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Research Article

Nutritional, Sensory, and Microbial Quality of Cookies Produced by Partial Replacement of Wheat Flour with Plantain (*Musa paradisiaca*) and Cocoyam (*Colocasia esculenta*) Flours

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Nutritional, sensory, texture, and microbiological load analyses were made of cookies consisting of a partial replacement of wheat flour with plantain (*Musa paradisiaca*) or cocoyam (*Colocasia esculenta*) flour. There were slight differences in the amounts of protein, fat, and carbohydrate. Accordingly, the nutritional values per 100 g of the cookies correspond to 10-14% protein and 19-21% energy of the recommended daily allowance. In contrast, cookies containing either cocoyam or plantain flour have 20% and 30% more fiber, respectively, compared to cookies containing wheat flour alone. Similarly, plantain and cocoyam cookies' iron and zinc contents were, respectively, 1-16% and 2-9% more than ($p < 0.05$) the control. The levels of aerobic plate count in the cookies were lower than recommended thresholds for such food products. Those cookies containing 20% and 40% of either plantain or cocoyam flour had comparable sensory, texture, and color quality compared to the control. The effect of intake of plantain and cocoyam cookies is likely to eliminate population mineral deficiencies, particularly iron, and zinc. These results underline the potential of enabling food security crops such as plantain and cocoyam in sustaining cookies production, utilization, nutritional value, and the role of such crops in addressing food and nutrition insecurity.

1. Introduction

Global malnutrition and food security are prototypical sustainable development goals in a rapidly rising human population. Perversely, the malnutrition prevalence rate continues to rise [1]. Consequently, it is now a common emphasis to eradicate hunger and reduce the number of malnourished people per the 2015 United Nations Sustainable Development Goals 1, 2, 3, 5, 6, 8, 9, 10, 11, 12, and 13. Addressing global malnutrition and food insecurity calls for a reduction in poverty and the promotion of sustainable agriculture. With regard to the aforementioned goals, it is indispensable to explore the feasibility of food security crops to enhance their inclusion towards the reach of these goals. Plantain (*Musa paradisiaca*) and cocoyam (*Colocasia esculenta*) are among the major enabling food security crops with a low environmental footprint [1, 2]. They are considered food security crops because they contain substantial nutrients and are an important contributor to sustainable food production and the environment compared to cereals [3]. Additionally, such crops are gluten-free, making them suitable for people with celiac disease [4], and contain high-quality phytonutrients and antioxidants [3, 5]. Plantain and cocoyam tend to be high in potassium (390-460 mg/100 g), magnesium (79-110 mg/100 g), and calcium (24-43 mg/100 g) [6–8]. They are also popular sources of vitamins such as riboflavin, pyridoxine, folate, and thiamine [9, 10]. Plantain and cocoyam can provide other health benefits, including digestive health where resistant starch a prebiotic embedded in these crops ferments and feeds the gut bacteria [11], and also play a significant role in glycemic control because of their slowly digestible starch [12]. These crops have sparked a lot of interest as wheat flour substitutes for bakery food products such as bread and cookies. Cookies are a popular source of snacks and thus, increasing their availability, affordability, and accessibility of cookies could help improve nutrition outcomes and food security [13]. However, the cost of producing healthy bakery food products in particular cookies and the importation of wheat flour are barriers to more industries and women engaging in producing cookies as sustainable food products for the local markets in many rural communities. In addition, imported wheat flour encompasses a larger portion of the weight of cookies than any other ingredients [13]. Under the current food production system, this is a major challenge, since most countries have experienced a decline in wheat production due to sustainability issues [14, 15]. And in most tropical countries, the harsh climatic conditions prohibit large wheat production but favor plantain and cocoyam [16]. Additionally, most root and tuber crops including plantain and cocoyam are easily perishable. Consequently, their consumption in developing countries is subtantially low due to their short shelf life. They could be incorporated as flour in bakery food products such as cookies and bread to provide additional nutrients. As such, addressing food waste through value addition to plantain and cocoyam as an alternative flour substitute for making cookies will offer a major opportunity to improve food security, minimize the environmental footprint associated with crop production and importation of wheat flour [17].

Despite the above-mentioned benefits of plantain and cocoyam, few applications of these crops have been indicated in bakery food products. As such, this study is aimed at overcoming the obstacles to the use of a large amount of plantain and cocoyam flour in cookies by optimizing the formulation to achieve the maximum quality in relation to the nutritional, sensory, texture, physical, and microbial load of the resultant cookies.

2. Materials and Methods

2.1. Ingredients. The soft wheat flour, eggs, baking powder, salted butter, white sugar, corn flour, milk powder, and vanilla essence were purchased from the supermarket (Shoprite, Co. Ltd, Achimota, Accra, Ghana). The ingredients were stored at room temperature ($25 \circ C \pm 2$), except the salted butter which was refrigerated at -18°C and was defrosted to room temperature ($25 \circ C \pm 2$) before usage. Fresh unripe (green plantain) plantain and cocoyam were obtained from a local market in Ho, Volta Region, Ghana. They were stored at a cool dry place and were used the next day to produce the plantain and cocoyam flours. The flours were packed in a rigid plastic container covered with lids and stored at room temperature ($25 \circ C \pm 2$).

