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ORIGINAL ARTICLE

Food Chemistry, Engineering, Processing and Packaging Functional and Novel Foods

Quality Evaluation and Storage Stability of Low-Fat *Chin-Chin* Formulated with Wheat-Soybean Residue (Okara) Flour Blends

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ABSTRACT

Background: *Chin-chin* is a traditional wheat flour-based deep-fat fried snack widely consumed across West Africa. In light of escalating public health concerns associated with excessive dietary lipid intake, there is an imperative need to explore alternative processing technologies capable of reducing the fat content of such products while simultaneously enhancing their overall nutritional value.

Aims: The present study aimed to evaluate the physicochemical attributes and storage stability of a nutritionally enriched, low-fat chin-chin snack formulated from wheat–okara composite flour blends processed via air-frying technology.

Material and Methods: Composite flours were prepared by substituting wheat flour with okara at varying incorporation levels (0%, 10%, 20%, 30%, and 100%). The resulting doughs were processed using an air-fryer and subsequently stored under ambient conditions over a 28-day period. Functional, nutritional, and organoleptic properties were systematically evaluated at defined intervals throughout the storage period.

Results: The incorporation of okara flour at progressive substitution levels significantly improved the proximate composition of chin-chin samples in a dose-dependent manner, yielding increases in crude protein (0.8–10.62%), crude fat (15.03–41.47%), and crude fiber (0.21–2.53%) contents. Notably, air-fried samples exhibited a substantially reduced lipid profile and superior protein content relative to their deep-fried counterparts. Mineral concentrations likewise increased proportionally with progressive okara substitution. Over the 28-day storage period, a general trend of increasing moisture content, water activity, peroxide values, and thiobarbituric acid reactive substances (TBARS) was recorded across all treatments; however, these oxidative and hydrolytic deteriorative changes were significantly more pronounced in the deep-fried control samples.

Conclusions: The incorporation of okara at substitution levels of up to 30% yielded chin-chin products of high sensory acceptability with markedly improved nutritional profiles and reduced lipid content. Air-frying constitutes a technologically viable and health-conscious alternative to conventional deep-fat frying, offering comparable product quality with diminished lipid-associated health risks. These findings advocate for the valorization of okara as a functional food ingredient in the development of nutritionally fortified snack products.

Keywords: Air-Frying; Nutritional Enrichment; *Chin-chin*; Lipid Reduction; Agro-Industrial By-Product Valorization; Okara; Storage Stability.

Article Information

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1 INTRODUCTION

Snacks represent ready-to-eat food commodities typically consumed between meals. Accelerated urbanization and shifting socioeconomic dynamics—particularly the evolving professional roles of women—have concurrently escalated the global demand for snack foods within both developed and developing economies (Ganpule *et al.*, 2023; Robledo-Ramírez *et al.*, 2022). Fried snacks exhibit high consumer acceptability primarily driven by their desirable aromatic profiles, palatability, and distinctive textural properties. These products are conventionally formulated from a wheat flour matrix combined with auxiliary ingredients, and are subsequently structured via baking or deep-fat frying operations (Rani *et al.*, 2023). Owing to their affordability, pre-packaged convenience, and widespread accessibility, these commercial products are ubiquitously distributed across diverse public sectors, educational institutions, commercial transit corridors, and social gatherings. Within the specific context of popular Nigerian confectionery, "*chin-chin*" constitutes a highly prevalent fried snack.

Chin-chin is characterized as a deep-fried, golden brown, and highly texturally crunchy wheat-based product that commands broad demographic appeal in Nigeria. The traditional processing framework involves kneading a composite dough matrix composed of wheat flour, sucrose, water, sodium chloride, and chemical leavening agents, frequently enriched with whole eggs, fluid milk, and aromatic spices such as nutmeg (*Myristica fragrans*). (Kayode *et al.*, 2025). Post-frying, the product exhibits a rigid, crisp crystalline structure and distinct organoleptic properties. It is fabricated into highly variable geometric configurations—including cuboidal, spherical, and linear geometries—, and its robust market penetration is continuously propelled by entrepreneurial commercialization and scaled marketing strategies (Adebayo-Oyetoro *et al.,* 2017).

Extensive research has focused on the nutritional fortification and functional optimization of *chin-chin.* Prior investigations have successfully incorporated diverse high-protein and bioactive substrates into the foundational recipe, including germinated finger millet, okra seed, tiger nut flour, cauliflower, African walnut, edible palm weevil, chicken powder, pigeon pea, immature plantain, whole soybean, and orange-fleshed sweet potato flours (Abioye *et al.,* 2020; Alagbu, 2022; Amonyeze *et al.*, 2025; Arukwe, 2021; Ndife *et al.*, 2020; Ojinnaka *et al.*, 2016). Notwithstanding these advancements, research elucidating the valorization of high-nutrient agro-industrial by-products, such as okara, within chin-chin formulations remains conspicuously absent.

Okara represents the residual, water-insoluble pulp generated during the wet-milling and subsequent aqueous extraction of soybeans *(Glycine max)* during tofu or soymilk manufacturing. Following macro-component separation, a substantial proportion of the endogenous lipids, structural carbohydrates, and proteins remain bound within the okara residue matrix (Riaz, 2006; Voss *et al.*, 2018). Biochemically, dried okara comprises approximately 50% dietary fiber, 25% crude protein, and 10% lipids (Li *et al.,* 2011; Voss *et al.,* 2018). It is established that dietary fibre exerts critical regulatory effects on human metabolic pathways and mitigates the risk profiles of various chronic etiology diseases (Redondo-Cuenca *et al.*, 2008). Furthermore, okara exhibits an abundance of non-nutritive bioactive constituents, including flavonoids and other phenolic compounds, which possess potent antioxidant activities capable of mitigating oxidative stress and conferring chemopreventive defense mechanisms (Li *et al.,* 2011, Sun *et al.*, 2018). However, the massive volume of okara produced annually poses a profound ecological challenge due to its elevated moisture content and rapid putrefaction kinetics (Li *et al.,* 2013). Consequently, this can lead to environmental burdens and systemic wastage of highly valuable nutrients.

As previously noted, conventional *chin-chin* production relies heavily on deep-fat frying. Epidemiological evidence robustly associates the sustained consumption of deep-fried food matrices with an elevated prevalence of overweight and clinical obesity. These metabolic conditions have been associated with high incidence of cardiovascular diseases, type 2 diabetes mellitus, and associated metabolic syndromes (Gadiraju *et al.*, 2015; Guallar-Castillon *et al.*, 2012; Qin *et al.,* 2021).

Consequently, there is an imperative to explore alternative thermal technologies to reduce the oil-uptake kinetics of fried commodities. Convective hot-air frying (air-frying) has emerged as a prominent alternative technology. Air-frying operates by rapidly circulating superheated air around the food substrate via forced convection loops, eliminating the requirement for total lipid immersion (Téllez-Morales *et al.*, 2024). The process consists of an enclosed, thermally insulated cooking chamber coupled with a high-velocity convective fan system (Abd Rahma *et al*, 2017; Zaghi *et al.*, 2019). Crucially, comparative data indicate that air-frying can achieve up to an 80% reduction in total fat retention within the final food matrix compared to traditional immersion frying techniques (Andrés *et al.*, 2013).

