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Chemical, Physicochemical, Microbiological and Sensory Characteristics of Chin-Chin Formulated from Blends of Chia (*Salvia hispanica* L.) and Njansang (*Ricinodendron heudelotii*) Seed Flours

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ABSTRACT

Objective: This study evaluated the chemical, physicochemical, microbiological and sensory characteristics of chin-chin produced from wheat flour partially substituted with chia (*Salvia hispanica* L.) and njansang (*Ricinodendron heudelotii*) seed flours, with the aim of developing a nutritionally enhanced cereal-based snack.

Materials and Methods: Five formulations were prepared: a 100% wheat flour control and four composite blends containing wheat flour, chia flour and njansang flour at ratios of 90:5:5, 80:10:10, 70:15:15 and 60:20:20, corresponding to 10, 20, 30 and 40% combined substitution, respectively. Proximate composition, Peroxide Value (PV) and Thiobarbituric Acid Reactive Substances (TBARS) were determined in triplicate using AOAC and AOCS methods. Microbial counts were determined using standard plate-count techniques and sensory attributes were evaluated by 20 semi-trained panellists using a nine-point hedonic scale. Data were analysed using one-way analysis of variance (ANOVA) and means were separated using Duncan's multiple range test at $p<0.05$.

Results: Substitution significantly increased crude protein, ash, crude fibre and crude fat contents, whereas carbohydrate content decreased and calculated energy increased. Peroxide value and TBARS increased with increasing substitution levels but remained below thresholds conventionally applied to fried products. Total viable counts remained below the 10 CFU/g safety criterion in all samples. Overall acceptability did not decline progressively with increasing substitution. The 10 and 30% substitution levels did not differ significantly from the control, whereas the 20 and 40% substitution levels received significantly lower scores. Nevertheless, all composite products remained within the "like slightly" to "like moderately" range of the hedonic scale.

Conclusion: Partial substitution of wheat flour with chia and njansang seed flours at 10% and 30% combined substitution levels produced chin-chin with enhanced nutritional characteristics, satisfactory microbiological quality and acceptable sensory properties. These findings support the potential use of chia and njansang seed flours as functional ingredients in the development of nutritionally enhanced indigenous snack products.

INTRODUCTION

Consumers increasingly expect daily foods to provide more than energy and to contribute to a long and healthy lifespan. The global burden of overweight and obesity, type 2 diabetes mellitus (T2DM), cardiovascular diseases (CVDs) and certain types of cancer is closely associated with poor dietary quality and unhealthy dietary patterns[1,2]. Accordingly, food manufacturers have begun exploring food

reformulation using inexpensive, nutrient-dense and bioactive food sources that can enhance nutritional value while maintaining the sensory characteristics preferred by consumers[3,4].

Chin-chin, a deep-fried, cereal-based, egg-rich snack traditionally prepared from wheat flour, sugar, fat and baking powder, is one of the most widely consumed Nigerian snacks and is also popular in other West African countries. Its widespread consumption is attributed to its relatively low cost, convenient storage and high acceptability due to its palatable taste. However, chin-chin is typically characterized by a high proportion of energy-yielding carbohydrates and fats, with relatively low amounts of dietary fibre, essential fatty acids and micronutrients. Regular consumption of energy-dense but micronutrient-poor snack foods may contribute to diet-related disorders, particularly among children and young adults, who constitute a substantial proportion of snack consumers. Composite flour technologies, which involve replacing part of the wheat flour with less expensive, nutrient-rich local ingredients, offer an opportunity to improve the nutritional quality of snacks while maintaining the use and consumer familiarity of wheat-based products and potentially reducing dependence on imported wheat.

Previous research has demonstrated the potential of partially substituting wheat flour with protein- and fibre-rich oilseeds, seeds and pulses in baked and fried products without requiring specialized equipment. Recent reports have confirmed the successful incorporation of oilseeds, legumes and some minor cereal flours to enhance the protein, fibre and mineral contents of various food products, although the level of incorporation can influence dough rheology, colour, texture and crispness[5,6].