2.2. Production of Plantain and Cocoyam Flours. The plantain and cocoyam flours were produced at the Food Science and Technology Department, Ho Technical University. The flour production procedures involve rinsing, peeling, and grating the plantain and cocoyam into smaller chip sizes ($0.7 \times 0.5 \times 0.4$ cm). The chips were dried at 80°C according to the procedures of [18] utilizing a hot air oven (Model BF 720, Tuttlingen, Germany). The oven was preheated for 15 minutes before starting to dry the samples. Flours were produced by oven-drying 500 g plantain and 500 g cocoyam chips per drying tray in 10 drying batches. During the oven drying, the samples were individually weighed at 30 minutes regular intervals to determine the moisture content pursuant to the formula (weight of chips before drying – weight of chips after drying/weight of chips before drying) $\times$ 100 [18]. Both plantain and cocoyam chips were dried to moisture content of 10%. The dried chips were then milled into flour using a commercial blender (OTTO BE-128, Thailand), and passed through a fine screen (100-mesh sieve, Taisite, USA). The flours were packed in plastic rigid containers, covered with lids, and stored at room temperature ($25 \circ C \pm 2$).

2.3. Cookies Formulation and Processing. A preliminary study was conducted by varying the composition of plantain or cocoyam flour incorporated into wheat flour in the amount of 20%, 40%, 60%, 80%, and 100%. The results from the pilot study showed that cookies produced with 20%, 40%, and 60% of plantain or cocoyam flour incorporated into wheat flour are suitable for making the cookies. This is because, at the 80% and 100% of plantain or cocoyam flour inclusion in wheat flour, the resultant cookies had a very softened texture, and were slightly dark and easily breakable. Hence, seven types of cookies were finally produced. The treatments consisted of 20% (P20), 40% (P40), and 60% (P60) wheat flour replacement with plantain flour. Likewise, 20% (C20), 40% (C40), and 60% (C60) wheat flour replacement with cocoyam flour. The control cookies were made up of 100% wheat flour. The cookies were produced according to the procedures of [13], with slight modifications, including baking temperature and time. The control cookies (100% wheat flour), comprise 500 g wheat flour, 400 g salted butter, 260 g sugar, baking powder 2 g 140 g corn flour, 30 g milk powder, 80 g eggs, and 17 g vanilla essence. The treatment cookies were made by replacing the wheat flour with 20%, 40%, and 60% for each plantain and cocoyam flour incorporated into wheat flour. The amounts of the other ingredients were held constant in all types of cookies.

The wheat flour, corn flour, and milk powder were passed through a 100-mesh sieve (100-mesh sieve, Taisite, USA), and set aside, likewise the beaten eggs. The salted butter was defrosted to room temperature ($25 \circ C \pm 2$) and cut into pieces. Salted butter and white sugar were placed in a mixing bowl and mixed on medium speed using a kitchen hand mixer (KHM7210, KitchenAid, USA) until light and fluffy in 15 minutes. The eggs were added little by little while mixing at a medium speed. Vanilla essence was also added. The mixture was mixed for additional 2 minutes to incorporate the ingredients. Further, corn flour, milk powder, and wheat flour were then added and the mixture was mixed for 5 minutes to fully incorporate the added ingredients, including wheat flour, corn flour, and milk powder. The dough was shaped into a ball, placed on a working flat surface, and rolled out and flattened to a thickness of 7 mm with the aid of a cylindrical wooden dowel. It was then cut into round smaller shapes of 50 mm diameter using a cookie cutter and then transferred into a baking tray lined with parchment paper. The cookies were individually positioned in the baking tray, leaving a distance of 10 mm between them to keep cookies from sticking together and making room for expansion. The oven was preheated at 180°C for 20 minutes. The baking trays were lined with parchment paper and the surfaces of the parchment papers were brushed with butter to prevent cookies from sticking to the parchment papers. The cookies were baked at 180°C for 10 minutes and were swapped back and forth to enhance even baking, and then baked for additional 10 minutes. Ready-to-cool cookies were transferred from parchment papers to cooling racks using a spatula. After cooling, the cookies were stored in airtight plastic containers at room temperature (25 ∘ C ± 2).

2.4. Nutritional Analysis

2.4.1. Analysis of Proximate Composition. The protein, ash, fibre, fat, and moisture contents of the cookies were determined according to Association Official Analytical Chemists (AOAC) standard method [19]. Whereas, carbohydrate content was also estimated using the AOAC method indicated by [20], and energy content according to AOAC standard method [21].

2.4.2. Analysis of Mineral Content. The concentration of minerals (potassium, calcium, iron, and zinc) was quantitatively estimated in accordance with a wet procedure based on acid digestion with a heated mixture of strong acids [22] to solubilize the food matrix and liberate mineral elements to be measured.