To the best of our knowledge, there is sparse empirical literature addressing the synergistic integration of okara-wheat composite flours with advanced lipid-reduction thermal technologies for snack production. Therefore, this study was designed to evaluate the physicochemical, nutritional, and shelf-life quality of *chin-chin* formulated with okara as an affordable protein source in combination with air-frying techniques as a fat reduction method.

2 METHODS

2.1 Acquisition of Raw Materials

Whole soybeans utilized in the present study were procured from the Ogige Main Market, Nsukka, Enugu State, Nigeria. Standard culinary ingredients required for *chin-chin* fabrication, including wheat flour, frying oil, baking fats, etc., were purchased from the same market. All chemicals used for the analysis were of analytical grade.

2.2 Production of Okara Flour

Okara processing was executed in accordance with the method described by Ostermann-Porcel *et al.* (2017)with minor modifications. A 2.0 kg batch of soybean seeds underwent rigorous mechanical sorting to eliminate stones, debris, and fractured seeds, followed by washing in distilled water to remove superficial particulate matter. The cleaned grains were hydrated via overnight immersion in water to achieve maximum turgor and facilitate cell-wall softening. The fully imbibed seeds were dehulled and subjected to wet mechanical milling employing an industrial hammer mill. Distilled water was incorporated into the resultant slurry at a standardized matrix ratio of 5:1 (w/v), followed by mechanical filtration through double-layered cheesecloth. The residual cake was subjected to high-pressure mechanical expression to extract maximum residual moisture. The isolated solid residue (crude okara) retained on the cloth filter was evenly distributed on drying trays and subjected to solar dehydration for 72 hours (ambient conditions 32 ± 2°C; relative humidity: 72 ± 3%). The dehydrated okara was subsequently pulverized using a laboratory mill and passed through a fine mesh sieve to isolate standardized okara flour.

2.3 Formulation of Blends

Composite flour matrices were prepared by systematically blending refined wheat flour with the processed okara flour at predetermined substituting levels, as systematically delineated in Table 1.

Table 1. Wheat and Okara Composite Flours for *Chin-Chin* Production

Sample code	WF (g)	OK (g)	Total (g)
OK$_{0}$	100	0	100
OK$_{10}$	90	10	100
OK$_{20}$	80	20	100
OK$_{30}$	70	30	100
OK$_{100}$	0	100	100

Note: OK$_{0}$ = 100% wheat flour (WF); OK$_{10}$ = 90% WF,10% okara flour (OK); OK$_{20}$ = 80% WF, 20% OK; OK$_{30}$ = 70% WF, 30%OK; OK$_{100}$ = 100%OK. *Source: Author's experimental data*

2.4 Production of *Chin-Chin* Samples

The quantitative ingredient configurations utilized for the distinct chin-chin treatments are summarized in Table 2. The formulation and preparation steps were adapted from the empirical protocols of Akubor (2004) with minor modifications. For each batch, 100 g of the respective composite flour blend was weighed and homogenized through a 250-micron particle size analytical sieve. The sieved flour was transferred into a sterile mixing vessel and dry-blended with crystalline sucrose and pulverized nutmeg. Solid margarine was sequentially incorporated into the dry matrix via manual rubbing until a uniform, crumb-like texture was achieved. Evaporated milk and water were incrementally incorporated, and the composite mass was thoroughly kneaded to yield a cohesive, viscoelastic dough structure.

The resulting dough was transferred to a flat working surface and sheeted uniformly using a calibrated rolling pin. The sheeted dough matrix was precisely portioned into standardized dimensions of 0.2 cm by 2 cm utilizing a mechanical pastry cutter. The portioned dough units were subjected to parallel thermal treatments—either conventional deep-fat immersion or convective air-frying—at a fixed temperature of 170°C. Deep-frying was conducted using a commercial immersion deep fryer (Cookworks deep fryer, MDS330N1, UK), while air-frying was executed in a convective air-fryer apparatus (Binatone, Model BAF-5000 MK2, China). The samples were subjected to continuous, controlled agitation during the thermal cycle until uniform surface browning was achieved. Post-frying, the chin-chin samples were immediately transferred into a stainless-steel drainage sieve to remove superficial oil and cooled under ambient conditions for 30 minutes. All processed experimental samples were packaged in hermetically sealed plastic containers and stored under controlled ambient storage conditions (30°C ± 1°C; relative humidity: 43% ± 3 °C) for a duration of 28 days, with representative aliquots systematically withdrawn at weekly intervals for microbiological and quality stability analyses.

Table 2. Ingredients and Quantities Employed in the Production of *Chin-Chin*

Ingredient	Quantity
Wheat flour	100g
Sugar	10g
Evaporated Milk	15g
Margarine	25g
Ground Nutmeg	3g
Sodium chloride (salt)	Quantum satis (Q.S.)
Water	67.5 mL

Source: Author's experimental data

2.5 Frying Process

For conventional deep-frying, 100 g of *chin-chin* dough was fried in two (2.0) liters of refined vegetable oil employing a deep fryer (after a 5 min thermal equilibration period) for a total retention time of approximately 3 min. For air frying, a duplicate 100g of batch of portioned dough cuts was distributed within the air-frying chamber and processed for 10 minutes following a 5 min preheating and equilibration cycle of the apparatus. Both thermal processing configurations were strictly executed at a regulated temperature of 170 °C. The specific experimental matrix assigning the thermal processing methods to the respective treatments is systematically presented in Table 3.

Table 3. *Chin-Chin* Samples and their Frying Methods

Sample code	WF (g)	OK (g)	Frying method
OKD$_{0}$	100	0	DF
OKA$_{0}$	100	0	AF
OKA$_{10}$	90	10	AF
OKA$_{20}$	80	20	AF
OKA$_{30}$	70	30	AF
OKD$_{30}$	70	30	DF
COMM	-	-	-

Note: OKD$_{0}$ = 100% WF, Deep fried; OKA$_{0}$ = 100% WF, Air fried, OKA$_{10}$ = 90% WF, 10% OK Air fried; OKA$_{20}$ = 80% WF, 20%OK Air fried; OKA$_{30}$=70% WF, 30% OK Air fried; OKD$_{30}$= 70%WF, 30% OK Deep fried; COMM = commercial control. *Source: Author's experimental data*

2.6 Proximate Compositional Analysis

The proximate nutritional profiles of both the composite flour matrices and the processed chin-chin samples were determined in accordance with the standardized analytical protocols established by the Association of Official Analytical Chemists (AOAC, 2010).

2.7 Determination of Selected Mineral Profiles

Mineral analysis was performed following the empirical procedures outlined by AOAC (2010). The concentrations of specific micronutrients—namely iron (Fe), copper (Cu), magnesium (Mg), and zinc (Zn) were measured via Atomic Absorption Spectrophotometer (AAS).

2.8 Functional Properties of Composite Flour Blends

Volumetric and Hydration Properties

The bulk density, water absorption capacity (WAC), oil absorption capacity (OAC), emulsification activity, swelling capacity, and water solubility index (WSI) of the composite flour blends were systematically determined according to the methods described by Onwuka (2018).