Among oilseeds, chia seeds (*Salvia hispanica* L.) have attracted considerable interest because of their distinctive nutritional composition. They are rich in polyunsaturated fatty acids, particularly α-linolenic acid, as well as protein, dietary fibre and antioxidant phenolic compounds. Chia flour can therefore enhance the nutritional and functional properties of baked and snack products, although high inclusion levels may adversely affect texture and dough rheological properties[7-9].

Another African oilseed of interest is African nutmeg (*Ricinodendron heudelotii*), commonly known as njansang and also referred to as Okwe or Nganja in parts of West and Central Africa. Njansang seeds are traditionally used in soup preparation and as a spice. In addition to their lipid content, which contains a mixture of unsaturated fatty acids, njansang seeds provide protein, dietary fibre, antioxidants and minerals. These nutritional characteristics indicate their potential as an ingredient for developing nutrient-enriched food products and improving dietary quality[10,11]. However, the use of njansang as a food ingredient requires optimization of processing conditions and comprehensive application studies to preserve its nutritional value and control process-related oxidative and microbiological risks during product formulation[12].

The combined use of chia and njansang seed flours in chin-chin may provide complementary nutritional benefits by increasing protein, dietary fibre, omega-3 fatty acids and mineral content. However, the incorporation of seed flours rich in polyunsaturated fatty acids raises concerns regarding lipid oxidative stability during deep-frying. Therefore, it is important to evaluate oxidative stability alongside nutritional, microbiological and sensory characteristics at different levels of incorporation.

Although, previous studies have investigated the use of chia and njansang individually in food products, information on their combined use in chin-chin, particularly with respect to chemical composition, oxidative stability, microbiological quality and sensory characteristics, appears to be limited. Therefore, this study investigated the effects of different levels of chia and njansang seed flour incorporation on the nutritional composition, lipid oxidative stability, microbiological quality and sensory acceptability of chin-chin.

MATERIALS AND METHODS

Study location: Sample preparation, chin-chin production and sensory evaluation were carried out in the Food Processing and Sensory Evaluation Laboratories of the Department of Food Science and Technology, Chukwuemeka Odumegwu Ojukwu University, Igbariam, Anambra State, Nigeria. Chemical, physicochemical and microbiological analyses were carried out in the Food Chemistry and Microbiology Laboratories of the Department of Food Science and Technology, Madonna University Nigeria, Enugu.

Materials: Standard-grade wheat flour (Harvest-All), njansang seeds (*Ricinodendron heudelotii*), chia seeds (*Salvia hispanica* L.), whole eggs, date syrup, refined soybean oil, extra-virgin olive oil, virgin coconut oil and baking powder were purchased from the local market in Awka, Anambra State, Nigeria. Stones, dirt and broken seeds were manually removed before the seeds were ground and sieved using a laboratory hammer mill fitted with a 0.5-mm sieve. All reagents used were of analytical grade (Sigma, St. Louis, USA).

Preparation of seed flours and composite flours: The cleaned and washed chia and njansang seeds were air-dried for 24 hrs at 28°C. The seeds were ground separately using a laboratory hammer mill and sieved to obtain flours with a particle size below 500 µm. The flours were then stored in airtight polypropylene bags at ambient temperature until use. Composite flours were prepared using five different blends

comprising a control (100% wheat flour) and four formulations containing chia and njansang at a ratio of 1:1. The formulations were as follows: 90% wheat flour + 5% chia+5% njansang (MC3A), 80% wheat flour +10% chia +10% njansang (MC3B), 70% wheat flour +15% chia +15% njansang (MC3C) and 60% wheat flour +20% chia +20% njansang (MC3D). These formulations corresponded to combined chia and njansang substitution levels of 10%, 20, 30 and 40%, respectively. Wheat is denoted as W, chia as Ch and njansang as Ns throughout the formulations. The recipe is presented in Table 1.

