

# Enhancing Food Security and Nutrition Through Indigenous Agro-Product-Based Functional Foods: A Case Study on Composite Flour Development <sup>†</sup>

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**Abstract:** The current rising food prices, influenced by importation costs, the global food crisis, as well as pre- and post-harvest losses, have contributed majorly to malnutrition and food insecurity. Therefore, utilizing technologies that harness our indigenous agro-products as composite flours to develop functional foods will address these issues. In this study, dry raw samples of perishable and healthy yellow potato, yellow maize and pigeon pea were obtained from the agricultural development program, Edo State, Nigeria, and authenticated and processed into gluten-free fermented composite flours. The flours were profiled physicochemically and nutritionally, providing valuable insight into their multiple benefits. An experimental design software (Design Expert 13.0.) was applied to achieve optimum blended flours regarding the ratio of sweet potato–pigeon pea–maize, and mix 5 (67.70:20.00:12.31) displayed more outstanding attributes than other blends for the production of biscuits, bread and cakes using creaming and mixing methods. Various standard tests for flours and products were appropriately carried out to evaluate the proximate, techno-functional, mineral, antioxidant, anti-nutrient, sensory and color values. Individual antioxidant parameters were improved across all products compared to wheat-based products (control) under the same production conditions, showing a statistical significance at  $p < 0.05$ . A similar trend was observed in the proximate, anti-nutritional and mineral contents, while all products had a desirable color outlook. A sensory evaluation revealed the general acceptability, while an in vivo animal experimental model revealed that all animals fed with the various product samples gained weight with improved general body organs and no evidence of disease. This research underscores the potential of harnessing agri-value chain approaches in developing functional foods and promoting food security.

**Keywords:** flour development; botanical value-chain; food fermentation; functional pastries



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## 1. Introduction

Malnutrition and undernourishment remain an existential threat especially among vulnerable people globally [1,2]. In Sub-Saharan Africa, the large population, massive post-harvest food wastages and poor technological know-how in transforming botanicals

into highly nutritional, therapeutic and economic food products across the entire food value chain have caused economic crisis, poverty and, largely, food insecurity. For instance, using Nigeria as a case study, the 2021 preponderance of undernourished individuals was recorded as 15.9% [3]. By the end of 2024, the human population is estimated to rise to over 229.2 million, and with a yearly increase of over 2.41%, it is projected to rise to over 400 million by the year 2050 [4,5]. In 2022, the National Bureau of Statistics report on the Multidimensional Poverty Index (MPI) projected over 133 million Nigerians (63%) to be multidimensionally poor; food insecurity and nutrition were some of the parameters used in arriving at this conclusion [6]. Amalgamated nutritional support with supplementary and therapeutic diets is needed to address these challenges [7–10].

Although staples vary from place to place, cereals, tubers/root crops, legumes, grains and fruits/vegetables are generally inexpensive and are known to make up about 90% of the food calorie intake worldwide [2,11]. They are used alone or as composite flour combinations in preparing readily available functional foods. This diet therapy is necessary not only for survival but it can also help confer substantial health benefits providing some physiological effects and specific health and nutritional enhancements for the prevention and management of persistent ailments, such as polygenic diseases and hyperpiesia [12,13], because of their macronutrient's composition [14,15] and their various collections of ancillary metabolic substances having antioxidant capacities [16,17].

The current cultivation of wheat in many African nations is insufficient, and importation has become a massive drain on local economies. In 2021, Nigeria was ranked in the second position among the leading top five countries that imported the highest dollar value of wheat globally, with USD 3.32 billion [18]. With the threatening effects of the global climatic variations coupled with various armed conflicts affecting wheat production, there is a need to harness indigenous botanicals and develop them into agro-processed flour composite bio-resources as a more sustainable alternative in functional food product development [2,15]. This will aid in accomplishing Sustainable Development Goal (SDG) number two by mitigating post-harvest losses through the formulation of composite flours from indigenous raw botanicals and producing nutritionally enhanced baked products (bread, biscuits and cakes) from the developed raw composite flours. The adoption of this innovation would drastically reduce the amount spent on wheat importation [15].

Generally, composite food technology is an excellent way of creating distinctively novel food products from the combinations of conventional and unconventional botanicals. These composite flour developments will accelerate the further exploitation of native food crops for producing ready-to-eat, highly nutritious functional foods, such as bread, cakes and biscuits [10]. The nutritional quality and value and health derivatives obtained from using unseemly, underutilized plant materials as composite flour mixes in the preparation of ready-to-eat bakery and pastry staple food products cannot be overemphasized [2].

This study is aimed at developing gluten-free composite flours from a blend of perishable and healthy yellow potato, yellow corn and pigeon pea as a suitable alternative to wheat flour. These flour mixes were utilized in the production of ready-to-eat baked functional staples.

## 2. Methods

### 2.1. Sample Collection and Authentication

Dry tubers from the yellow-fleshed variety of sweet potato (*Ipomea batatas*), yellow-grain variety maize (*Zea mays*) and pigeon peas (*Cajanus cajan*) were bought from agricultural development program foodstuff sellers in Jattu, Etsako-West Local Government Area, Edo State, Nigeria and were confirmed taxonomically at the Plant Biology and Biotechnology Unit (Herbarium Curation Sub-division), Department of Biological Sciences, Edo

University Uzairue, Edo State, Nigeria. Wistar albino rats were obtained from the animal house, Federal University of Agriculture, Abeokuta, Ogun State.

