fungal growth. Hyun *et al*. [64] stated that conditions such as moisture content, efficiency of drying, and packaging conditions affect variability of mold counts. Uchegbu *et al.* [13] reported a close mold count ranging from 1.48×10^4 to 2.02×10^4 CFU/g after 24 hours of fermentation, which, however, decreased gradually to 1.01×10^3-1.21×10^3 CFU/g, which is slightly lower than the one in this study.

The results for total fungal count showed no growth of fungi on the potato dextrose agar medium; hence, total fungal count across all the complementary flour blends was not detected, nor was it detected in the commercial control.

3.8 Sensory Evaluation of the Complementary Flours

The sensory evaluation of the reconstituted complementary flour blends formulated from grain amaranth, African yam bean, and carrot was conducted to assess appearance, aroma, taste, flavour, mouthfeel, texture, and overall acceptability, as presented in Table 7. Among all attributes, across the formulated blends, AYC3, consisting of 70% grain amaranth, 20% African yam bean, and 10% carrot flour, consistently received the highest scores. Its values for appearance (8.97), aroma (8.79), taste (8.52), flavour (8.38), mouthfeel (8.62), texture (8.72), and overall acceptability (9.07) were significantly higher, $p < 0.05$, than those obtained for AYC1 and AYC2. Therefore, the better performance of AYC3 indicated improved visual appeal, sweetness, and aroma as the proportion of carrot increased. The mothers in this study also preferred more colourful complementary foods, supporting the higher attractiveness of AYC3, since colour is often an attractive stimulus for infants due to the bright, natural colours of foods. This may be linked to the claim of Lawless and Heymann [65] that most times, the visual profile of complementary foods is a critical determinant of quality and consumer acceptance. AYC1 and AYC2 got positive but relatively low ratings, with values ranging from 6.50 to 7.90 for AYC1 and from 6.62 to 7.93 for AYC2. These scores, while being significantly lower than those of AYC3 ($p < 0.05$), were still within the category "like moderately" for both blends, suggesting that these products were acceptable for consumption by the panelists. The commercial control AYC10 also fared well, with scores running from 7.20 to 8.76. Its ratings were close to those of AYC3, and panelists noted its sweeter taste and slightly less smooth consistency when compared with the formulated blends. This positions AYC10 as the second-most-preferred sample.

Table 7 Sensory Evaluation of the Complementary Flours.

Sample	Appearance	Aroma	Taste	Flavor	Mouthfeel	Texture	Overall Acceptability
AYC1	7.63 ± 1.08^{b}	6.63 ± 1.68^{b}	6.50 ± 1.41^{c}	7.37 ± 1.40^{b}	7.33 ± 1.07^{b}	7.47 ± 1.50^{b}	7.90 ± 1.19^{ab}
AYC2	8.20 ± 1.25^{a}	6.93 ± 1.91^{bc}	6.62 ± 2.02^{c}	7.59 ± 2.13^{b}	7.38 ± 2.06^{b}	7.79 ± 1.69^{b}	7.93 ± 1.64^{ab}
AYC3	8.97 ± 081^{a}	8.79 ± 1.35^{a}	8.52 ± 1.33^{a}	8.38 ± 1.27^{a}	8.62 ± 1.32^{a}	8.72 ± 1.14^{a}	9.07 ± 0.78^{a}
AYC10	7.20 ± 1.08^{b}	8.76 ± 1.68^{a}	8.14 ± 1.49^{a}	8.03 ± 1.33^{a}	8.00 ± 1.57^{a}	7.55 ± 1.20^{b}	8.34 ± 1.08^{a}

Values are means ± SD with different superscripts in the same column are significantly different ($p < 0.05$), n = 3.

KEY: AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control.

The observed sensory responses in the present study are consistent with the trends of similar complementary food systems reported in the literature. Ashun *et al*. [66] reported appearance scores ranging from 3.25 to 4.36 when working on orange-fleshed sweet potato-based blends. In contrast, the products formulated from pearl millet, African yam bean, and carrot yielded an appearance score of 6.00 to 7.80, which was closer to the present findings, according to Arukwe *et al*. [37]. Aroma scores obtained in this study were also within the ranges so far reported. Babarinde *et al*. [67] recorded a lower rating in the aroma of sweet-potato-African-yam-bean meals from 3.95 to 6.70, while Adepeju *et al*. [38] recorded values from 5.90 to 8.30 in the blends of maize-sorghum-soybean enriched with crayfish and date fruit. The taste scores in the present study are comparable to those of Badau *et al*. [68], who reported values between 6.40 and 7.3 in complementary flours fortified with soybean and sorghum malt. Flavour ratings also fall within the range previously published: Arukwe *et al*. [37] reported flavour scores of 6.00 to 7.80 for similar plant-based blends, while Agbaje *et al*. [69] and Adepeju *et al*. [38] recorded values of 6.53-8.00 and 5.70-7.60, respectively. Overall acceptability scores in this study further correspond with those of Adepeju *et al*. [38], who recorded values between 5.50 and 8.20. In contrast, Agbaje *et al*. [69] reported lower acceptability scores (5.60-6.60) in maize-plantain-soybean formulations.