Composite flour blends and chin-chin recipe: Table 1 presents the five wheat-chia-njansang flour blends together with the fixed non-flour ingredients used to produce chin-chin from each formulation.

Production of chin-chin: Chin-chin was prepared according to a modified version of the method described by Akubor[13]. Baking powder was mixed with each type of composite flour, including the control. Subsequently, the wet ingredients, including whole eggs, olive oil, virgin coconut oil and date syrup, were added and thoroughly mixed to form a smooth, non-sticky dough (Table 1).

The dough was allowed to stand for 15 min and then pressed into sheets approximately 0.5 cm thick using a rolling pin. The sheets were cut into small cubes measuring approximately 2×2 cm and deep-fried in refined soybean oil at 170-180°C for 5-7 min or until golden brown. The fried chin-chin was removed and placed on kitchen tissue to drain excess oil and allowed to cool at ambient temperature. The frying oil was replaced with fresh refined oil for each treatment and the oil-to-flour ratio was kept constant across treatments. Fresh samples were packed in airtight polyethylene sachets and analyses were carried out within 24 hrs of production.

Chemical and physicochemical analysis: Moisture, ash, crude protein, crude fat, and crude fibre contents were determined in triplicate according to AOAC[14] Official Methods 925.10, 923.03, 984.13, 920.39, and 962.09, respectively. Carbohydrate content was calculated by difference, and metabolisable energy was estimated using Atwater factors. Peroxide value was determined using AOCS Official Method Cd 8b-9015, while thiobarbituric acid-reactive substances (TBARS) were assayed spectrophotometrically at 532nm according to Piranavatharsan *et al*[16]. The TBARS results were expressed as mg malondialdehyde (MDA)/kg.

Microbiological analysis: Total aerobic bacteria were enumerated on Plate Count Agar using the pour-plate method after incubation at 37°C for 24-48 hrs. Yeasts and moulds were enumerated on acidified Sabouraud Dextrose Agar after incubation at 25°C for 5 days, following the procedures described in the FDA Bacteriological Analytical Manual[17]. Results were expressed as colony-forming units per gram (CFU/g). A single determination was performed for each formulation; therefore, microbiological data are presented descriptively and were not subjected to analysis of variance.

Sensory evaluation: Twenty semi-trained panelists, comprising staff and students of the Department who were accustomed to consuming chin-chin, evaluated the coded, randomly presented samples for colour, taste, mouthfeel, crispness, flavour, aftertaste, aroma and overall acceptability using a nine-point hedonic scale (9 = like very much; 1 = dislike very much). Panelists rinsed their mouths with tap water between samples[18]. Individual sensory booths equipped with normal white lighting were used during the evaluation. Each panelist evaluated all five products in a single session. The samples were evaluated monadically.

Ethical considerations: Written informed consent was obtained from each panelist before the study commenced. No identifiable personal information from participants was presented; therefore, specific consent for publication of images of panelists was not required.

Table 1: Composition of the composite flour blends and chin-chin formulation

Ingredients	Control	MC3A	MC3B	MC3C	MC3D
Composite flour blend (g/100 g total flour)					
Wheat flour	100	90	80	70	60
Chia flour	0	5	10	15	20
Njansang flour	0	5	10	15	20
Combined chia+njansang substitution (%)	0	10	20	30	40
Added ingredients (g/100 g composite flour)					
Whole egg	5	5	5	5	5
Olive oil	5	5	5	5	5
Coconut oil	5	5	5	5	5
Date syrup	25	25	25	25	25
Baking powder	1.5	1.5	1.5	1.5	1.5

Control = 100% wheat flour (no chia, no njansang), MC3A-MC3D contain chia and njansang in equal proportions at progressively increasing levels. Flour blend proportions sum to 100 g of total flour. Added ingredients are expressed per 100 g of composite flour and were held constant across all formulations; they are additional to and not included within the 100 g flour base. Batch size was 100 g of composite flour per formulation

Statistical analysis: Chemical and physicochemical analyses of the samples were performed in duplicate and the results were expressed as Mean±standard deviation. Data were analysed by one-way analysis of variance (ANOVA) using IBM SPSS Statistics, Version 26.0. Means were compared at a 95% confidence level ($p<0.05$) using Duncan's multiple range test when the F-test was significant.