Evaluation of Lipid Oxidation and stability indices

- *Peroxide Value (PV)*

The primary lipid oxidation status was monitored through peroxide value determination executed in compliance with the standard chemical methods of the AOAC)(2010).

- *Thiobarbituric acid (TBA) Reactive Substances*

Secondary lipid degradation kinetics were quantified via the thiobarbituric acid (TBA) assay to determine the malondialdehyde equivalent concentrations, following the technical framework delineated by Onwuka (2018).

- *Determination of Water Activity (a_w)*

The water activity a_w of the ground chin-chin matrices was measured using a calibrated water activity analyzer (Model 58–03). Prior to analysis, the instrument was standardized by inserting a specialized filter paper was saturated with a barium chloride ($BaCl_2$) solution into the test chamber for a duration of for three hours. Subsequently, the homogenized sample was sealed within the analytical chamber and allowed to equilibrate for three hours. Appropriate mathematical correction factors and temperature adjustments were systematically applied before and after each determination to ensure data fidelity.

2.9 Sensory Evaluation

Organoleptic profiling of the fried chin-chin treatments was carried out by a 15-member semi-trained panel randomly selected from the student population of the Department of Food Science and Technology at the Enugu State University of Science and Technology. The evaluated sensory attributes included texture, colour, aroma, taste, perceived oiliness, crispiness, flavour, external appearance, and overall acceptability. Assessments were scored employing a 9-point Hedonic scale as described by Ihekoronye and Ngoddy (1985).

2.10 Experimental Design and Statistical Analysis

The experiment was laid out utilizing a Completely Randomized Design (CRD). All analytical determinations were executed in duplicate, with the data expressed as mean values ± standard deviation (SD). The computational datasets were subjected to a one-way Analysis of Variance utilizing SPSS software (version 22). Statistically significant differences among treatment means were resolved utilizing Duncan's Multiple Range Test (DMRT) at an alpha significance criterion of $p < 0.05$.

3 RESULTS AND DISCUSSION

The techno-functional properties of the raw-wheat okara composite flour blends are summarized in Table 4. Statistical analysis revealed significant variations ($p < 0.05$) among the samples across all evaluated functional parameters. The values obtained for water absorption capacity (WAC) ranged from 68.67 in the control wheat flour (OK_0) to 374.35 % in the pure okara flour matrix (OK_{100}). The WAC exhibited a statistically significant, dose-dependent escalation as the level of okara supplementation increased. This upward trend in

Table 4. Techno-Functional Properties of the Raw-Wheat Okara Composite Flour Blends

Samples	WAC (%)	OAC (%)	Solubility (%)	Swelling capacity (%)	Bulk Density (g/cm^3)	Emulsion capacity (%)
OK_0	$68.67^e \pm 0.20$	$41.37^e \pm 0.42$	$13.38^a \pm 0.00$	$20.3^d \pm 0.01$	$0.76^a \pm 0.00$	$47.15^e \pm 0.25$
OK_{10}	$79.98^d \pm 0.81$	$128.01^d \pm 0.17$	$10.04^b \pm 0.02$	$21.3^e \pm 0.00$	$0.73^b \pm 0.01$	$48.02^d \pm 0.02$
OK_{20}	$98.86^c \pm 0.42$	$131.28^c \pm 0.42$	$6.73^c \pm 0.03$	$22.4^c \pm 0.03$	$0.68^c \pm 0.01$	$48.49^c \pm 0.23$
OK_{30}	$125.49^b \pm 0.37$	$139.07^b \pm 0.24$	$6.06^d \pm 0.15$	$23.9^b \pm 0.04$	$0.66^c \pm 0.01$	$50.01^b \pm 0.02$
OK_{100}	$374.31^a \pm 0.28$	$164.59^a \pm 0.21$	$4.53^e \pm 0.04$	$49.7^a \pm 0.01$	$0.52^d \pm 0.00$	56.44a ± 0.02

Note: OK_0 = 100% wheat flour (WF); OK_{10} = 90% WF,10% okara flour (OK); OK_{20} = 80% WF, 20% OK; OK_{30} = 70% WF, 30%OK; OK_{100} = 100%OK. WAC = water absorption capacity, OAC = oil absorption capacity. Mean values within a row bearing different superscripts are significantly different ($p < 0.05$). Values are mean ± standard deviation of duplicate determinations. *Source: Author's experimental data* hydration kinetics is heavily attributable to the high total protein content intrinsic to the okara residue, which contains numerous hydrophilic peptide domains capable of binding water molecules (Otegbayo *et al.*, 2013). This mechanism aligns with the findings of Ilelaboye and Ogunsina (2018) who reported a parallel enhancement in the hydration capacity of stiff dough (amala) produced formulated with progressive ratios of okara into plantain–sorghum flour composites. Similarly, Abioye *et al.* (2020) observed that incorporating germinated finger millet flour into a wheat matrix significantly reinforced the overall water binding performance. From a food engineering standpoint, a high WAC is highly advantageous in dense systems where moisture retention must occur without structural dissolution of protein networks, thereby effectively augmenting viscosity, yield, and matrix body-thickening properties (Akinwale *et al.*, 2017).

Concurrently, the oil absorption capacity (OAC) increased progressively with expanding okara inclusion levels. The peak OAC value was recorded for pure okara flour (164.59%), whereas the lowest retention baseline was observed in refined wheat flour (111.37%). Mechanistically, OAC reflects the capacity of proteins hydrophobic amino acid side-chains to physically bind lipid droplets. This parameter is highly critical since endogenous lipids act as volatile flavor retainers while significantly enhancing product palatability and mouthfeel (Otegbayo *et al.*, 2013). This specific experimental behavior mirrors the structural trends reported by Ilelaboye and Ogunsina (2018) as well as Uzo-Peters and Ola (2020) regarding sorghum-based flour incorporated with okara.

The water solubility index (WSI) of the composite flour varied from 4.53 to 13.38%, with unblended wheat flour displaying the maximum value and pure okara flour recording the lowest index. This divergence is biochemically logical, as the solubility index is fundamentally an indirect measure of the starch content. Consequently, the progressive dilution of the starch-rich wheat matrix by the fiber-rich okara substrate led to a significant decrease in the solubility profiles. Conversely, the values for swelling capacity ranged from 20.3% for OK_{10} to 49.7% for OK_{100}, showing a steady inflation with higher okara concentrations. Swelling power serves as a primary marker of starch granule hydration and reflects the strength of associative binding networks operating within starch granules.

The volumetric bulk density values ranged from 0.52 g/cm^3 for the OK_{100} treatment to 0.76 g/cm^3 for OK_0 control. The bulk density decreased significantly higher okara substitution. An identical structural reduction trend was established by Uzo-Peters and Ola (2020) for sorghum-okara flour blends. Methodologically, bulk density is a crucial index that dictates the relative volume required for food packaging materials, playing a decisive role in economic storage, transportation logistics, commercial marketing, and industrial wet-processing design (Bello and Ekeh, 2014; Ngoma *et al.*, 2019). It also yields fundamental insights into product porosity, which heavily dictates optimal package selection and structural material barrier design (Adeleke & Odedeji, 2010; Ngoma *et al.*, 2019). The lower bulk densities values of wheat-okara flour blends offer distinct industrial advantages; flours with lower bulk density are highly suited for packaging, generating significant cost reductions since they require less protective structural material per unit volume during post-production handling (Ngoma *et al.*, 2019).