3.9 Principal Component Analysis for the Samples

The multivariate structure of the nutritional parameters across the flour samples was analyzed using Principal Component Analysis (supporting document). Based on the Kaiser criterion, three principal components were retained for further analysis because their eigenvalues exceeded 1. In total, they explained 95.9% of the variance, with the highest share contributed by PC1 (71.5%), followed by PC2 with 24.4%, and finally PC3 with a share of 4.1%. The high cumulative variance indicates that the principal components adequately represented the nutritional variability of the dataset in line with well-established principles for PCA.

The orientation and magnitude of variable loadings in the biplot (Figure 13) give insight into the nutritional gradients responsible for the observed sample distribution. The first principal component, PC1, was primarily driven by the proximate variables: protein, fat, crude fibre, ash, and moisture, all projecting strongly and in the same direction along the positive region of the PC1 axis. Their closely aligned and elongated vectors reflect high positive correlations and demonstrate that these macronutrients collectively define the dominant axis of variation. Carbohydrate, on the other hand, extended in the opposite direction to show its strong negative contribution to PC1. This opposite position reveals a clear nutrient dilution gradient, in which the samples enriched in protein, fat, fibre, and moisture tend to show reduced carbohydrate contents. Similar inverse relationships between carbohydrate and nutrient-dense components have been reported in cereal-legume flour blends and plant-based composite foods [70]. Hence, PC1 can be interpreted as a macronutrient density axis that distinguishes carbohydrate-rich samples from those with enhanced proximate composition.