Sensory data were subjected to one-way ANOVA at a 95% confidence level using the same software. Hedonic scores were treated as continuous variables (interval data), which is an accepted convention for preference-testing data[18].

Calculated energy values and microbiological counts were not subjected to ANOVA. Superscripts in Table 2, 3 and 4 indicate significant differences among means within a row when the F-test was significant, according to Duncan's multiple range test at $p<0.05$. Means with different superscript letters are significantly different, with 'a' representing the highest mean, followed by 'b' and 'c' (a >b>c).

RESULTS AND DISCUSSION

Proximate composition: Partial replacement of wheat flour with chia and njansang flours significantly ($p<0.05$) affected each of the determined proximate composition parameters (Table 2). Crude protein content increased progressively with increasing inclusion of chia and njansang flours, from 10.29% in the control to 18.45% in MC3D. Ash content also increased from 1.64% in the control to 3.88% in MC3D. Moisture content decreased from 7.30% in the control to 3.82-3.94% in the three most highly substituted composite products, with no significant differences among these formulations. Crude fibre content, which was initially low in the control (1.45%), increased progressively throughout the substitution series, reaching 7.27% in MC3D. The corresponding values were 2.22% in MC3A, 4.07% in MC3B, 5.72% in MC3C and 7.27% in MC3D. Crude fat content increased from 15.59% in the control to 24.13%, 26.50%, 29.52% and 34.42% in MC3A, MC3B, MC3C and MC3D, respectively. In contrast, carbohydrate content decreased systematically from 63.73% in the control to 32.05% in MC3D. Calculated energy content increased from 436.39 to 511.78 kcal/100 g, with the highest energy value observed in MC3D.

Peroxide value and TBARS: Both oxidative indices increased with increasing substitution level, although they exhibited different patterns (Table 3). Peroxide value increased from 4.06 meq O_2/kg fat in the control to 7.76 meq O_2/kg fat in MC3D, with each formulation differing significantly from the subsequent formulation. Thus, even the lowest inclusion level had a significantly higher peroxide value than the control. All values remained below 10 meq

Table 2: Proximate composition of chin-chin enriched with chia and njansang seed flours

Component (%)	Control	MC3A	MC3B	MC3C	MC3D
Crude protein	10.29±0.70^{d}	13.29±0.23^{c}	16.62±0.23^{b}	17.02±0.04^{b}	18.45±0.31^{a}
Ash	1.64±0.03^{e}	2.15±0.04^{d}	2.95±0.06^{c}	3.40±0.08^{b}	3.88±0.13^{a}
Moisture	7.30±0.09^{a}	5.92±0.10^{b}	3.94±0.06^{c}	3.82±0.06^{c}	3.93±0.06^{c}
Crude fibre	1.45±0.00^{e}	2.22±0.08^{d}	4.07±0.06^{c}	5.72±0.06^{b}	7.27±0.11^{a}
Crude fat	15.59±0.07^{e}	24.13±0.07^{d}	26.50±0.08^{c}	29.52±0.09^{b}	34.42±0.20^{a}
Carbohydrate (by difference)	63.73±0.14^{a}	52.29±0.30^{b}	45.92±0.25^{c}	40.52±0.07^{d}	32.05±0.42^{e}
Energy (kcal/100 g)	436.39	479.49	488.66	495.84	511.78

Values are mean ± standard deviation of three independent determinations (n = 3). Means within a row bearing different superscript letters differ significantly ($p < 0.05$; Duncan's Multiple Range Test); letters are assigned in descending order of the mean (a = highest). Energy was calculated from the mean proximate values using Atwater factors and is a derived quantity with no independent experimental error; it is therefore reported without a standard deviation and was not subjected to mean separation. Formulation codes are defined in Table 1