2 g of each sample was transferred into a digestion flask labelled with an identification number. And 1 g of glass beads was added to each sample as antibumping granules. An acid mixture consisting of 20 ml of 65% HNO_3 + 10 ml of 70% $HClO_4$ was then added. One digestion flask containing only a chemical mixture was labelled as a blank flask. The flasks were shaken slowly and kept in a fume hood to digest at ambient temperature (25°C) for 24 h.

After 24 h, formation of brown-red coloration was observed due to the fume of HNO_3 from the reaction of the acid with the sample was observed. The digestion flasks were shaken for about 1 min to mix content, placed on the heating mantle of the digestor and heated at 120°C. The digestor was turned off when brown red fume and coloration were clearly out after 60 min of concentrating the content of digestion flasks to 7.3 ml in a gentle heat at 120°C to avoid heating the content of the digestion flask to dryness, as this may lead to an explosion. 30 ml of deionized water was added to each digestion flask to dilute the content. This was filtered into a 50 ml volumetric flask through funnels containing Whatman filter paper, and diluted with diluent (H_2O) to reach the 50 ml mark.

Sequential determination of the concentration of iron, zinc, potassium and calcium was carried out by an Inductively Coupled Plasma Emission Spectrometer-ICP-OES (Jarrell-Ash Model 975 Atom comp, USA). The instrument was connected to a peristaltic pump to introduce the sample into the ICP nebulizer and system. Prior to the identification and quantification of the elements, calibration of the instrument was conducted using internal standards made up to 1000 μg/ml. The following operation parameters were employed in the identification and quantification of the elements: reflected power, 4 watts; forward power, 1.1 Kw; analyte uptake rate, 0.8 ml/min; exposure time, 5 s; warm-uptime, 30 min; and observation height 16 mm above load coil, noted to sustain the ICP instrument.

2.5. Microbial Load Analysis. Aerobic Plate Count (APC) was determined following the procedures set out by the Food and Drug Administration (FDA) and Bacteriological Analytical Manual (BAM) [23] in three replicates one for each sample. A brief outline of the procedures adopted is set out below:

2.5.1. Preparation of Sample Diluent Butterfield's Phosphate Buffer (Neogen, USA) Solution. 34 g potassium dihydrogen orthophosphate anhydrous was transferred into a flask containing 500 ml of distilled water (Aqua Laboratory Co Ltd., UK), and swirled to mix the content. The pH (5.01) of the solution was adjusted to a pH of 7.2 with 1 N NaOH solution.

2.5.2. Preparation of Microbiological Substrate (Plate Count Agar) (PCA). 7 g Plate Count Agar dehydrated medium (Fisher Scientific, Co.Ltd., England) was transferred into a Duran bottle containing 300 ml distilled water and the content was swirled to mix thoroughly. It was then boiled at 100°C in a water bath (Clifton, BAT2840, England) for 5 minutes, autoclave (OEM, XFS-280A, China) at 121°C and 15 lb pressure for 15 minutes, and was then brought to gentle heat at 48°C using a water bath. A sterile spoon was used to transfer 25 g of a homogeneous portion of the sample into a sterilized stomacher bag. 225 ml of prepared Butterfield's Phosphate Buffer solution was transferred into the stomacher bag containing the sample. The content was thoroughly mixed using a 400 ml mixer (Bag mixer 221040, Switzerland).

2.5.3. Preparation of Dilutions. Sample solutions were diluted utilizing serial dilution techniques. The first dilution (10^{-1}) for each sample consisted of a mixture of 25 g sample and 225 ml diluents. 1 ml of the first sample solution (10^{-1}) was transferred into a 9 ml sterile diluent to obtain (10^{-2}) solution. This solution was vortexed for 30 seconds to obtain a homogenized solution. Accordingly, serial dilutions were made up to 10^{-6}, and each solution vortexed using a vortex mixer (VEVOR, 3000RPM mini vortex mixer shaker, UK) for 30 seconds, following 1 ml of the second, third, fourth, fifth, and sixth dilutions into 9 ml of a separate sterile diluent one for each solution to obtain 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} dilutions for each sample, respectively.

2.5.4. Enumeration of Bacteria and Viable Bacteria Count Calculation in the Samples. The bacteria were isolated by the pour plate method using sterile Petri dishes. All dilutions were vortexed and 1.0 ml of each dilution was placed in Petri dishes in duplicate. 2.0 ml of the Plate Count Agar media was added to each Petri dish, thoroughly mixed, and the lids were opened and set aside. The Agar media was allowed to solidify within 20 minutes, the Petri dishes were collected, keeping them upended, and were incubated (Binder, CB

60, Germany) at 35°C for 48 hours. Petri dishes with a countable number of bacteria colonies ranging from 25-250 were considered acceptable and counted. The number (N) of colony-forming units per gram (CFU/g) of each petri dish with bacterial colonies within the acceptable threshold was calculated using the relation below and represented the number of viable bacteria count in CFU/g (colony-forming units per gram) for the samples [23].

$$N = \frac{C1 + C2}{(1 \times n1)(0.1 \times n2) \times d}. \quad (1)$$

$C1$ is the total colony of 1st dilution counted. $C2$ is total colony of 2nd dilution counted. $n1$ is the number of trial plates of 1st dilution. $n2$ is the number of trial plates of 2nd dilution. d is thedilution from which the 1st counts were obtained.