## 2.2. Sample Processing and Fermentation

The sweet potato, maize and pigeon pea botanicals were each spontaneously fermented for 72 h at  $28 \pm 2$  °C as reported by [19] to produce their respective fermented flours.

## 2.3. Experimental Design

The optimum blending used to produce the composite flours was obtained using the modified D-optimal mixture (Design Expert 13.0.). Experimental designs for mixtures in the food sector are described by [20]. Different blends were obtained by mixing the respective proportions of sweet potato, pigeon pea and maize flour as selected by the developed experimental design. The composite blends of these flours were thoroughly mixed using a mixer and packaged in different polyethylene bags for analysis.

## 2.4. Production of Baked Products

The baked products (biscuits, bread and cakes) were produced from blended composite flours, using traditional creaming and mixing methods by [21–23]. Additionally, wheat flour (100%) was used in preparing the respective control products.

## 2.5. Physicochemical Property Determination

### 2.5.1. Proximate Composition

The proximate compositions of the raw and composite flours and products were carried out according to the standard methods of [24]. Tests carried out include crude fiber, protein, ash, moisture, fat and carbohydrate.

### 2.5.2. Techno-Functional Composition of the Flours

The methods of [25] were used for the techno-functional analysis of the raw and composite flours for the following parameters: Bulk Density, Water Absorption Capacity (WAC), Oil Absorption Capacity (OAC), Foaming Capacity (FC), Swelling Capacity (SC), Least Gelation Concentration (LGC) and Emulsion Capacity (EC).

### 2.5.3. Mineral Analysis

The determination of mineral elements in the samples followed the dry ash methods outlined in [24]. The analyzed mineral elements of the samples are calcium and magnesium, using Atomic Absorption Spectroscopy (AAS) Model TAS-990, Yima, China, and sodium and potassium (flame photometer).

### 2.5.4. Antioxidant Activities

The methods of [26] were used in analyzing the antioxidant activities of the samples for the presence of 2,2-Diphenyl-1-picrylhydrazyl (DPPH) free radicals scavenging activity, iron ( $\text{Fe}^{2+}$ ) chelation, hydroxyl (OH) radical scavenging activity, 2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonate) (ABTS) radical scavenging activity, Ferric-Reducing Antioxidant Property (FRAP) and the total phenol content.

### 2.5.5. Anti-Nutritional Composition

The anti-nutritional composition of the product samples was analyzed for tannin, oxalate, phytate and saponin contents according to the method of [27].

## 2.6. The Determination of the Color

The color of all the product samples was analyzed using the methods described by [28].

### 2.7. Sensory Evaluation

Sensory evaluation studies to determine customers' preferences were carried out for the baked bread, cake and biscuit products using both descriptive and discriminatory evaluation as described by [29] for the following characteristics: color, crispiness, texture, aroma, taste and overall acceptability.

### 2.8. In Vivo Animal Experiment

Fifty (50) healthy two-week-old Wistar albino weaning rats were used to determine the anthropometric parameters of the formulated products and the control products over 14 days following the method described by [30,31].

### 2.9. Analysis of Data

Data generated were subjected to statistical analyses such as ANOVA and the Duncan multiple range test. All data samples were obtained in triplicates and the results were presented as mean  $\pm$  SD. The means were separated at  $p < 0.05$  significant difference.

## 3. Results

The ratio of sweet potato–pigeon pea–maize (67.70:20.00:12.31) in mix 5 displayed more outstanding physicochemical and nutritional attributes than other blends for the production of baked products. The data presented in Table 1 compare the proximate properties of the composite flour (mixture 5) with the mean proximate value of the respective raw fermented botanical flours. It reveals that the composite flour (mixture 5) had all of its proximate parameters in moderate proportions, showing a statistical significance ( $p < 0.05$ ).