Table 3: Peroxide value and TBARS of chin-chin produced from wheat, chia and njansang seed flour blends

Parameter	Control	MC3A	MC3B	MC3C	MC3D
TBARS (mg MDA/kg)	0.11±0.01^{c}	0.13±0.01^{c}	0.15±0.01^{b}	0.19±0.01^{a}	0.20±0.01^{a}
Peroxide value (meq O^2/kg fat)	4.06±0.08^{e}	5.73±0.07^{d}	6.73±0.23^{c}	7.09±0.01^{b}	7.76±0.11^{a}

Values are mean±standard deviation of three independent determinations (n = 3). Means within a row bearing different superscript letters differ significantly ($p<0.05$). MDA, malondialdehyde. Formulation codes are defined in Table 1

Table 4: Sensory attributes of chin-chin produced from wheat, chia and njansang seed flour blends

Attribute	Control	MC3A	MC3B	MC3C	MC3D
Colour	8.45±0.60^{a}	7.45±1.05^{b}	7.16±1.00^{b}	7.19±1.44^{b}	7.45±1.76^{b}
Flavour	8.20±0.89^{a}	6.90±1.33^{b}	7.11±0.87^{b}	7.14±1.39^{b}	7.00±1.32^{b}
Mouthfeel	8.05±1.01^{a}	6.85±1.14^{b}	7.16±1.12^{b}	7.00±1.14^{b}	6.55±1.50^{b}
Crispness	8.00±1.12^{a}	7.55±1.05^{b}	7.11±1.10^{c}	6.90±1.41^{d}	6.55±1.57^{e}
Taste	8.20±0.77^{a}	6.90±1.33^{C}	6.47±1.54^{e}	7.38±1.39^{b}	6.80±1.20^{d}
Aftertaste	7.45±0.94^{a}	6.75±1.25^{ab}	6.11±1.45^{b}	7.10±1.41^{e}	6.05±1.43^{b}
Aroma	7.40±1.54^{a}	7.15±1.22^{a}	6.89±1.41^{e}	6.86±1.46^{e}	6.50±1.50^{a}
Overall acceptability	8.25±0.97^{a}	7.70±0.98^{ab}	7.16±1.38^{b}	7.48±1.44^{ab}	7.10±1.48^{b}

Values are mean±standard deviation of scores from twenty semi-trained panelists (n = 20) on a nine-point hedonic scale. Means within a row bearing different superscript letters differ significantly ($p<0.05$), Formulation codes are defined in Table 1

Table 5: Microbiological quality of chin-chin produced from wheat, chia and njansang seed flour blends

Sample	Total viable count (CFU/g)	Total fungal count (CFU/g)
Control	5.0×10^3	1.0×10^4
MC3A	5.5×10^4	ND
MC3B	2.0×10^4	ND
MC3C	1.5×10^4	1.5×10^4
MC3D	3.5×10^4	ND

Values are colony-forming units per gram (CFU/g), single determination per formulation, ND, not detected (below the limit of detection of the method), Formulation codes are defined in Table 1

O_2/kg, the maximum value specified by Codex for refined oils[19]. However, this standard applies to oils as marketed rather than to fat extracted from a composite fried food and is therefore used here only as a reference point.

TBARS increased from 0.11 mg MDA/kg in the control to 0.20 mg MDA/kg in MC3D. However, MC3A did not differ significantly from the control, while MC3C and MC3D did not differ significantly from each other. These results indicate that measurable TBARS accumulation was not evident at the lowest inclusion level and tended to level off at the two highest substitution levels.

Microbiological quality: Total viable counts in all formulations were below the 10 CFU/g criterion generally applied to ready-to-eat cereal-based snacks[20], ranging from 5.0×10^3 CFU/g in the control to 5.5×10 CFU/g in MC3A (Table 5). Counts did not vary systematically with substitution level. The highest count was observed in MC3A, the least-substituted composite formulation, rather than in MC3D. Nevertheless, all four composite formulations had higher counts than the control. Fungal colonies were detected only in the control and MC3C, at 1.0×10 and 1.5×10 CFU/g, respectively and were not detected in the remaining samples. Because enumeration was performed as a single determination, these differences are reported descriptively and were not subjected to statistical analysis.