2.6. Physical Attribute Analysis. The texture values (hardness) of cookies were determined according to the procedures indicated by [13]. The instrumentation included HDP/BS cutting blade (Stable Micro Systems, UK). The pretest speed, test speed, distance, and posttest speed were 0.5 mm/s, 1.0 mm/s, 5 mm/s, and 10 mm/s, respectively. In either plantain or cocoyam cookies, ten repeated measurements conducted in three replicates one for each type of cookie were obtained and the hardness values were presented in the form of mean ± standard deviation. The weight (g) of the cookies was determined using an analytical balance, and the thickness (mm) and width (mm) of the cookies were determined using a vernier calliper. The spread ratio was estimated from width (mm) to thickness (mm) [24].

2.7. Color Analysis. The cookies' color parameters (L^*, a^*, and b^*) were measured using a Hunter colorimeter (Ultra Scan PRO Spectrophotometer, USA). L^* is a prediction of the lightness of the cookies. This parameter ranged from 0 to 100, where values at the higher end of the range represent the lightness of the products. The parameters predicting yellowness and redness of products are represented by b^* and a^* values, respectively. In plantain or cocoyam cookies, chroma (C^*) and total color difference (ΔE) were derived using a previous formula given by [25], and recently reported by [26]. Chroma indicates the purity of the color in the cookies, and total color difference (ΔE) represents the color accuracy with values between 1 and 2, indicating that the color difference is very perceptible. The values for each color parameter were obtained from six repeated and three replicated measurements.

2.8. Sensory Evaluation and Analysis. The consumer testing and evaluation of the cookies included 17 males and 23 females in Ho, Volta Region. Students from Ho Technical University, including staff and nonstaff, residing around Ho and familiar with cookies were invited to participate in the consumer testing and evaluation of the cookies. To obtain a better understanding of the panelists' knowledge of cookies relating to the sensory descriptors utilize in this study, questions about if they like cookies and what they like about them were included in the questionnaire. Knowing the panelists' knowledge about traditional products helps in understanding their sensory needs. A modified version of the questionnaire was used to collect the panelists' scores on the sensory descriptors. They were asked to rate their preferences of how they liked the taste, smell, color, appearance, and acceptability of the cookies. The rating was based on a 9-point hedonic scale from 1, representing how they dislike the cookies extremely to 9, representing how they like the cookies extremely.

2.9. Data Analysis. One-way ANOVA was utilized to evaluate the effect of plantain or cocoyam flour incorporated into wheat flour on the nutritional value, sensory, texture, and physical and microbiological quality of the resultant cookies. Afterwards, Duncan's multiple range test was used to assess significant differences ($p < 0.5$) among group means. All statistical tests were performed using SPSS software version 20 (IBM, New York, USA).

3. Results and Discussion

3.1. Nutritional Composition of Cookies. The proximate composition of the cookies varied slightly (Table 1). Incorporating either plantain or cocoyam flour into wheat flour reduced the protein value and moisture content while fiber, carbohydrate, and energy contents of the resultant cookies were increased. This obviously reflects the fact that wheat flour is a good source of protein. As such, replacing wheat flour with either plantain or cocoyam flour will decrease the protein content of the resultant cookies. The results were in the range of those previously reported by [27] in cookies made from blends of fermented sorghum and cocoyam flours and similar to those detected by [13] in cookies enriched with microwave crickets' powder, deferring in only protein content. In terms of the percentage of the recommended daily allowance (RDA), 100 g of the cookies represented 10-14% and 19-21% of protein and energy requirements, respectively. Iron, zinc, calcium, and potassium are essential nutrients that play vital roles in sustaining blood, water, and bone homeostasis [28, 29]. These nutrients have been linked to the risk of chronic dietary diseases and conditions, particularly anemia, diarrhea, osteoporosis, and rickets [28]. Cookies' calcium and potassium contents were slightly increased. In contrast, iron and zinc contents of C20, C40, and C60 and P20, P40, and P60 cookies were noted to increase substantially at higher amounts of either plantain or cocoyam flour incorporated into wheat flour (Table 2). A 100 g of P20, P40, and P60 cookies were noted to provide 20%, 25%, and 29% of the RDA for iron, respectively, and 21-22% of the RDA for zinc [28]. Similarly, iron and zinc contents of WF, C20, C40, and C60 cookies were found to provide 19%, 31%, 33%, and 35% for iron, respectively, and 13%, 15%, 16%, and 18% (Table 2) for the RDA for zinc, respectively [28]. Nutritional value is not the only sustainability issue with traditional cookies (100% wheat flour cookies) but other concerns including price and environment are barriers to its utilization. Plantain and cocoyam, however, are good sources of minerals and may serve

Table 1: Proximate composition (g/100 g wet basis) and energy (kcal/100 g wet basis) content of control cookies and cookies produced by partial replacement of wheat flour with either cocoyam or plantain flour.