**Table 1.** Proximate properties of raw and composite flours.

| Parameter                   | Sweet Potato                     | Pigeon Pea                       | Maize                          | Composite Flour Mixture 5     |
|-----------------------------|----------------------------------|----------------------------------|--------------------------------|-------------------------------|
| <b>Moisture content (%)</b> | 6.666 $\pm$ 0.05 <sup>a</sup>    | 4.105 $\pm$ 0.04 <sup>c</sup>    | 4.190 $\pm$ 0.02 <sup>c</sup>  | 5.869 $\pm$ 0.35 <sup>b</sup> |
| <b>Fat (%)</b>              | 2.535 $\pm$ 0.08 <sup>d</sup>    | 5.645 $\pm$ 0.02 <sup>b</sup>    | 6.095 $\pm$ 0.08 <sup>a</sup>  | 4.477 $\pm$ 0.16 <sup>c</sup> |
| <b>Crude fiber (%)</b>      | 4.675 $\pm$ 0.21 <sup>c</sup>    | 7.665 $\pm$ 0.06 <sup>a</sup>    | 7.225 $\pm$ 0.15 <sup>b</sup>  | 4.866 $\pm$ 0.63 <sup>c</sup> |
| <b>Ash (%)</b>              | 2.365 $\pm$ 0.06 <sup>c</sup>    | 3.230 $\pm$ 0.13 <sup>a</sup>    | 2.435 $\pm$ 0.05 <sup>c</sup>  | 2.553 $\pm$ 0.13 <sup>b</sup> |
| <b>Protein (%)</b>          | 7.265 $\pm$ 0.22 <sup>c</sup>    | 11.665 $\pm$ 0.32 <sup>a</sup>   | 3.610 $\pm$ 0.20 <sup>d</sup>  | 9.000 $\pm$ 1.82 <sup>b</sup> |
| <b>Carbohydrate (%)</b>     | 76.494 $\pm$ 0.05 <sup>a,b</sup> | 75.745 $\pm$ 0.41 <sup>b,c</sup> | 77.805 $\pm$ 0.23 <sup>a</sup> | 72.25 $\pm$ 1.60 <sup>d</sup> |
| <b>pH</b>                   | 5.770 $\pm$ 0.72 <sup>b</sup>    | 5.770 $\pm$ 0.72 <sup>b</sup>    | 6.030 $\pm$ 0.01 <sup>a</sup>  | 5.253 $\pm$ 0.01 <sup>c</sup> |

Data presented as mean  $\pm$  SD; in each column different superscripts indicate diverse significant differences at  $p \leq 0.05$ .

The techno-functional properties of the fermented raw flours and the blended mixture 5 composite are shown in Table 2. These characteristics help in predicting and evaluating the precise behavior of each proximate property when designing and developing food. Most of the results for composite flour mixture 5 showed enhanced techno-functional properties with statistical significances ( $p < 0.05$ ).

The proximate compositions of the bread, biscuit and cake samples made from mixture 5 of the fermented composite flour blends and the wheat flour used as the control are shown in Table 3. It can be observed that the ash, carbohydrate and crude fiber contents of the fermented mixture 5 samples had higher values than their respective controls. These values (apart from the crude fiber contents) were statistically significant at  $p < 0.05$ .

**Table 2.** Techno-functional properties of raw and composite flours.

| Parameter                             | Sweet Potato               | Pigeon Pea                 | Maize                      | Composite Flour Mixture 5  |
|---------------------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| WAC (%)                               | 21.01 ± 0.14 <sup>d</sup>  | 23.03 ± 0.04 <sup>b</sup>  | 22.16 ± 0.01 <sup>c</sup>  | 25.00 ± 0.00 <sup>a</sup>  |
| OAC (%)                               | 17.45 ± 0.07 <sup>b</sup>  | 16.06 ± 0.08 <sup>c</sup>  | 15.99 ± 0.07 <sup>d</sup>  | 19.00 ± 0.00 <sup>a</sup>  |
| EMULSION CAPACITY (%)                 | 40.50 ± 0.00 <sup>c</sup>  | 41.67 ± 0.01 <sup>a</sup>  | 41.85 ± 0.03 <sup>a</sup>  | 41.06 ± 0.01 <sup>b</sup>  |
| SWELLING CAPACITY (%)                 | 426.60 ± 0.01 <sup>d</sup> | 427.48 ± 1.43 <sup>c</sup> | 448.45 ± 0.06 <sup>b</sup> | 471.93 ± 0.00 <sup>a</sup> |
| FOAM CAPACITY (%)                     | 2.01 ± 0.07 <sup>d</sup>   | 4.0 ± 0.00 <sup>c</sup>    | 5.0 ± 0.01 <sup>b</sup>    | 8.05 ± 0.07 <sup>a</sup>   |
| LEAST GEL CONC. (mg/cm <sup>3</sup> ) | 0.2 ± 0.00 <sup>b</sup>    | 0.2 ± 0.00 <sup>b</sup>    | 0.25 ± 0.00 <sup>a</sup>   | 0.21 ± 0.01 <sup>b</sup>   |
| BULK DENSITY (gm/ cm <sup>3</sup> )   | 0.69 ± 0.00 <sup>a</sup>   | 0.69 ± 0.00 <sup>a</sup>   | 0.70 ± 0.00 <sup>a</sup>   | 0.73 ± 0.00 <sup>a</sup>   |

Data presented as mean ± SD; in each column different superscripts indicate diverse significant differences at  $p \leq 0.05$ .