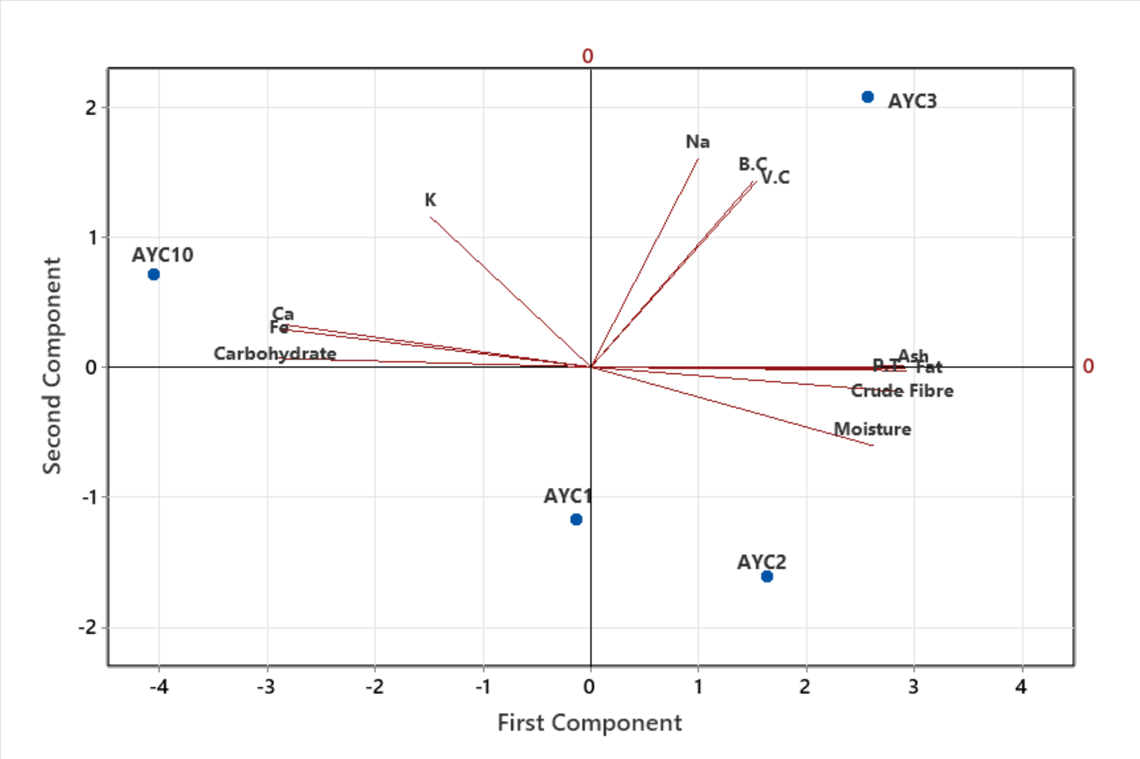


Figure 13 Biplot of all Parameters for the Complementary Flour Blends. **KEYS:** V.C: Vitamin C; B.C: Beta-carotene; P.T: Protein; AYC1 = 90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot; AYC2 = 80% Grain Amaranth, 15% African Yam Bean Seeds and 5% Carrot; AYC3 = 70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot; AYC10 = Commercial Control.

PC2 described a variation that was completely different from the one characterized by the proximate composition, and, therefore, it represented the micronutrient and antioxidant factors only. The vectors of sodium, potassium, vitamin C, and β-carotene pointed very much to the positive side of PC2, and their coming together was a sign of their strong interdependence. The fact that they were in the same direction as the proximate variables but at a slight right angle to them implies that the antioxidant properties of mineral electrolytes and carotenoids do not depend on macronutrient levels. Thus, PC2 is a micronutrient-antioxidant axis that separates the samples based on the amounts of β-carotene, vitamin C, and mineral salts. The two main elements of nutritional variation among the samples were graphically displayed in the biplot. Samples on the right-hand side of PC1 display higher levels of protein, fat, crude fiber, ash, and moisture. On the other hand, the sample on the left side of the negative PC1 axis is mainly comprised of carbohydrates. The right movement on the PC2 axis separates the samples enriched with β-carotene, vitamin C, potassium, and sodium from the corresponding samples with lower levels of these components in the lower plot region. The corresponding separation among these samples thus provides a graphical indication of their nutritional dissimilarity: those that are close together have similar dietary patterns, whereas those that are far apart have different macro- and micronutrient characteristics. The whole structure of the biplot thus points out how proximate composition and micronutrient-antioxidant profiles separately and combinedly contribute to the differentiation of the flour formulations.

4. Conclusions

This research confirms that complementary foods based on grain amaranth, African yam bean seed, and carrot have higher nutritional quality compared to a commercial standard diet. The complementary samples, particularly AYC1 (90% Grain Amaranth, 5% African Yam Bean Seeds and 5% Carrot), had higher proportions of protein, energy, and essential minerals while having low moisture and fibre, and were ideal for complementary feeding activities. The complementary diets had good sodium-to-potassium ratios and adequate concentrations of iron and calcium, which are ideal for growth and the maintenance of metabolic functions during complementary feeding. The observed antinutritional factors at safe levels would not pose any threat to mineral bioavailability or protein absorption during their utilization. The presence of bioactive components and high antioxidant activity would provide additional benefits beyond nutritional functions. The low microbial count and absence of faecal contamination imply that microbiological safety was ensured during the processing of the complementary diet products. Sensory acceptability revealed that sample AYC3 (70% Grain Amaranth, 20% African Yam Bean Seeds and 10% Carrot) with a higher proportion of African yam bean compositions of complementary diets was well preferred, revealing that improvements in nutritional quality would not affect nutrient palatability or desirability of complementary diet products during complementary feeding activities. The principal component analysis helped elucidate relationships among nutrient, antioxidant activity, and microbiological indices, thereby indicating the adequate nutritional quality of optimized diet products during complementary feeding activities. Further studies focusing on the inclusion of powdered milk to improve the amino acid profile should be adopted. Additionally, protein digestibility, mineral bioavailability, shelf-life stability, and in vivo growth performance should be evaluated to support large-scale adoption.

Author Contributions

FJI: Conceptualization, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing. BSS: Formal Analysis, Methodology, Resources, Writing – original draft. DSA: Formal Analysis, Software, Visualization, Writing – original draft, Writing – review & editing. ITI: Investigation, Resources, Validation, Writing – original draft.

Competing Interests

The authors declared that no competing interests exist.

AI-Assisted Technologies Statement

During the preparation of this work/manuscript, the authors used Perplexity and Grammarly to paraphrase and Gemini to search for articles using prompts such as: “kindly suggest recent articles that reported the effects of composite flours on complementary foods”. The authors, thereafter, reviewed and edited the output of the AIs as necessary, hence, taking full responsibility for the content of the manuscript prepared for publication/published article.

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