Cookies	Moisture	Protein	Ash	Fiber	Fat	Carb	Energy
WF	6.89 ± 0.03^{ab}	9.19 ± 0.12^{a}	1.34 ± 0.03^{a}	0.99 ± 0.04^{c}	22.15 ± 0.05^{e}	60.46 ± 0.18^{c}	477.98 ± 0.17^{a}
C20	6.22 ± 0.05^{bc}	7.85 ± 0.11^{b}	1.37 ± 0.02^{a}	1.15 ± 0.04^{b}	23.47 ± 0.54^{d}	61.26 ± 0.46^{bc}	483.69 ± 1.78^{a}
C40	6.19 ± 0.03^{bc}	7.14 ± 0.02^{c}	1.34 ± 0.34^{a}	1.15 ± 0.02^{b}	23.82 ± 0.55^{cd}	61.48 ± 0.22^{ab}	488.86 ± 1.03^{a}
C60	5.92 ± 0.08^{c}	6.42 ± 0.04^{d}	1.16 ± 0.02^{ab}	1.17 ± 0.02^{b}	24.82 ± 0.18^{a}	61.68 ± 0.18^{a}	495.70 ± 1.08^{a}
P20	6.34 ± 0.03^{a}	7.11 ± 0.02^{c}	1.06 ± 0.07^{b}	1.19 ± 0.04^{b}	24.25 ± 0.05^{bc}	60.52 ± 0.12^{c}	488.77 ± 0.24^{a}
P40	6.21 ± 1.16^{abc}	6.11 ± 0.04^{e}	1.12 ± 0.01^{ab}	1.39 ± 0.06^{ab}	24.37 ± 0.01^{abc}	61.37 ± 0.02^{ab}	489.22 ± 0.17^{a}
P60	6.13 ± 0.02^{a}	5.59 ± 0.03^{f}	1.16 ± 0.01^{ab}	1.54 ± 0.05^{a}	24.41 ± 0.05^{a}	61.71 ± 0.08^{a}	488.90 ± 0.30^{a}

[1]WF: 100% wheat flour cookies (control cookies). [2]C20, C40, and C60: cookies produced by incorporating 20%, 40% and 60% cocoyam four into wheat flour, respectively. [3]P20, P40, and P60: cookies produced by incorporating 20%, 40%, and 60% plantain four into wheat flour, respectively. [4]Values are mean ± standard deviation of triplicate analysis. [5]Mean values represented in the same column with different superscript letters are significantly different ($p < 0.05$).

Table 2: Mineral content (mg/100 g wet basis) of control cookies and cookies produced by partial replacement of wheat flour with either cocoyam or plantain flour.

Cookies	Iron	Zinc	Potassium	Calcium
WF	3.71 ± 0.01^{f}	0.53 ± 0.02^{e}	10.77 ± 0.09^{c}	17.07 ± 0.03^{c}
C20	6.16 ± 0.03^{c}	0.65 ± 0.03^{d}	14.11 ± 0.02^{a}	18.44 ± 0.48^{b}
C40	6.56 ± 0.01^{b}	0.67 ± 0.02^{d}	14.15 ± 0.05^{a}	18.86 ± 0.01^{ab}
C60	6.79 ± 0.21^{a}	0.76 ± 0.02^{c}	14.18 ± 0.02^{a}	19.08 ± 0.04^{a}
P20	3.94 ± 0.04^{f}	0.87 ± 0.03^{b}	12.32 ± 1.67^{b}	17.59 ± 0.39
P40	4.97 ± 0.05^{e}	0.94 ± 0.03^{a}	12.77 ± 1.38^{ab}	18.76 ± 0.08^{ab}
P60	5.74 ± 0.02^{d}	0.93 ± 0.02^{a}	13.47 ± 0.20^{ab}	18.74 ± 0.16^{ab}

[1]WF: 100% wheat flour cookies (control cookies). [2]C20, C40, and C60: cookies produced by incorporating 20%, 40%, and 60% cocoyam four into wheat flour, respectively. [3]P20, P40, and P60: cookies produced by incorporating 20%, 40%, and 60% plantain four into wheat flour, respectively. [4]Values are mean ± standard deviation of triplicate analysis. [5]Mean values represented in the same column with different superscript letters are significantly different ($p < 0.05$).

as viable flour substitutes for producing bakery food products [30–32]. This calls for the promotion of these root and tuber crops in bakery food products because they are easily accessible and affordable and consequently enhancing their use in cookies will contribute to efforts to address food insecurity and malnutrition.