**Table 3.** Proximate composition of bread, biscuit and cake.

| Sample | Ash Content (%)           | Moisture Content(%)        | Fat Content (%)            | Crude Fiber Content (%)   | Protein Content (%)        | Carbohydrate (By Difference) Content (%) |
|--------|---------------------------|----------------------------|----------------------------|---------------------------|----------------------------|------------------------------------------|
| CB     | 1.011 ± 0.02 <sup>c</sup> | 10.324 ± 0.05 <sup>b</sup> | 18.934 ± 0.0 <sup>b</sup>  | 4.140 ± 0.02 <sup>c</sup> | 13.222 ± 0.01 <sup>a</sup> | 52.370 ± 0.13 <sup>b</sup>               |
| 5FB    | 1.495 ± 0.14 <sup>b</sup> | 8.875 ± 0.68 <sup>c</sup>  | 17.592 ± 0.07 <sup>c</sup> | 5.752 ± 0.04 <sup>a</sup> | 10.450 ± 0.04 <sup>b</sup> | 55.835 ± 0.75 <sup>a</sup>               |
| CA     | 3.163 ± 0.03 <sup>b</sup> | 5.982 ± 0.01 <sup>b</sup>  | 21.161 ± 0.08 <sup>a</sup> | 1.271 ± 0.04 <sup>b</sup> | 12.805 ± 0.25 <sup>a</sup> | 55.622 ± 0.12 <sup>c</sup>               |
| 5FA    | 3.711 ± 0.11 <sup>a</sup> | 3.639 ± 0.05 <sup>c</sup>  | 17.339 ± 0.03 <sup>c</sup> | 3.485 ± 0.01 <sup>b</sup> | 11.918 ± 0.08 <sup>b</sup> | 58.491 ± 0.70 <sup>b</sup>               |
| CC     | 1.808 ± 0.12 <sup>c</sup> | 13.918 ± 0.38 <sup>a</sup> | 25.508 ± 0.11 <sup>c</sup> | 7.116 ± 0.91 <sup>a</sup> | 14.586 ± 0.06 <sup>a</sup> | 36.780 ± 0.67 <sup>b</sup>               |
| 5FC    | 3.197 ± 0.00 <sup>b</sup> | 11.859 ± 0.19 <sup>b</sup> | 24.179 ± 0.12 <sup>b</sup> | 7.401 ± 0.12 <sup>a</sup> | 12.813 ± 0.13 <sup>b</sup> | 40.838 ± 0.58 <sup>a</sup>               |

Data presented as mean ± SD; in each column different superscripts indicate diverse significant differences at  $p \leq 0.05$ . **Key:** CB = Control Bread; FB = Fermented Bread; CA = Control Biscuit; FA = Fermented Biscuit; CC = Control Cake; and FC = Fermented Cake.

The mineral compositions of the bread, biscuit and cake samples made from mixture 5 of the fermented composite flours and the wheat flour used as the control are shown in Table 4. The result shows that all the baked samples had some level of minerals present. These are positive effects since food products are required to be mineral-rich. However, the lower the sodium content, the better. Out of all the formulated products (including the controls), the Fermented Cake (5FC) performed better because it has a very high potassium content (23.005 ppm) and the lowest sodium content (15.798 ppm). In many instances the controls obtained higher values than the products produced due to the more refined process of the wheat flour.

**Table 4.** Mineral composition of bread, biscuit and cake.

| Samples | Sodium (Na) (ppm)          | Potassium (K) (ppm)        | Calcium (Ca) (ppm)         | Magnesium (Mg) (ppm)       |
|---------|----------------------------|----------------------------|----------------------------|----------------------------|
| CB      | 18.701 ± 0.00 <sup>d</sup> | 24.100 ± 0.00 <sup>b</sup> | 12.702 ± 0.00 <sup>a</sup> | 17.499 ± 0.00 <sup>a</sup> |
| 5FB     | 18.011 ± 0.02 <sup>d</sup> | 20.007 ± 0.01 <sup>c</sup> | 10.706 ± 0.01 <sup>c</sup> | 14.298 ± 0.00 <sup>c</sup> |
| CA      | 27.501 ± 0.00 <sup>a</sup> | 20.601 ± 0.00 <sup>d</sup> | 14.099 ± 0.00 <sup>a</sup> | 9.200 ± 0.00 <sup>e</sup>  |
| 5FA     | 17.105 ± 0.01 <sup>e</sup> | 19.803 ± 0.00 <sup>e</sup> | 10.505 ± 0.01 <sup>d</sup> | 15.160 ± 0.06 <sup>a</sup> |
| CC      | 20.096 ± 0.01 <sup>d</sup> | 18.501 ± 0.00 <sup>f</sup> | 15.001 ± 0.00 <sup>a</sup> | 7.901 ± 0.00 <sup>f</sup>  |
| 5FC     | 15.798 ± 0.00 <sup>f</sup> | 23.005 ± 0.01 <sup>c</sup> | 13.901 ± 0.00 <sup>b</sup> | 11.890 ± 0.01 <sup>c</sup> |

Data presented as mean ± SD; in each column different superscripts indicate diverse significant differences at  $p \leq 0.05$ . **Key:** CB = Control Bread; FB = Fermented Bread; CA = Control Biscuit; FA = Fermented Biscuit; CC = Control Cake; and FC = Fermented Cake.

The antioxidant compositions of the breads, biscuit and cake samples made from mixture 5 of the fermented composite flour and the wheat flour used as the control are given in Table 5. The ranges observed among some antioxidant parameters such as OH

and FRAP are quite wide, indicating significant differences at  $p < 0.05$  between the various baked products in terms of their antioxidant potential, while for DPPH, ABTS and  $\text{Fe}^{2+}$  chelation, the antioxidant parameters have no statistical variations at  $p < 0.05$ . Across all three samples, the ABTS, DPPH and FRAP values obtained for the fermented composite flour were consistently higher than their control samples.