The emulsion capacity of the flours ranged from 47.15% for OK_0 to 56.44% for OK_{100}. A statistically significant ($p < 0.05$) increase in emulsification capacity was observed concurrent with progressive okara supplementation. Because proteins act as highly effective surface-active amphiphilic agents, the elevated protein content inherent to okara likely enhanced the emulsification properties of the composite matrix. Consequently, okara-augmented formulations could interact more efficiently with the lipid fraction of the dough, thereby yielding a more structurally homogenous matrix during processing.

3.1 Proximate Composition of Wheat-Okara Flour Blends.

The proximate compositional profiles of the raw wheat-okara composite flour blends are summarized in Table 5. The moisture content of the samples ranged from 7.63% to 9.64%; refined wheat flour displayed the highest moisture retention (9.64%), whereas the pure okara flour exhibited the lowest value (7.63%). Significant variations ($p < 0.05$) in moisture content were observed among the treatment groups. Dietary enrichment via okara may mitigate the prevalence of

Table 5. Proximate Composition (%) of the Raw-Wheat Okara Composite Flour Blends

Samples	Moisture	Crude Protein	Crude Fat	Crude Fibre	Ash	Carbohydrate
OK_0	$9.64^c \pm 0.25$	$14.30^e \pm 0.13$	$1.00^b \pm 0.05$	$0.32^e \pm 0.05$	$0.75^d \pm 0.04$	$74.00^a \pm 0.42$
OK_{10}	$8.20^a \pm 0.02$	$15.93^d \pm 0.27$	$1.20^b \pm 0.02$	$1.28^d \pm 0.06$	$1.31^c \pm 0.01$	$47.10^c \pm 0.29$
OK_{20}	$8.13^a \pm 0.02$	$17.75^c \pm 0.02$	$1.17^b \pm 0.03$	$2.07^c \pm 0.06$	$1.41^c \pm 0.11$	$71.48^a \pm 0.18$
OK_{30}	$8.14^a \pm 0.03$	$21.96^b \pm 0.04$	$1.44^b \pm 0.03$	$4.15^b \pm 0.29$	$2.03^b \pm 0.06$	$64.30^b \pm 0.32$
OK_{100}	$7.63^b \pm 0.93$	$42.66^a \pm 0.20$	$9.94^a \pm 0.50$	$21.94^a \pm 0.91$	$3.39^a \pm 0.01$	$14.01^d \pm 0.27$

Note: OK_0 = 100% wheat flour (WF); OK_{10} = 90% WF,10% okara flour (OK); OK_{20} = 80% WF, 20% OK; OK_{30} = 70% WF, 30%OK; OK_{100} = 100%OK. CHO = Carbohydrate. Mean values within a row bearing different superscripts are significantly different ($p < 0.05$). Values are mean ± standard deviation of duplicate determinations. *Source: Author's experimental data* systemic metabolic syndromes, such as cardiovascular diseases, obesity, and type 2 diabetes mellitus, which are epidemiologically coupled with low fiber intake (Fei *et al.*, 2013). The crude fiber value obtained for okara in this study was lower than the baseline of 36.62% reported by Mbaeyi-Nwaoha and Uchendu (2016).

The total ash content of the composite flours was inversely related to the proportion of refined wheat flour, indicating that the okara fraction possessed the highest mineral concentration. Statistically significant variations ($p < 0.05$) in ash content of were established across all treatments. Conversely, the total carbohydrate content decreased progressively with declining wheat flour ratios within the composite matrices. Carbohydrate concentrations ranged from 14.01% to 74.00%, with unblended wheat flour displaying the maximum concentration, while okara recorded the lowest carbohydrate fraction as a direct consequence of its elevated crude protein content. These differences in carbohydrate profiles were statistically significant ($p < 0.05$).

3.2 Proximate Composition of Processed *Chin-Chin* samples

The proximate nutritional profiles of the processed *chin-chin* samples are presented in Table 6. Significant variations ($p < 0.05$) were observed in the moisture retention profiles of the final products, with values ranging from 2.28% to 4.65%. The 100% wheat deep fried control sample (OKD_0) exhibited the highest moisture content (4.65%), followed closely by the deep-fried formulation containing 30% okara (OKD_{30}; 4.63%), while the commercial (COMM) displayed the minimum moisture content 2.28%. The incorporation of okara at distinct substitution ratios significantly ($p < 0.05$) altered the moisture dynamics of the fried snacks. Sanni *et al.* (2006) established that minimized moisture content in shelf-stable food commodities suppresses water activity, thereby restricting microbial proliferation and enhancing overall shelf stability.

All deep-fried treatments retained a significantly higher ($p < 0.05$) moisture content compared to their parallel air-fried counterparts. This observation contrasts with the findings of Priya *et al.* (2017), who reported higher moisture content in air-fried fish fingers relative to the deep-fried controls. This divergence could be attributed to structural and compositional differences between the two food matrices. In this study, the elevated moisture retention in deep-fried samples can be ascribed to their higher total lipid profile; heavy oil absorption potentially established a hydrophobic surface barrier that restricted moisture desorption during thermal processing. This structural phenomenon implies that air-fried samples may possess superior microbiological shelf-life stability compared to deep-fried products.

Significant differences ($p < 0.05$) were resolved regarding the crude protein content of the *chin-chin* samples. The OKD_0 treatment exhibited the lowest crude protein rates (0.80%) treatment exhibited. Conversely, OKA_{30} displayed the maximum crude protein content (10.62%), driven by the protein-dense nature of the okara substrate. Crude protein concentrations expanded in a dose-dependent manner with progressive okara addition. Furthermore, air frying led to a significant increase in the crude protein fraction. This concentration effect is evidenced by the higher protein contents of OKA_0 (1.53%) relative to OKD_0 (0.80%), and OKA_{30} (10.62%) compared to OKD_{30} (9.09%). This apparent increase of protein density within the air-fried matrices could be attributed to the lower relative moisture and fat contents. Air-frying of *chin-chin* represents a superior technological approach for maximizing protein density compared to traditional immersion frying. This dietary optimization mirrors the trends reported by Abioye *et al.* (2020), wherein the protein profiles of chin-chin expanded linearly with increasing substitution of germinated millet flour.