3.2. Texture and Physical Features of Cookies. The addition of either plantain or cocoyam flour at 20%, 40%, and 60% resulted in a soft texture of the resultant cookies as evidenced by decreasing trend of cookies' hardness (Table 3). This could be interpreted as a better indicator for making soft cookies. In more detail, the higher the amount of plantain or cocoyam flour added, the lower the hardness (N) values. However, the weight (g) of the cookies was not affected by the partial replacement (20%, 40%, and 60%) of plantain or cocoyam flour (Table 3). These results are in accordance with those previously reported by [27], thus suggesting that the added plantain or cocoyam flour does not compensate for gliadin and glutenin interaction and three-dimension structures responsible for the swelling of dough when baking. Also, as emerged from previous studies, plantain and cocoyam flours have high water absorption capacity [33]. Consequently, replacing wheat flour with each one of these flours impaired water absorption and gliadin and glutenin network, simultaneously lowering the hardness (N) and thickness (mm) of the cookies. Similarly, functional restriction in relation to gliadin and glutenin interaction and covalent network structure leads to cookies collapsing and falling flat [13], thus decreasing the thickness (mm) of the cookies (Table 3).

3.3. Shelf-Life Study-Aerobic Plate Counts (TACs) Analysis of Cookies. An evaluation of aerobic plate counts showed that the levels increased slightly from day 3 to day 123 in the cookies (Table 4). In all cookies, the levels of aerobic plate counts ranged from <10 to 1.25 log CFU/g (Table 4). The cookies containing wheat flour alone recorded the highest aerobic plate count from day 63 to day 123 while the lowest plate count was recorded in C60 (Table 4). The results were consistent with previous reports of TACs in cookies produced from Chia (*Salvia hispanica L.*) [34] and bread produced from a blend of wheat and potato flours [35]. The total aerobic counts in this study were lower than the threshold recommended for processed food products [36, 37]. This is partly due to low the moisture content of the cookies (Table 1), and good manufacturing and personal hygiene practices, adopted in producing the cookies. Additionally,

Table 3: Physical attributes of control cookies and cookies produced by partial replacement of wheat flour with either cocoyam or plantain flour.

Cookies	Hardness (*N*)	Weight (g)	Thickness (mm)	Width (mm)	Spread ratio
WF	1.26 ± 0.03^{a}	18.02 ± 0.03^{a}	8.38 ± 0.13^{a}	55.12 ± 0.03^{a}	6.58 ± 0.10^{c}
C20	1.21 ± 0.03^{ab}	18.03 ± 0.02^{a}	8.32 ± 0.07^{ab}	55.14 ± 0.01^{a}	6.63 ± 0.05^{bc}
C40	1.13 ± 0.02^{b}	18.03 ± 0.01^{a}	8.28 ± 0.05^{ab}	55.13 ± 0.02^{a}	6.66 ± 0.04^{abc}
C60	1.15 ± 0.01^{b}	18.04 ± 0.01^{a}	8.25 ± 0.05^{bc}	55.14 ± 0.01^{a}	6.68 ± 0.04^{ab}
P20	1.18 ± 0.02^{ab}	18.03 ± 0.03^{a}	8.25 ± 0.02^{bc}	55.09 ± 0.07^{a}	6.67 ± 0.02^{ab}
P40	0.99 ± 0.03^{c}	18.03 ± 0.02^{a}	8.20 ± 0.04^{bc}	55.06 ± 0.19^{a}	6.71 ± 0.01^{ab}
P60	0.98 ± 0.04^{c}	18.02 ± 0.03^{a}	8.15 ± 0.04^{c}	54.82 ± 0.04^{b}	6.73 ± 0.03^{a}

[1]WF: 100% wheat flour cookies (control cookies). [2]C20, C40, and C60: cookies produced by incorporating 20%, 40%, and 60% cocoyam four into wheat flour, respectively. [3]P20, P40, and P60: cookies produced by incorporating 20%, 40%, and 60% plantain four into wheat flour, respectively. [4]Values are mean ± standard deviation of triplicate analysis. [5]Mean values represented in the same column with different superscript letters are significantly different ($p < 0.05$).

Table 4: Aerobic plate counts (log CFU/g) of control cookies and cookies produced by partial replacement of wheat flour with either cocoyam or plantain flour.

Cookies	Day 3	Day 33	Day 63	Day 93	Day 123
WF	$<10 \pm 0.00^{a}$	$<10 \pm 0.00^{a}$	1.16 ± 0.02^{a}	1.25 ± 0.04^{a}	1.60 ± 0.25^{a}
C20	$<10 \pm 0.00^{a}$	$<10 \pm 0.00^{a}$	1.13 ± 0.02^{a}	1.23 ± 0.03^{a}	1.27 ± 0.07^{a}
C40	$<10 \pm 0.00^{a}$	$<10 \pm 0.00^{a}$	1.15 ± 0.06^{a}	1.23 ± 0.02^{a}	1.26 ± 0.03^{a}
C60	$<10 \pm 0.00^{a}$	$<10 \pm 0.00^{a}$	1.11 ± 0.01^{a}	1.22 ± 0.02^{a}	1.22 ± 0.01^{a}
P20	$<10 \pm 0.00^{a}$	$<10 \pm 0.00^{a}$	1.13 ± 0.02^{a}	1.21 ± 0.03^{a}	1.25 ± 0.02^{a}
P40	$<10 \pm 0.00^{a}$	$<10 \pm 0.00^{a}$	1.15 ± 0.04^{a}	1.15 ± 0.04^{a}	1.24 ± 0.03^{a}
P60	$<10 \pm 0.00^{a}$	$<10 \pm 0.00^{a}$	1.12 ± 0.02^{a}	1.13 ± 0.01^{a}	1.23 ± 0.02^{a}