Sensory attributes: The control recorded the numerically highest mean score for every attribute evaluated, although several of these differences were not statistically significant (Table 4). For overall acceptability, MC3A (7.70) and MC3C (7.48) did not differ significantly ($p>0.05$) from the control (8.25), whereas MC3B (7.16) and MC3D (7.10) had significantly lower scores. Aroma did not differ significantly among the formulations. Crispness declined progressively with increasing substitution level, whereas among the composite formulations, taste and aftertaste received the highest scores in MC3C.

Nutritional implications of substitution: Substitution modified each proximate composition parameter in the direction and manner expected from the composition of the two seed flours, with the magnitude of the changes generally increasing with inclusion level.

The 79% increase in crude protein content between the control and MC3D reflects the relatively high protein contents of both fortifying ingredients. The reported crude protein content is approximately 22% for njansang seed[21] and ranges from 47.0 to 61.3% for defatted *R. heudelotii* kernel flour[22]. These values indicate that njansang and chia seed flours can serve as protein-fortifying ingredients. Chia has also been reported to increase protein content in composite foods. For example, Chemutai *et al.*[23] reported an increase in protein content from 7.22 to 9.16% in ugali with 9% chia substitution. The greater increase observed in the present study may be attributable to the higher combined inclusion level of the two fortifying ingredients and the use of two protein-rich seed flours.

The corresponding increase in ash content from 1.64 to 3.88% reflects the mineral-rich nature of the two seed flours compared with refined wheat flour. The progressive increase in ash content is consistent with that reported for okra-seed chin-chin[24]. Njansang seed, which is particularly rich in magnesium and phosphorus[21], may contribute substantially to the overall increase observed across the composite formulations. However, ash content is an index of total mineral residue and does not identify individual mineral elements. Therefore, claims regarding enrichment with specific minerals would require elemental analysis.

Crude fibre increased from 1.45% in the control to 7.27% in MC3D. This increase may be largely attributed to the relatively high fibre content of chia, for which values ranging from 18 to 30% have been reported[25]. The low fibre content of the control is expected because refined wheat flour undergoes substantial removal of bran during milling and this limitation may be partly addressed through incorporation of the seed flours. Similar increases have been reported for okra-seed chin-chin[24]. In contrast, only a relatively small increase in fibre content, from 0.95 to 1.12%, was reported across soursop-flour-incorporated chin-chin samples[26]. This difference further indicates that the relatively large increase in fibre observed in the present study may be associated with the fibre contribution of chia and njansang.

Crude fat more than doubled, increasing from 15.59% in the control to 34.42% in MC3D. This increase is attributable to the inherent lipid content of chia (approximately 30-33%) and njansang (approximately 46%)[21], in addition to the contribution of oil absorbed during

frying. Similar increases in fat content have been reported in soursop-substituted chin-chin, from 33.31 to 39.29%[26] and in chin-chin formulated with njansang seed flour[12]. The relatively low initial fat content of the control in the present study, compared with the wheat-flour control reported by Deedam et al.[26], may reflect differences in formulation and processing conditions, including dough thickness and frying method. The resulting increase in calculated energy content from 436.39 to 511.78 kcal/100 g was mainly associated with the increase in crude fat content. Similar increases in energy content have been reported in other studies involving composite-flour substitutions in chin-chin[23,24]. Thus, increased energy density represents an important nutritional consideration when using this substitution strategy, although the products also contain higher levels of protein and fibre. The nutritional implications of the increased fat content should therefore be considered when developing the product for commercial consumption.