**Table 5.** Antioxidant properties of bread, biscuit and cake.

| Sample | OH (%)                         | ABTS (mMol/g)                 | DPPH (%)                       | $\text{Fe}^{2+}$ Chelation (%) | FRAP (mg/g)                    |
|--------|--------------------------------|-------------------------------|--------------------------------|--------------------------------|--------------------------------|
| CB     | 42.810 $\pm$ 0.61 <sup>a</sup> | 0.010 $\pm$ 0.00 <sup>c</sup> | 71.345 $\pm$ 0.23 <sup>b</sup> | 7.360 $\pm$ 0.36 <sup>b</sup>  | 7.292 $\pm$ 0.13 <sup>c</sup>  |
| 5FB    | 36.960 $\pm$ 0.64 <sup>b</sup> | 0.019 $\pm$ 0.00 <sup>b</sup> | 72.547 $\pm$ 0.41 <sup>b</sup> | 5.788 $\pm$ 0.93 <sup>b</sup>  | 10.500 $\pm$ 0.27 <sup>b</sup> |
| CA     | 42.143 $\pm$ 0.34 <sup>d</sup> | 0.025 $\pm$ 0.00 <sup>a</sup> | 52.502 $\pm$ 0.82 <sup>c</sup> | 2.980 $\pm$ 0.23 <sup>f</sup>  | 5.842 $\pm$ 0.09 <sup>f</sup>  |
| 5FA    | 60.000 $\pm$ 0.45 <sup>a</sup> | 0.026 $\pm$ 0.00 <sup>a</sup> | 55.608 $\pm$ 0.44 <sup>b</sup> | 12.848 $\pm$ 0.14 <sup>d</sup> | 26.309 $\pm$ 0.76 <sup>a</sup> |
| CC     | 40.22 $\pm$ 0.76 <sup>d</sup>  | 0.007 $\pm$ 0.00 <sup>d</sup> | 26.275 $\pm$ 0.04 <sup>g</sup> | 12.747 $\pm$ 0.46 <sup>e</sup> | 8.342 $\pm$ 0.10 <sup>g</sup>  |
| 5FC    | 43.157 $\pm$ 0.25 <sup>c</sup> | 0.025 $\pm$ 0.00 <sup>a</sup> | 72.657 $\pm$ 0.50 <sup>c</sup> | 16.440 $\pm$ 0.21 <sup>d</sup> | 18.314 $\pm$ 0.02 <sup>d</sup> |

Data presented as mean  $\pm$  SD; in each column different superscripts indicate diverse significant differences at  $p \leq 0.05$ . Key: CB = Control Bread; FB = Fermented Bread; CA = Control Biscuit; FA = Fermented Biscuit; CC = Control Cake; FC = Fermented Cake; OH = Hydroxyl Radical; ABTS = 2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonate); DPPH = 2,2-Diphenyl-1-picrylhydrazyl;  $\text{Fe}^{2+}$  Chelation = iron chelation; FRAP = Ferric-Reducing Antioxidant Property.

The anti-nutritional composition of the bread, biscuit and cake samples made from mixture 5 of the fermented composite flour (Table 6) showed the presence of anti-nutritional contents with a statistical significance at  $p < 0.05$  for all the samples. Across all three samples, the fermented composite flour values obtained for saponins and oxalates were consistently higher than their control samples. The color analysis of the bread, biscuit and cake samples made from the fermented composite flour showed a statistical significance at  $p < 0.05$ , resulting in a desirable darker color outlook for all the fermented composite flour samples (except cake) when compared with their controls. For the bread with the fermented composite flour, the color value was  $1.20 \pm 0.01$  vs.  $0.11 \pm 0.01$  for the Control Bread, while the color of the biscuits made from fermented mixture 5 was  $2.325 \pm 0.01$  vs.  $0.803 \pm 0.00$  for the control. For the cake,  $0.389 \pm 0.00$  was recorded for the fermented mixture 5 sample and  $0.098 \pm 0.00$  for the control, indicating a higher absorbance at 560 nm.

**Table 6.** Anti-nutritional composition of bread, biscuit and cake.

| Sample | Tannins (mg/g)                | Oxalates (mg/g)               | Phytates (mg/g)               | Saponins (%)                   |
|--------|-------------------------------|-------------------------------|-------------------------------|--------------------------------|
| CB     | 1.316 $\pm$ 0.00 <sup>a</sup> | 0.315 $\pm$ 0.00 <sup>c</sup> | 1.650 $\pm$ 0.00 <sup>d</sup> | 14.494 $\pm$ 0.03 <sup>c</sup> |
| 5FB    | 0.917 $\pm$ 0.01 <sup>c</sup> | 3.731 $\pm$ 0.07 <sup>b</sup> | 1.728 $\pm$ 0.18 <sup>c</sup> | 21.424 $\pm$ 0.01 <sup>a</sup> |
| CA     | 0.720 $\pm$ 0.00 <sup>d</sup> | 0.902 $\pm$ 0.00 <sup>e</sup> | 1.858 $\pm$ 0.01 <sup>a</sup> | 12.497 $\pm$ 0.00 <sup>e</sup> |
| 5FA    | 1.461 $\pm$ 0.02 <sup>b</sup> | 2.261 $\pm$ 0.01 <sup>c</sup> | 1.742 $\pm$ 0.01 <sup>b</sup> | 23.495 $\pm$ 0.03 <sup>a</sup> |
| CC     | 0.708 $\pm$ 0.02 <sup>d</sup> | 0.241 $\pm$ 0.04 <sup>g</sup> | 0.929 $\pm$ 0.00 <sup>f</sup> | 13.711 $\pm$ 0.23 <sup>f</sup> |
| 5FC    | 0.754 $\pm$ 0.02 <sup>c</sup> | 1.791 $\pm$ 0.01 <sup>d</sup> | 1.441 $\pm$ 0.00 <sup>e</sup> | 20.654 $\pm$ 0.06 <sup>a</sup> |