The experimental treatments displayed highly significant ($p < 0.05$) variations in crude fat concentrations. The 100% wheat air-fried ample (OKA_0) exhibited the minimum lipid retention (15.03%), whereas the deep-fried counterparts (OKD_0 and OKD_{30}) displayed the maximum levels (41.47% and 40.44% respectively). Crude fat content increased as a

Table 6. Proximate Composition (%) of Processed *Chin-Chin* Samples

Samples	Moisture	Crude Protein	Crude Fat	Crude Fibre	Crude Ash	Carbohydrate
OKD_0	$4.65^{a} \pm 0.01$	$0.80^{f} \pm 0.01$	$41.47^{a} \pm 0.85$	$0.21^{g} \pm 0.04$	$1.84^{d} \pm 0.00$	$51.05^{sf} \pm 0.81$
OKA_0	$3.23^{d} \pm 0.08$	$1.53^{e} \pm 0.02$	$15.03^{f} \pm 0.08$	$0.30^{f} \pm 0.01$	$1.90^{d} \pm 0.01$	$78.04^{a} \pm 0.16$
OKA_{10}	$3.20^{d} \pm 0.01$	$9.20^{c} \pm 0.02$	$16.41^{e} \pm 0.15$	$1.17^{e} \pm 0.04$	$1.99^{c} \pm 0.07$	$68.05^{b} \pm 0.16$
OKA_{20}	$3.51^{c} \pm 0.04$	$9.80^{b} \pm 0.05$	$17.93^{d} \pm 0.23$	$1.90^{d} \pm 0.03$	$2.16^{b} \pm 0.01$	$65.00^{c} \pm 0.18$
OKA_{30}	$3.61^{b} \pm 0.14$	$10.62^{a} \pm 0.11$	$19.39^{c} \pm 0.38$	$2.53^{b} \pm 0.06$	$2.76^{a} \pm 0.03$	$61.32^{d} \pm 0.43$
OKD_{30}	$4.63^{a} \pm 0.01$	$9.09^{d} \pm 0.01$	$40.44^{a} \pm 0.85$	$2.36^{c} \pm 0.01$	$1.56^{e} \pm 0.01$	$40.35^{g} \pm 0.85$
COMM	$2.28^{e} \pm 0.04$	$9.09^{d} \pm 0.02$	$23.83^{b} \pm 0.38$	$4.36^{a} \pm 0.06$	$0.91^{f} \pm 0.01$	$60.24^{e} \pm 0.47$

Note: OKD_0 = 100% WF, Deep fried; OKA_0 = 100% WF, Air fried, OKA_{10} = 90% WF, 10%OK Air fried; OKA_{20} = 80% WF, 20%OK Air fried; OKA_{30}=70% WF, 30% OK Air fried; OKD_{30}= 70%WF, 30% OK Deep fried; COMM= Commercial.MC Moisture content; CHO = Carbohydrate. Mean values within a row bearing different superscripts are significantly different ($p < 0.05$). Values are mean ± standard deviation of duplicate determination. *Source: Author's experimental data* function of okara substitution due to the higher endogenous lipid profile of okara relative to wheat flour. Crucially, the total fat content of all air-fried samples was significantly ($p < 0.05$) lower than that of the deep-fried groups. This structural trend is directly governed by the thermal processing mechanisms; oil uptake is minimized during convective air-frying because the apparatus utilizes superheated air loops rather than direct lipid immersion to drive heat transfer (Priya *et al.*, 2017; Téllez-Morales *et al.*, 2024). In contrast, conventional deep-fat frying completely immerses the food matrix in hot oil, triggering extensive capillary oil absorption upon cooling. These results indicate that air frying yields a nutritionally optimized, low-fat alternative to traditional frying. Elevated dietary lipid consumption is epidemiologically linked to systemic pathophysiologies, including cardiovascular diseases, chronic inflammatory states, hypercaloric metabolic profiles, and clinical weight gain (Saguy & Dana, 2003).

Okara incorporation induced statistically significant ($p < 0.05$) variations in the crude fiber content of the *chin-chin* samples. The OKD$_0$ and OKA$_0$ treatments displayed baseline crude fiber contents of 0.21 and 0.30%, respectively, which were significantly lower than the range of 1.17 to 2.53% observed in all okara-supplemented formulations. The fiber-rich cell wall matrix of okara directly enhanced the total dietary fiber profiles of the enriched snacks. The commercial control displayed the highest crude fiber content (4.36%), which may be attributed to proprietary ingredient configurations. Additionally, air-fried samples exhibited marginally higher fiber percentages than their deep-fried equivalents, as demonstrated by comparing OKA$_0$ (0.30%) with OKD$_0$ (0.21%). The synergistic application of okara substitution and convective air-frying is therefore highly effective at increasing the dietary fiber density of *chin-chin*.

The total ash content of the *chin-chin* samples ranged from 0.91% to 2.16% (Table 6). The commercial control displayed the lowest ash content (0.91%), while the OKA$_{30}$ treatment reached the highest concentration (2.16%). Okara incorporation resulted in a general, statistically significant elevation of the ash profile across all treatments. Interestingly, when comparing identical formulation ratios, air-fried chin-chin samples exhibited a slight reduction in total ash content relative to deep-fried samples. In food chemistry, the ash content serves as a direct proxy for the total concentration of nutritionally essential inorganic minerals within the food matrix (Lewu *et al.*, 2009).

The carbohydrate concentrations of the *chin-chin* samples exhibited statistically significant ($p < 0.05$) variations. The OKA$_0$ displayed the highest carbohydrate fraction (78.04%) followed by OKA$_{10}$ (68.05%), while OKD$_{30}$ recorded the minimum value (40.35%). Total carbohydrate content was inversely correlated with the crude lipid percentage of each sample, shifting downward as the relative fat concentration increased. Consequently, all deep-fried *chin-chin* samples possessed lower total carbohydrate percentages than their parallel air-fried counterparts due to the massive influx of oil during immersion frying, which structurally altered the macro-component mass balance of the final products.

3.3 Assessment of Mineral Composition

The inorganic mineral profiles of the formulated *chin-chin* samples are presented in Table 7. The experimental treatments displayed significant ($p < 0.05$) variations in magnesium (Mg) content, with values ranging from 9.61 to 10.21 mg/100g. The OKA$_0$ formulation exhibited the lowest Mg concentration, whereas the COMM sample displayed the highest baseline. The data indicate that Mg concentrations increased as a function of okara substitution. However, okara enrichment did not significantly alter the magnesium profiles within the air-fried cohort. Interestingly, deep-fried samples possessed higher total magnesium concentrations than corresponding air-fried treatments, potentially due to trace mineral migration from the commercial vegetable oil utilized during immersion frying. Magnesium represents a critical physiological cofactor required for the regulation of systemic blood pressure, immunological homeostasis, and neuromuscular function (Bertinato *et al.*, 2015).