Carbohydrate content decreased consistently from 63.73% in the control to 32.05% in MC3D. This decline is expected because the wheat flour was progressively replaced with seed flours, which have different proximate compositions. Because carbohydrate content was calculated by difference, the observed reduction also reflects the increases in the other proximate components. Similar inverse relationships between composite flour incorporation and carbohydrate content have been reported in studies of composite chin-chin products[24,26].

Moisture content was lowest in MC3C and MC3D, at values below 4% and increased progressively with decreasing substitution level, reaching 7.30% in the control. The lower moisture content of the more highly substituted formulations may be related to differences in the water-binding characteristics of the composite seed flours and to moisture loss during frying. The high lipid contents of chia and njansang may also influence the distribution and retention of water within the dough. For comparison, Deedam et al.[26] reported an increase in moisture content from 4.85 to 7.65% with increasing incorporation of soursop flour into chin-chin. The contrasting trends may reflect differences in the composition and functional properties of the substituted flours, particularly the relatively higher lipid content of chia and njansang compared with fruit flour.

Lipid oxidation: Peroxide value increased significantly with successive increases in substitution level, with MC3A already exhibiting a significantly higher value than the control. TBARS showed a somewhat different pattern. No significant difference was observed between MC3A and the control, whereas TBARS increased significantly with further substitution through MC3B and MC3C. Although, TBARS increased further in MC3D, this increase was not statistically significant. The different responses of these two indices are consistent with their measurement of different stages or products of lipid oxidation. Peroxide value primarily reflects primary oxidation products, whereas TBARS is commonly used as an indicator of secondary oxidation products. Thus, the results suggest that incorporation of the seed flours increased the susceptibility of the product to lipid oxidation, although the two indices did not respond identically across substitution levels. The lack of a significant increase in TBARS between MC3C and MC3D should not be interpreted as evidence that oxidation had ceased at the higher inclusion levels.

The overall increase in oxidative indices with increasing seed-flour incorporation is consistent with observations in other chia-enriched foods. Sharma et al.[27], for example, reported a progressive increase in TBARS values with increasing chia incorporation in plant-based patties. Chia is rich in α-linolenic acid, a polyunsaturated fatty acid that is susceptible to oxidation, particularly under thermal processing conditions[28,29]. Therefore, increasing the proportion of chia-derived unsaturated lipids may increase the susceptibility of the product to oxidative reactions during frying and subsequent storage.

Nevertheless, the measured oxidation indices remained below the reference value of 10 meq O_2/kg used in this study. This comparison should be interpreted cautiously because the Codex limit cited for refined oils applies to oils as marketed rather than to fat extracted from a composite fried food. Moreover, peroxide value and TBARS provide information about lipid oxidation but do not by themselves establish overall product quality or oxidative rancidity. Importantly, the present measurements describe the oxidative status of the products at the time of analysis and do not establish their oxidative stability during storage. Therefore, storage studies evaluating changes in peroxide value, TBARS and sensory quality over time would be necessary to determine shelf-life stability. For formulations with the highest lipid content, such as MC3C and MC3D, oxygen- and moisture-barrier packaging, appropriate storage conditions and the use of food-grade antioxidants may be considered as potential strategies for improving oxidative stability. Antioxidant extracts such as rosemary or garlic have shown potential in chia- and flaxseed-enriched food systems[30].

Microbiological quality and sensory acceptability: Total viable counts were relatively low across all five formulations and showed no clear relationship with substitution level. The counts ranged from 5.0×10^3 CFU/g in the control to 5.5×10 CFU/g in MC3A. The relatively low counts may be associated with the heat treatment during deep-frying and the low moisture content of the finished products. However, the present data do not allow the effect of frying temperature alone to be isolated and the microbiological results should therefore be interpreted descriptively. The higher counts observed in the composite formulations than in the control

may reflect differences in the initial microbial loads of the seed ingredients, processing, or post-frying handling. This emphasizes the importance of adequate cleaning of seed materials, hygienic processing and appropriate post-frying handling during commercial production.