Data presented as mean  $\pm$  SD; in each column different superscripts indicate significant differences at  $p \leq 0.05$ . Key: CB = Control Bread; FB = Fermented Bread; CA = Control Biscuit; FA = Fermented Biscuit; CC = Control Cake; FC = Fermented Cake.

The results from the sensory evaluation of the fermented composite baked products (bread, biscuits and cake) using the composite mixture 5 flour (Figure 1) show that the organoleptic characteristics of the biscuit were highest among the three baked products, while bread consistently had lower scores for all sensory parameters. The values obtained from each sensorial parameter for these baked products all showed a statistical significance at  $p < 0.05$ . All the products assessed were judged to be generally acceptable.

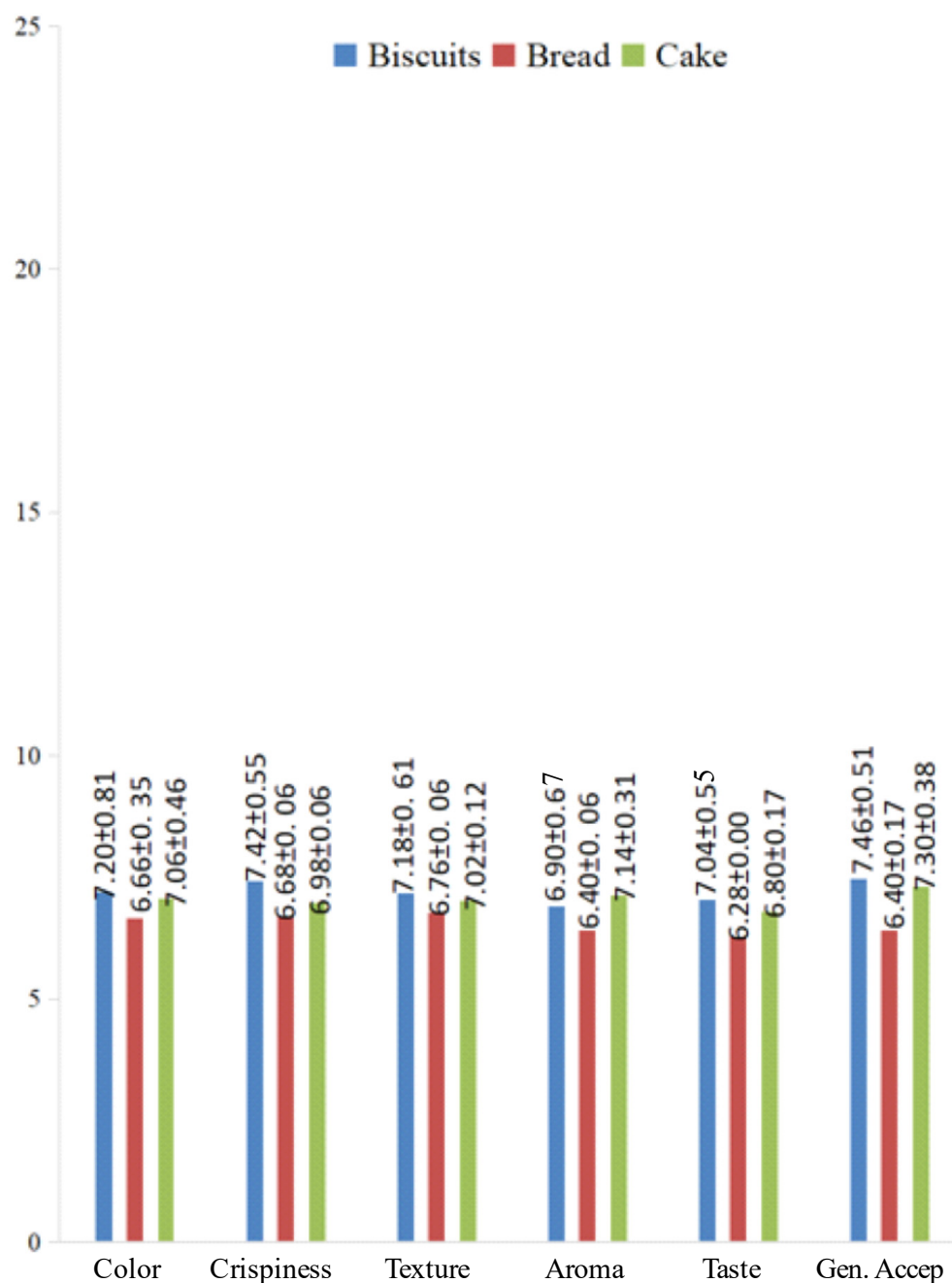


**Figure 1.** Sensory evaluation of fermented bread, biscuits and cake made from composite mixture 5 flour.

The results of the *in vivo* animal studies on the percentage weight gain of animals fed with the formulated bread, biscuit and cake products made from composite flour blends along with their respective control products show that there was a significant percentage weight gain for all the experimental animal models fed (Figure 2). The composite flour supports a similar weight gain as the control flour in biscuits and bread. By Day 14, animals fed with the composite biscuits (21.5%) and bread (15.2%) had comparable weight gains to those on the Control Biscuits (17.3%) and bread (10.5%). However, the Control Cake led to greater weight gain (33.8%) than the composite cake (23.2%), suggesting differences in their nutrient composition or digestibility.