[1]WF: 100% wheat flour cookies (control cookies). [2]C20, C40, and C60: cookies produced by incorporating 20%, 40%, and 60% cocoyam four into wheat flour, respectively. [3]P20, P40, and P60: Cookies produced by incorporating 20%, 40%, and 60% plantain four into wheat flour, respectively. [4]Values are mean ± standard deviation of triplicate analysis. [5]Mean values represented in the same column with different superscript letters are significantly different ($p < 0.05$).

the prevention of invasion by microorganisms through appropriate packaging and heat treatment in producing the flour and cookies' baking temperature also revolves around reducing the level of total aerobic counts available to grow and multiply [18].

3.4. Sensory Evaluation and Color Attributes of Cookies. Consumer food choice motivation is strongly influenced by sensory parameters such as smell, taste, texture, appearance, and color. Among the seven cookies (C20, C40, C60, and P20, P40, and P60) and the control cookies (WF), consumer acceptability declined from 8.33-6.99 (Table 5). There were comparable sensory scores among the cookies (Table 5): cookies produced at 20% and 40% of either plantain or cocoyam flour inclusion in wheat flour had comparable sensory parameters to cookies containing wheat flour alone. With these consumer scores and preferences made on the cookies, plantain or cocoyam flour should be incorporated into wheat flour at 20% and 40%. These results concur with those previously reported by [27] in cookies produced from fermented sorghum, and cocoyam flours, as well as, cookies enriched with crickets' powder [18].

Color quality increases consumers' acceptability of food products [13]. As such, the color properties of cookies are important indicators of their quality. The recorded L^* values between cookies containing wheat flour alone (WF) and the C20, C40, and C60 ranged from 61.19 to 62.82. (Table 6). Whereas a^* ranged from 2.10 to 2.30 with b^* ranging from 18.51 to 22.30. The highest L^*, a^* and b^* values were observed in WF (Table 6). Similarly, in cookies produced with partial replacement of either plantain or cocoyam flour, chroma was found in the range of 18.65 to 22.30 and with deta E (ΔE) deferring more than 2 units (Table 6), indicating perceptible color difference to the human eye. As the proportion of plantain or cocoyam flour is increased, L^*, b^* and chroma values decrease in the cookies, while a^* was found to decrease in C20, C40, and C60, but increase in P20, P40, and P60 (Table 6). However, this observation did not affect consumer acceptability of the cookies at 20% and 40% partial replacement of wheat flour with either plantain or cocoyam flour (Table 5). It is noteworthy that [13, 38] also reported a linear correlation between L^* and b^*. The L^* values recorded for plantain, cocoyam and wheat flours were 63.78 ± 0.03, 66.07 ± 0.02, and 68.02 ± 0.5, respectively (Table 5). This finding was in line with observations made by [6, 7]. Accordingly, cookies produced from wheat flour alone and those produced by partial replacement of wheat flour with cocoyam flour tend to have a comparable lighter

Table 5: Sensory evaluation of control cookies and cookies produced by partial replacement of wheat flour with either cocoyam or plantain flour.

Cookies	Smell	Color	Taste	Texture	Appearance	Acceptability
WF	8.08 ± 0.27^{a}	8.10 ± 0.71^{a}	7.98 ± 0.58^{a}	7.70 ± 1.11^{a}	8.18 ± 0.59^{a}	8.33 ± 0.62^{a}
C20	8.15 ± 0.86^{a}	8.20 ± 0.76^{a}	8.05 ± 0.81^{a}	7.53 ± 0.72^{ab}	8.08 ± 0.73^{ab}	8.25 ± 0.54^{ab}
C40	8.03 ± 0.83^{a}	7.18 ± 0.64^{c}	7.75 ± 0.87^{ab}	7.23 ± 0.53^{bc}	7.83 ± 0.64^{bc}	7.83 ± 1.08^{b}
C60	7.73 ± 0.72^{b}	7.58 ± 0.84^{b}	7.45 ± 0.60^{b}	6.75 ± 0.63^{d}	7.93 ± 0.66^{abc}	7.35 ± 0.95^{c}
P20	7.85 ± 0.36^{ab}	7.88 ± 0.94^{ab}	7.80 ± 0.85^{ab}	7.40 ± 1.15^{abc}	7.70 ± 0.76^{b}	7.93 ± 0.73^{ab}
P40	7.98 ± 0.42^{ab}	8.18 ± 0.75^{a}	7.70 ± 0.82^{ab}	7.55 ± 0.88^{ab}	7.95 ± 0.81^{abc}	7.90 ± 0.74^{ab}
P60	7.11 ± 0.90^{c}	7.53 ± 0.99^{bc}	6.88 ± 1.04^{cd}	7.11 ± 0.94^{c}	7.61 ± 0.79^{c}	6.99 ± 1.22^{c}