Table 7. Mineral Composition of Processed *Chin-Chin* Samples

Samples	Magnesium (mg/100g)	Copper (µg/100g)	Iron (mg/100g)	Zinc (mg/100g)
OKD$_0$	$9.64^d \pm 0.25$	$25.50^d \pm 0.42$	$1.65^d \pm 0.09$	$0.43^g \pm 0.02$
OKA$_0$	$9.61^d \pm 0.25$	$26.80^d \pm 0.28$	$1.52^e \pm 0.02$	$0.45^f \pm 0.00$
OKA$_{10}$	$10.03^c \pm 0.54$	$53.10^c \pm 0.71$	$1.69^d \pm 0.25$	$0.52^e \pm 0.00$
OKA$_{20}$	$10.08^c \pm 0.04$	$80.15^b \pm 0.21$	$1.92^c \pm 0.07$	$0.60^c \pm 0.00$
OKA$_{30}$	$10.07^c \pm 0.06$	$105.60^a \pm 1.98$	$2.28^b \pm 0.04$	$0.64^a \pm 0.00$
OKD$_{30}$	$10.10^b \pm 0.04$	$53.85^c \pm 0.35$	$2.43^a \pm 0.01$	$0.61^b \pm 0.00$
COMM	$10.21^a \pm 0.04$	$107.05^a \pm 0.35$	$1.92^c \pm 0.16$	$0.47^d \pm 0.00$

Note: OKD$_0$ = 100% WF, Deep fried; OKA$_0$ = 100% WF, Air fried, OKA$_{10}$ = 90% WF, 10%OK, Air fried; OKA$_{20}$ = 80% WF, 20%OK Air fried; OKA$_{30}$=70% WF, 30% OK Air fried; OKD$_{30}$= 70%WF, 30% OK Deep fried; COMM= Commercial. Mean values within a row bearing different superscripts are significantly different ($p < 0.05$). Values are mean ± standard deviation of duplicate determinations. *Source: Author's experimental data*

The copper (Cu) content of the *chin-chin* samples varied from 25.50 to 107.05 ug/100g; the OKD$_0$ treatment displayed the minimum concentration, while the COMM control exhibited the peak value (107.05 ug/100g). Total Cu concentrations expanded linearly with progressive okara substitution. Furthermore, air-fried samples exhibited higher copper retention than corresponding deep-fried products, which can be attributed to the minimized moisture and lipid content focusing the micronutrient density within the air-fried matrix.

The total iron (Fe) content of the *chin-chin* samples varied significantly ($p < 0.50$) between 1.52 and 2.43 mg/100g. The non-supplemented OKD_0 and OKA_0 displayed baseline iron contents of 1.65 mg/100g and 1.52 mg/100g, respectively, which were significantly ($p < 0.50$) lower than the values (1.69 to 2.43 mg/100g) recorded across all okara-supplemented treatments. The incorporation of okara into the wheat matrix successfully enhanced the total iron profile of the final formulations. This indicates that validating okara utilization in value-added consumer foods including *chin-chin* could serve as an effective dietary strategy to combat the high prevalence of iron-deficiency anemia within developing nations, such as Nigeria. Iron acts as an indispensable trace element that mediates hemoglobin synthesis and systemic oxygen transport (Underwood and Suttle, 1999). Interestingly, all deep-fried samples exhibited higher total iron content than their corresponding air-fried samples, which may be driven by endogenous iron traces present within the frying oil medium.

The experimental samples exhibited significant ($p < 0.50$) variations in total zinc (Zn) content, ranging from 0.40 to 0.64mg/100g. Zinc concentrations expanded concurrently with higher okara inclusion levels. All air-fried formulations displayed higher zinc content than their deep-fried counterparts, a phenomenon driven by the reduced moisture and lipid retention that concentrated the inorganic micronutrients within the final food structures

3.4 Organoleptic and Sensory Properties

The sensory evaluation scores for the distinct *chin-chin* samples are delineated in Table 8. Statistically significant ($p < 0.05$) differences emerged among the samples across all evaluated organoleptic parameters. No significant ($p > 0.05$) deviations were detected in taste scores among the various okara-enriched formulations. However, unsupplemented control samples, irrespective of the thermal processing method applied, received significantly higher acceptability scores for taste, with the commercial control securing the peak rating (8.33).

The integration of okara induced a decline in taste scores, a result likely driven by consumer unfamiliarity with the distinct flavor notes of soy by-products within traditional chin-chin formulations. It is noteworthy that the average score for okara-enriched hovered around six (6.0) on the Hedonic scale, which corresponds to the "liked slightly" classification. This indicates that targeted public education regarding the nutritional and therapeutic benefits of okara-enriched foods could substantially improve consumer acceptance and market viability.

The scores for product crunchiness ranged from 5.67 to 7.4 for OKA_{30} and COMM, respectively. Notably, neither deep-fat immersion frying nor convective air-frying significantly impacted the crunchiness of the matrices. This is highly crucial because crunchiness is a critical sensory parameter for *chin-chin* snacks. Crunchiness constitutes a textural attribute universally associated with the freshness and firmness of natural products and manufactured foods. Consequently, adopting convective air-frying protocols for chin-chin production will not adversely affect this parameter. Conversely, progressive okara supplementation significantly reduced the overall crunchiness scores of the samples.

Regarding the mean sensory scores for appearance, the OKD_0 recorded the lowest baseline (5.53), whereas the commercial control (COMM) achieved the peak score (8.67). No significant differences ($p > 0.05$) were observed among the various okara-supplemented formulations. Crucially, the air-fried samples secured consistently higher scores for appearance compared to their deep-fried counterparts. This preference may be attributed to the fact that air-frying yielded products with a lighter, more uniform surface coloration than conventional immersion frying. Although the volatile flavor profile of the commercial control (COMM) was rated higher

Table 8. Sensory Properties of Processed *Chin-Chin* Samples

Samples	Taste	Crunchiness	Appearance	Flavor	Color	Oiliness	After taste	Overall acceptability
OKD_0	$6.93^b \pm 0.94$	$7.27^a \pm 1.28$	$5.53^c \pm 1.19$	$6.13^b \pm$	$6.00^c \pm 1.89$	$5.33^d \pm$	$7.57^{ab} \pm 1.37$	$7.06^c \pm 1.22$
OKA_0	$6.87^b \pm 0.88$	$7.20^a \pm 1.42$	$6.73^b \pm$	$6.60^b \pm$	$6.33^c \pm 1.68$	$7.53^a \pm 1.25$	$7.73^a \pm 1.68$	$7.67^b \pm 1.21$
OKA_{10}	$6.47^c \pm 1.30$	$7.00^a \pm 1.20$	$6.93^b \pm$	$6.20^b \pm$	$6.47^c \pm 1.06$	$7.00^b \pm$	$6.87^b \pm$	$6.80^c \pm 1.26$
OKA_{20}	$5.80^c \pm 1.70$	$6.27^{ab} \pm 1.62$	$7.13^b \pm$	$5.47^b \pm$	$6.93^b \pm 1.49$	$6.73^b \pm$	$6.46^{bc} \pm 1.41$	$6.67^c \pm 1.40$
OKA_{30}	$5.73^c \pm 1.91$	$5.67^b \pm 1.59$	$6.67^b \pm$	$5.87^b \pm$	$6.60^c \pm 1.24$	$6.74^b \pm$	$6.07^c \pm 1.94$	$6.67^c \pm 1.40$
OKD_{30}	$6.20^c \pm 1.74$	$6.60^{ab} \pm 1.74$	$6.47^{bc} \pm 1.10$	$5.80^b \pm$	$6.60^c \pm 2.35$	$5.20^d \pm$	$7.45^b \pm$	$6.00^d \pm 1.35$
COMM	$8.33^a \pm 0.82$	$7.40^a \pm 1.45$	$8.67^a \pm 0.62$	$7.87^a \pm 0.52$	$8.07^a \pm 1.03$	$6.53^c \pm 0.62$	$7.40^b \pm 1.12$	$8.53^a \pm 0.99$

Note: OKD_0 = 100% WF, Deep fried; OKA_0 = 100% WF, Air fried, OKA_{10} = 90% WF, 10%OK Air fried; OKA_{20} = 80% WF, 20%OK Air fried; OKA_{30}=70% WF, 30% OK Air fried; OKD_{30}= 70%WF, 30% OK Deep fried; COMM= Commercial; AFT= After taste; OA= Overall availability. Mean values within a row bearing different superscripts are significantly different ($p < 0.05$). Values are mean ± standard deviation of fifteen semi-trained panellists. *Source: Author's experimental data* than all other treatments, no significant ($p > 0.05$) variations in flavor were detected among the experimental test samples. Perceived color scores fluctuated between 6.00 and 8.07; OKD$_0$ received the lowest sensory rating, while COMM obtained the highest. The air-fried cohorts scored higher (though not statistically significant) than the deep-fried groups, which aligns with the lighter, non-scorched surface coloration characteristic of air-convective thermal processing.