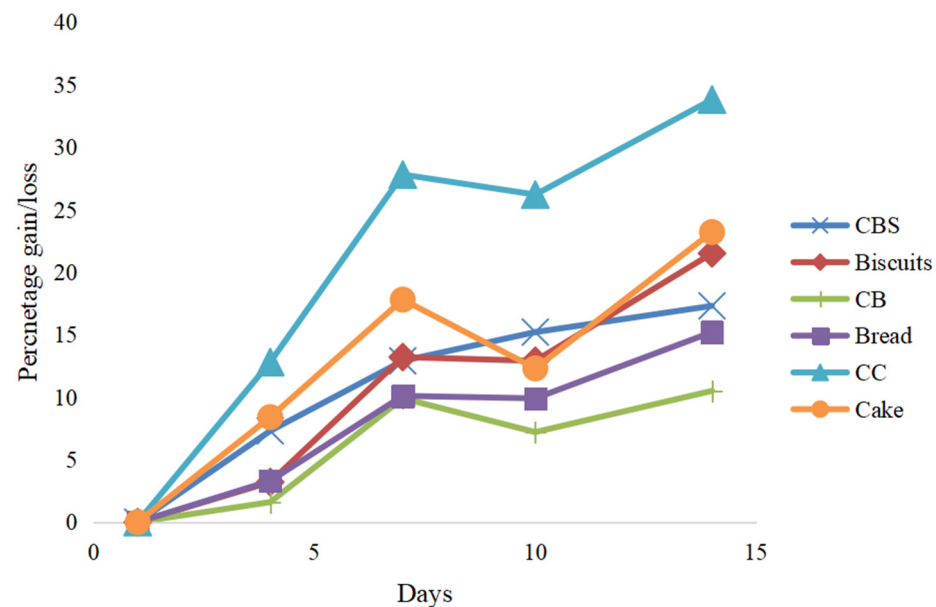


**Figure 2.** Percentage of weight gain of animals fed with formulated products made from composite mixture 5 flour along with their respective control products. Key: CBs: Control Biscuits, CB: Control Bread, and CC: Control Cake.

#### 4. Discussion

The proximate composition of the raw and composite flours in Table 1 shows significant variations in moisture, fat, crude fiber, ash, protein, carbohydrates and pH, which influence the nutritional quality and functionality [15,32]. The moisture content varied among the samples, with the composite mixture 5 flour indicating a more moderate shelf stability than each botanical flour. The fat content was highest in the maize and lowest in the sweet potato, with the composite flour exceeding previously reported values for pigeon pea–sorghum blends [33]. The crude fiber content also varied, with the composite flour showing a similarity to earlier studies on pigeon pea–sorghum blends [33]. The ash content, indicative of mineral presence, differed among the samples, aligning with reported values of [33]. The protein content was highest in the pigeon pea and lowest in the maize, with the composite flour surpassing the range observed in cassava–pigeon pea blends [34]. The carbohydrate content was highest in the maize and lowest in composite flour 5, which is comparable to values in cassava–pigeon pea blends [34]. Overall, the composite flour presents a balanced nutritional profile, demonstrating how flour blending enhances the nutritional quality and functionality, making it suitable for diverse food applications. In agreement with the findings of other researchers, the fermentation in this study enhanced the functional parameters of both the flour and baked products.

The techno-functional properties of raw and composite flours in Table 2 show statistically significant variations ( $p < 0.05$ ) in functional parameters such as the WAC, OAC, Emulsion Capacity, Swelling Capacity, foam capacity, Least Gelation Concentration and Bulk Density, which are critical for food processing and formulation. The composite flour mixture 5 exhibited the highest WAC (25.00%) and OAC (19.00%), aligning with studies by [35,36], which highlighted improved absorption properties due to ingredient synergy. The Emulsion Capacity varied slightly across samples and was influenced by the protein composition [36]. The Swelling Capacity, essential for texture and viscosity, was highest in the composite flour (471.93%), which is consistent with [37] who noted that ingredient proportions affect swelling indices. The foam capacity was also highest in the composite flour (8.05%), which is similar to [36] who observed enhanced foaming properties in certain blends. The Least Gelation Concentration varied slightly, with the maize flour requiring

the highest value (0.25 mg/cm<sup>3</sup>), while the Bulk Density remained comparable across samples (0.69–0.73 g/cm<sup>3</sup>), supporting findings by [36]. These results confirm that composite flours can be optimized to enhance specific functional properties, making them suitable for various food applications.