Two observations did not follow a clear substitution-level trend. The highest total viable count occurred in MC3A, which had the lowest level of seed-flour substitution, while fungal colonies were detected only in the control and MC3C. Because microbiological enumeration was based on a single determination per formulation, these observations cannot be used to establish systematic differences among treatments. They may reflect variation in raw-material contamination or processing and post-processing handling. Furthermore, the absence of specific pathogen testing limits the conclusions that can be drawn regarding microbiological safety. Thus, the present results provide an indication of the microbiological status of the products at the time of analysis rather than definitive evidence of their microbiological safety or shelf stability.

Regarding sensory acceptability, no significant difference was observed among MC3A, MC3C and the control for overall acceptability, whereas MC3B and MC3D received significantly lower scores than the control. The lower scores at some higher substitution levels may be associated with changes in colour, mouthfeel, crispness and flavour resulting from the incorporation of chia and njansang seed flours. However, overall acceptability did not decline monotonically with increasing substitution level. The relatively high acceptability of MC3C despite its greater level of substitution indicates that the sensory response to the composite formulations was not determined solely by the concentration of the added seed flours.

The sensory results should also be interpreted in the context of the panel size and composition. Twenty semi-trained panelists evaluated the products and the observed differences may partly reflect individual variation in sensory perception. A larger consumer panel representing a broader range of demographic and consumption characteristics would provide stronger evidence regarding consumer acceptance and could help identify the substitution level with the greatest market potential. The present findings are broadly consistent with reports from Nigerian studies of composite-flour snacks, in which moderate incorporation of functional ingredients was generally acceptable, whereas higher incorporation levels could alter familiar sensory characteristics of the conventional product[6,31].

LIMITATIONS

Five limitations should be considered when interpreting these findings. First, the measured variables relate only to the product as processed and, without a subsequent shelf-life study incorporating defined storage conditions and appropriate packaging, their extrapolation to stored products remains unconfirmed, particularly given the oxidative potential associated with the high PUFA content of the supplemented samples and their potential susceptibility to microbial spoilage. Second, the single determinations of total viable and fungal counts, together with the absence of specific microbial hazard analyses, such as screening for *Salmonella enterica*, *Staphylococcus aureus* and *Escherichia coli*, mean that the microbiological findings provide only limited evidence regarding product safety and cannot establish the microbiological safety of the finished ready-to-eat product. Third, the use of 20 semi-trained panelists recruited from within the research institution limits the generalizability of the sensory findings and the institutional testing environment may have influenced panelists' evaluations. Fourth, the fat analyses did not include individual fatty acid profiling; therefore, the effect of deep-frying on C18:3, particularly α-linolenic acid, could not be directly determined. Fifth, carbohydrate and energy values were not measured directly but were calculated from the other proximate components and therefore are subject to the cumulative errors associated with those measurements.

CONCLUSION

Partial replacement of wheat flour with chia and njansang seed flours significantly increased protein, ash, fibre and fat contents and decreased carbohydrate content, while the calculated energy value increased with increasing substitution. At the point of production, peroxide and TBARS values, as well as total viable and fungal counts, remained at relatively low levels; however, these findings should not be interpreted as establishing microbiological safety or long-term oxidative stability in the absence of storage and microbial hazard studies. Overall acceptability was relatively high across the formulations, with 10% and 30% combined substitution showing sensory acceptability comparable to the control, whereas acceptability decreased at higher substitution levels. These findings indicate that chia and njansang seed flours have potential as functional food ingredients for developing indigenous Nigerian snacks, with 10 and 30% combined substitution warranting further investigation for the development of protein-enriched chin-chin products based on chia, njansang and wheat flour composites.

Future commercialization of such fortified products should be preceded by comprehensive shelf-life evaluation under defined storage conditions and packaging systems, characterization of fatty acid profiles and oxidative stability, assessment of appropriate antioxidant strategies to mitigate lipid oxidation, targeted microbial hazard analyses and larger-scale consumer acceptance studies involving a broader and more diverse panel.

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