The sensory scores for perceived oiliness spanned from 5.20 to 7.53, with OKD$_{30}$ and OKD$_0$ received the lowest scores, while OKA$_0$ captured the highest score. Interestingly, all air-fried samples achieved higher scores for the oiliness parameter than the deep-fried samples, indicating that the consumer panel strongly preferred the subtle, non-greasy lipid perception of the air-fried matrices. Notably, the deep-fried treatments scored significantly lower for oiliness than the commercial baseline. This sensory feedback reflects an expanding consumer awareness regarding the negative epidemiological health impacts of high-fat dietary intakes, driving a clear consumer preference for processed foods with reduced oil profiles. Sensory values for product aftertaste ranged from 6.07 for OKA$_{30}$ to 7.73 for OKD$_0$. The aftertaste scores decreased linearly as a function of okara incorporation, an outcome directly tied to the presence of endogenous volatile compounds responsible for the characteristic "beany" flavor profile of soy by-products.

The overall acceptability scores varied from 6.00 for the OKD$_{30}$ treatment to 8.53 for the COMM control. General consumer acceptability decreased with increasing levels of okara. However, the air-fried cohorts achieved significantly higher acceptance rates than the deep-fried samples. All okara-supplemented, air-fried samples were classified within the "moderately liked" sensory band. These results imply that commercially acceptable, okara-incorporated *chin-chin* can be successfully manufactured utilizing convective air-frying technologies.

The sensory evaluation observed in this study are strongly corroborated by the findings of Uzo-Peters and Ola (2020), who reported a decline across all sensory parameters in sorghum-okara composite snacks as okara inclusion increased. Similarly, El-Reffaei *et al.* (2012) observed a decrease in the overall acceptability metrics of falafel formulations with increasing levels of okara. Furthermore, Abioye *et al.* (2020) demonstrated decreasing general acceptability patterns in *chin-chin* samples as the ratio of germinated millet flour to wheat flour expanded.

3.5 Influence of Storage Period on Moisture Content and Water Activity (a$_w$)

The effects of storage duration on the moisture content and water activity (a$_w$) of the *chin-chin* samples are illustrated in Figure 1 and Figure 2 respectively. A general elevation in moisture content was observed across all matrices after one week of storage under ambient conditions. As the storage period progressed, however, the moisture content progressively decreased and stabilized for the majority of the treatments. An identical kinetic trend was mirrored by the water activity profiles. The low moisture content and low a$_w$ indicate that the products would be shelf-stable, as the low values would inhibit microbial vegetative proliferation.

3.6 Influence of Storage Period on Peroxide Value and TBA Reactive Substances

The effect of storage period on the peroxide value and thiobarbituric acid values of the *chin-chin* samples are presented in Figure 3 and Figure 4.

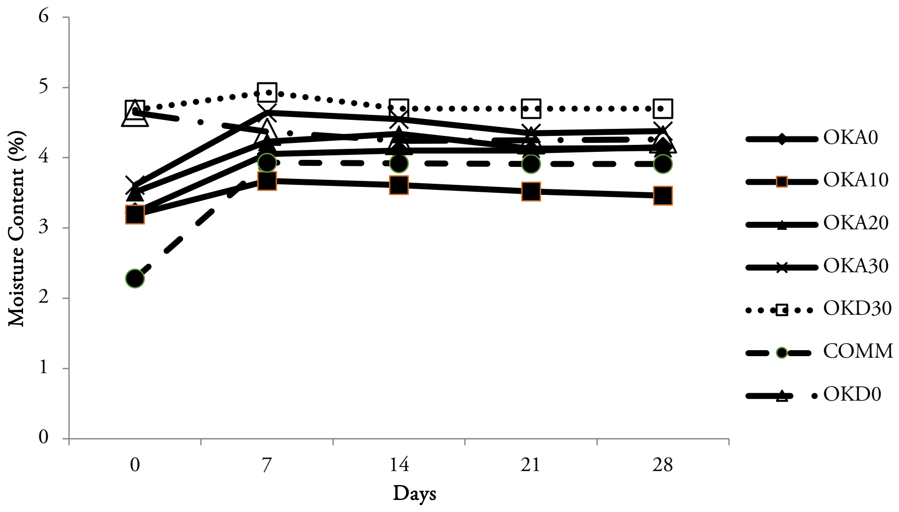

Figure 1. Effect of Storage Period on the Moisture Content

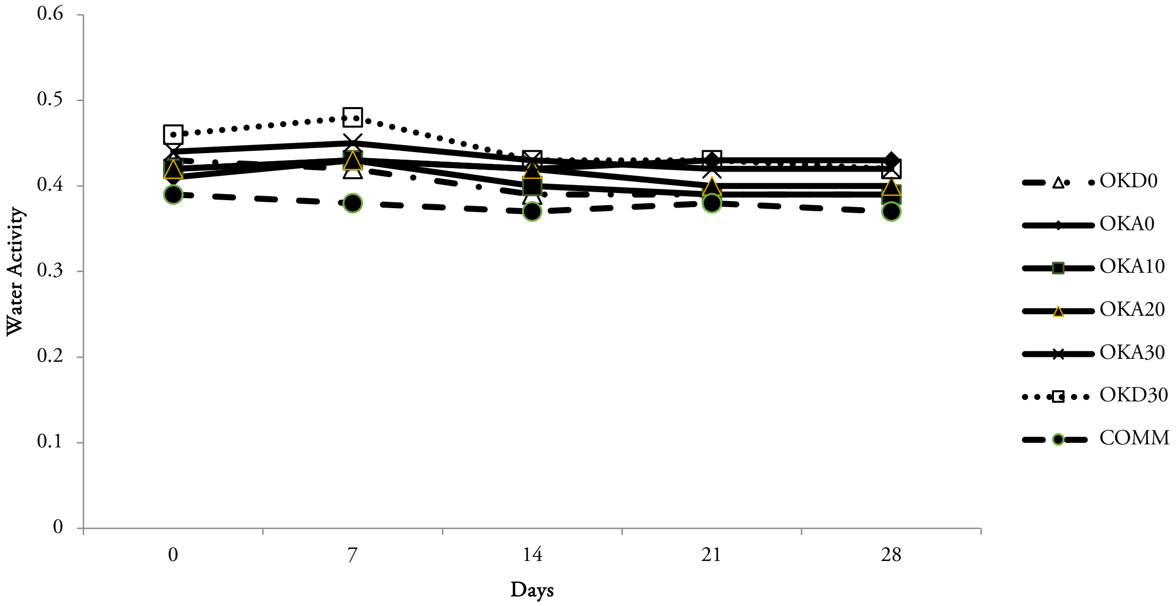

Figure 2. Effect of Storage Period on the Water Activity (a_w)