The proximate analysis of the baked products shows that there are significant differences ( $p < 0.05$ ) in the ash, moisture, fat, crude fiber, protein and carbohydrate contents between each baked product and their 100% wheat-based control products. The higher proximate parameter values obtained in the composite flour baked products showed that they are more nutritionally enhanced than their wheat-based control products, and this is consistent with the findings of [38–40].

The mineral content analysis of the baked products made from the fermented mixture 5 composite flour and their 100% wheat-based products showed statistically significant variations ( $p < 0.05$ ). The results showed a significant presence of biofunctional minerals in the baked products. This could be attributed to the fact that apart from the fermentation process, the botanical flour blends are known to be good sources of minerals. These combinations help to enhance the bioavailability of minerals in the flour blends and their food products [41]. The higher mineral content observed in control products compared to their fermented counterparts can be attributed to several factors inherent from the cultivation of the botanicals to the processing technologies employed in their development into flour forms as well as differences in flour types. Also, some microorganisms involved in fermentation may assimilate free minerals from the substrate for their metabolic activities, leading to a measurable decrease in mineral concentrations in the final product [42,43]. Additionally, during the processing of the raw gluten-free botanicals into composite flours, some steps, such as soaking, can cause soluble minerals to leach into the fermentation medium, resulting in their loss during subsequent production stages [44]. However, it is important to note that fermentation can enhance the mineral bioavailability by degrading anti-nutritional factors like phytic acid, which binds minerals and inhibits their absorption [45,46]. Therefore, despite a decrease in the measurable mineral content, the minerals present in fermented products are often more bioavailable, offering improved nutritional benefits [43].

The antioxidant composition of the baked products made from the fermented mixture 5 composite flour showed higher OH and DPPH values and moderate Fe<sup>2+</sup> chelation and FRAP values, indicating increased free radical scavenging activities. Overall, these results suggest that the fermentation process could improve the antioxidant properties of breads, biscuits and cakes made from the composite flour blends of sweet potato, pigeon pea and maize. These findings are consistent with previous studies that have shown fermentation to enhance the antioxidant properties of foods [47–49]. Antioxidants are vital in both food preservation and human health. In food products, they prevent oxidative deterioration, thereby maintaining the taste, color and nutritional value. This preservation extends the shelf life and ensures food safety [50]. In humans, antioxidants neutralize harmful free radicals, reducing oxidative stress linked to chronic diseases such as heart disease, cancer and neurodegenerative disorders [51]. The regular consumption of antioxidant-rich foods supports overall health by protecting cells from damage and bolstering the immune system [52].

The result of the anti-nutritional composition shows that the levels of anti-nutritionals (anti-nutrients/phytochemicals) vary depending on the baked product. In general, the fermentation process reduces the levels of anti-nutritionals, such as tannins, in food products by breaking down their complex molecules into simpler forms that are more easily absorbed by the body, while flavonoids are beneficial compounds with antioxidant properties, which may protect against cellular damage and reduce the risk of chronic diseases [53]. These

findings are consistent with previous studies that have reported variations in the levels of anti-nutritional factors in composite flour and foods [54–56].

For the color analysis, the higher color intensity observed in the fermented baked products could be attributed to the Maillard reaction, which occurs during fermentation and baking, leading to the formation of brown pigments and enhancing the color of the final product [57]. This may have also influenced the sensory properties positively since color is a crucial factor that influences the visual appeal of food [58].

Based on the sensory evaluation results, all the baked products (cake, bread and biscuits) were generally acceptable by the panelists. The general acceptability is the conclusive assessment of the products' overall quality by consumers, and it is important in determining the success of such products in the marketplace. However, biscuits received higher scores for color, crispiness, texture, aroma, taste and general acceptability compared to the other two baked products. This suggests that biscuits may be the preferred choice. These findings are consistent with those of [59,60].

Animals (Wistar albino rats) were used to determine the anthropometric, hematological and histopathological parameters of the formulated bread, biscuit and cake products obtained from the composite flour. This becomes necessary in this research to ascertain the products' toxicity or their values as good food. From this study, all animals fed with the various baked product samples gained weight with no evidence of disease and with optimal organ functionality. Therefore, the consumption of the bread, biscuit and cake products made from fermented flour blends of sweet potato, maize and pigeon pea will be of good nutrition, and they are safe for human consumption.

## 5. Conclusions

This study demonstrates that blending sweet potato, pigeon pea and maize flours, followed by fermentation, enhances the nutritional profile and functional properties of baked biscuit, bread and cake products. Specifically, the composite flour exhibited an increased protein content, improved water and oil absorption capacities and elevated antioxidant activities, contributing to a better texture, shelf stability and potential health benefits. Fermentation also reduces anti-nutritional factors, like tannins, oxalates and phytates, thereby improving the mineral bioavailability. Sensory evaluations indicated the high acceptability of the baked products, mainly biscuits, suggesting their potential for consumer preference. Animal studies confirmed these products' safety and nutritional adequacy, supporting their suitability for human consumption. These findings underscore the potential of composite flours in addressing nutritional deficiencies and improving food security.

The possibility and feasibility of harnessing and further exploiting fermented indigenous agro-processed flour blends of sweet potato, pigeon pea and maize as ternary composite bio-resources in producing and developing enhanced baked functional foods cannot be overemphasized.

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