[1]WF: 100% wheat flour cookies (control cookies). [2]C20, C40, and C60: cookies produced by incorporating 20%, 40%, and 60% cocoyam four into wheat flour, respectively. [3]P20, P40, and P60: cookies produced by incorporating 20%, 40%, and 60% plantain four into wheat flour, respectively. [4]Values are mean ± standard deviation of triplicate analysis. [5]Mean values represented in the same column with different superscript letters are significantly different ($p < 0.05$).

Table 6: Color parameters of control cookies and cookies produced by partial replacement of wheat flour with either cocoyam or plantain flour.

Cookies	L^*	a^*	b^*	Chroma	ΔE
WF	62.82 ± 0.58^{a}	2.30 ± 0.30^{c}	22.30 ± 0.56^{a}	22.42 ± 0.58^{a}	—
C20	62.53 ± 0.55^{a}	2.17 ± 0.01^{c}	21.75 ± 0.54^{a}	21.86 ± 0.54^{a}	1.13 ± 0.67^{d}
C40	62.03 ± 0.27^{ab}	2.10 ± 0.02^{c}	19.75 ± 0.09^{b}	19.87 ± 0.09^{b}	3.04 ± 0.15^{c}
C60	61.30 ± 0.73^{b}	2.25 ± 0.02^{c}	18.51 ± 0.35^{c}	18.65 ± 0.35^{c}	4.43 ± 0.51^{b}
P20	61.76 ± 0.95^{ab}	2.83 ± 0.50^{b}	18.85 ± 0.71^{c}	18.99 ± 0.79^{c}	4.18 ± 0.88^{b}
P40	61.19 ± 0.56^{b}	3.38 ± 0.22^{a}	18.14 ± 0.04^{c}	18.46 ± 0.06^{c}	4.97 ± 0.31^{b}
P60	60.01 ± 0.25^{d}	3.58 ± 0.05^{a}	17.14 ± 0.02^{d}	17.51 ± 0.01^{d}	6.32 ± 0.27^{a}

[1]WF: 100% wheat flour cookies (control cookies). [2]C20, C40, and C60: cookies produced by incorporating 20%, 40%, and 60% cocoyam four into wheat flour, respectively. [3]P20, P40, and P60: cookies produced by incorporating 20%, 40%, and 60% plantain four into wheat flour, respectively. [4]Values are mean ± standard deviation of triplicate analysis. [5]Mean values represented in the same column with different superscript letters are significantly different ($p < 0.05$).

appearance than cookies produced from the partial replacement of wheat flour with plantain flour (Table 6). In general, the color of a food product is influenced by variables, including color of ingredients and caramelization [39]. The color difference observed among the cookies was attributed to the color differences in the plantain, cocoyam, and wheat flours.

4. Conclusion

Plantain and cocoyam flours are sustainable alternative flours for producing cookies since cookies produced from these flours contain more fiber and are rich in several nutrients such as iron, zinc, potassium, and calcium than cookies containing wheat flour alone. Additionally, such flours are easily accessible and affordable and the aforementioned mineral provisions in cookies produced by partial replacement of wheat flour with either plantain or cocoyam flour are higher than cookies containing wheat flour alone. In all cookies, the levels of aerobic plate counts were lower than the recommended threshold advised for processed food products. Moreover, the partial replacement of the wheat flour with either plantain or cocoyam flour resulted in comparable texture and physical qualities such as hardness, thickness, width, weight, and spread ratio of the resultant cookies. However, cookies produced at 60% of either plantain or cocoyam flour substitution into wheat flour was the least accepted by consumers. This was evidenced by the slightly darker color of these cookies. Accordingly, incorporating plantain or cocoyam flour into wheat flour at 20% and 40% levels for producing cookies is highly encouraged. Such cookies are sustainable and rich sources of food than can be utilized to address global malnutrition and food insecurity.

Data Availability

All data generated or analysed during this study are included in this manuscript.

Additional Points

*Practical applications.*Plantain and cocoyam are sustainable and rich sources of nutrients with a low environmental footprint compared to wheat flour. The food industry will generally capitulate to innovation that put the food products in good light to consumers and addresses postharvest losses and nutrient deficiencies. Such as those highlighted in the present study, adding value to perishable root and tuber crops is primarily through flour production and producing cookies from them. In light of the numerous benefits of plantain or cocoyam cookies, their consumption will essentially contribute to food security and address population mineral deficiencies.

Conflicts of Interest

The authors wish to declare that there is no conflict of interest associated with this article.

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