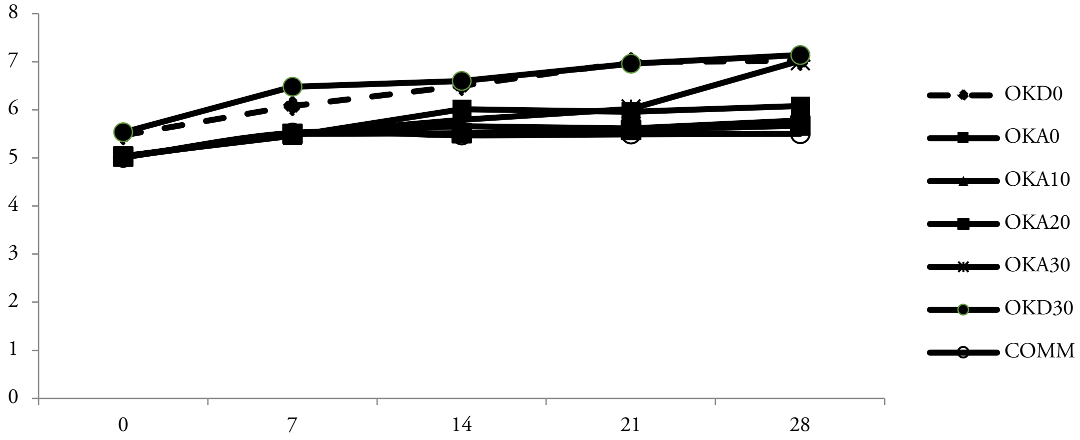

Figure 3. Effect of Storage Period on the Peroxide Value (PV)

There were increases in both the PV and TBA of all the samples as storage period increased. At the end of 28 days, the deep-fried samples had higher PV than the air fried ones. This could be attributed to the fact that their oil content came majorly from the frying oil unlike the air fried ones that their oil content came from the margarine used in forming the dough. The frying oils would be more susceptible to oxidation then the hydrogenated baking fat due to more unsaturated fatty acids therein. The TBA values also followed a similar trend as the PV. At the end of storage period the deep- fried samples had higher values than the air fried ones. The highest value (0.66 mg MDA) was obtained from OKD30.

3.7 Influence of Storage Period on Total Viable and Mycological Counts

The microbiological safety and stability of the chin-chin samples as a function of storage time are summarized in Table 9. No detectable vegetative cell proliferation (Total Viable Count) or fungal colony formation (Mould Count) was observed throughout the initial phases of storage. Active microbial colonies were only detected on day 28, manifested as highly sparse, negligible growth within the OKA_{20} and OKA_{30} treatments. This high microbiological stability is directly attributable to the low intrinsic moisture content and minimized water activity of the matrices. These outcomes

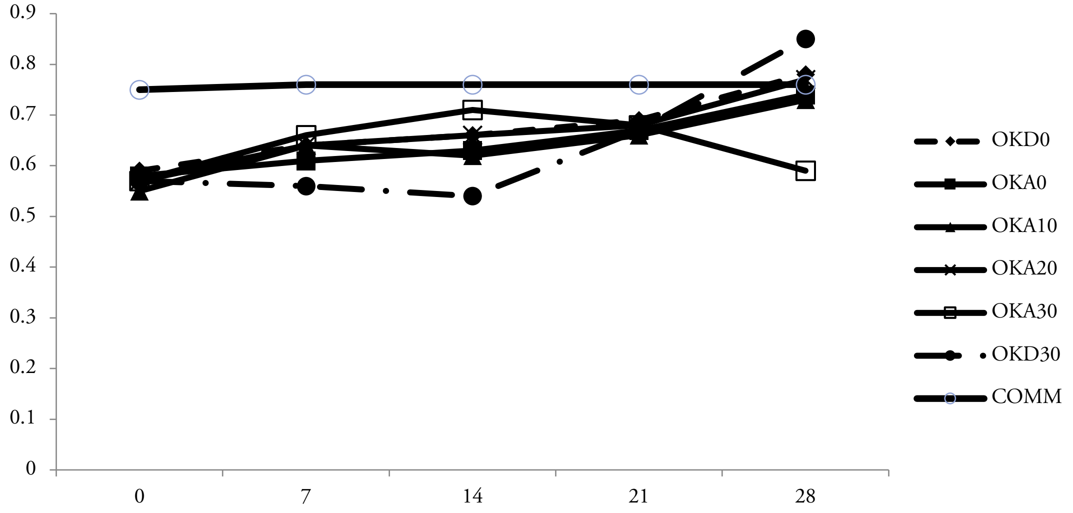

Figure 4. Effect of Storage period on the TBA Values

Table 9. Total Viable and Mycological Counts of the *Chin-Chin* Samples

	Day 0		Day 28	
Samples	TVC (cfu/g))	Mould count (cfu/g)	TVC (cfu/g))	Mould count (cfu/g)
OKD$_{0}$	ND	ND	ND	ND
OKA$_{0}$	ND	ND	ND	ND
OKA$_{10}$	ND	ND	ND	ND
OKA$_{20}$	ND	ND	ND	1.00x 10^{0}
OKA$_{30}$	ND	ND	ND	1.12 x 10^{0}
OKD$_{30}$	ND	ND	ND	ND
COMM	ND	ND	ND	ND

demonstrate that, under standard ambient storage conditions, okara substitution exerts no detrimental impact on the keeping quality, microbiological shelf life, or food safety status of the developed chin-chin snacks.

4 CONCLUSIONS

This study investigated the effect of okara substitution on the physicochemical, functional, and organoleptic properties of convective air-fried chin-chin snacks. The incorporation of okara into the raw flour blends induced significant ($p < 0.05$) enhancements in oil absorption, water absorption, and emulsification capacities. Following thermal processing, the finished snacks exhibited highly significant, dose-dependent increases in crude protein density and inorganic mineral concentration concurrent with expanding okara inclusion. From a sensory standpoint, all okara-supplemented, air-fried treatments were successfully validated within the commercially viable "moderately accepted" evaluation band.

Longitudinal storage testing demonstrated that the low moisture profiles (under 5.0%) and minimized water activity metrics (under 0.5%) effectively protected the products against severe quality deterioration over a 28-day window. While primary and secondary lipid oxidation metrics (PV and TBA) expanded over time, their final values remained well within safe, industrially acceptable thresholds, while total vegetative and mycological counts remained negligible In conclusion, nutritionally optimized, low-fat, protein-enriched air-fried chin-chin snacks can be successfully formulated by substituting refined wheat flour with okara up to a maximum threshold of 30%.

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