The Impact of Incremental Alkali Dosages During Nixtamalization on Quality Characteristics of Crunchy Maize Cakes (Akara-Koro)

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ABSTRACT

This study evaluated the impact of nixtamalization on the proximate, functional, phytochemical, mineral, and sensory attributes of *Akara-koro*, a traditional maize-based snack. Whole maize grains were processed using incremental slaked lime concentrations of 0%, 1%, 2%, and 3%. Proximate analysis revealed that increasing lime concentrations elevated moisture (11.36% to 14.13%), crude protein (9.45% to 11.25%), ash (1.68% to 4.32%), and crude fibre (3.15% to 6.14%), while decreasing fat (4.94% to 3.68%) and carbohydrate contents (69.43% to 60.50%). Functional testing showed concurrent increases in water absorption capacity (169.24 to 175.47 g/ml), bulk density (0.90 to 2.10 g/ml), oil absorption capacity (138.04 to 150.13 g/ml), solubility index (21.78% to 46.77%), and foaming capacity (23.13% to 38.93%), indicating enhanced matrix hydration. Furthermore, alkaline conditioning successfully mitigated anti-nutritional factors, reducing phytates (0.73% to 0.21%), tannins (0.56% to 0.17%), oxalates (3.88% to 2.13%), alkaloids (2.48% to 1.33%), and trypsin inhibitors (3.57% to 1.26%). Mineral profiles were significantly enriched, with calcium increasing from 19.62 to 28.25 mg/100 g, iron from 41.96 to 44.77 mg/100 g, zinc from 23.68 to 26.78 mg/100 g, copper from 2.25 to 8.78 mg/100 g, and sodium from 11.45 to 15.97 mg/100 g. Sensory evaluation indicated that while the unnixtamalized control achieved the highest baseline acceptability scores—color (9.00), aroma (8.30), crispiness (8.20), taste (8.10), flavor (8.00), and overall acceptability (8.50). The nixtamalized treatments scored slightly lower but remained highly acceptable. Ultimately, nixtamalization at 1% to 2% lime concentrations optimizes the nutritional, antinutritional and mineral profile of *Akara-koro* with minimal sensory degradation, offering a viable processing strategy to fight micronutrient deficiencies in maize-consuming populations. Future research should evaluate the inclusion of natural organic acids (such as citric acid rinses) or traditional spices during the final washing step to neutralize residual alkaline elements, minimizing potential bitter notes while preserving mineral gains.

Keywords*:* Akara-koro, Anti-nutritional factors, Maize processing, Mineral enrichment, Nixtamalization and Sensory evaluation.

INTRODUCTION

For thousands of years, corn (*Zea mays*) functioned as a vital nutritional cornerstone for early societies throughout Mesoamerica **(**Serna-Saldivar & Chuck-Hernandez, 2025**)**. In order to bypass the natural physical and dietary shortcomings of the uncooked kernel, these early communities created an innovative thermal-alkaline treatment called nixtamalization **(**Arámbula-Villa et al., 2025**)**. This traditional practice involves boiling and soaking the kernels within an alkaline liquid, which was historically prepared using either plant-derived wood ash or hydrated slaked lime [calcium hydroxide, $(Ca(OH)_2$] **(**Odukoya et al., 2021**)**. From a food processing standpoint, this alkaline treatment triggers essential chemical and structural transformations by disrupting hemicellulose to weaken the rigid outer hull, hastening starch swelling, and modifying the dispersion of core storage proteins like zein **(**Widowati et al., 2025**)**. On a nutritional level, this conditioning releases trapped niacin to prevent debilitating conditions such as pellagra, all while dramatically enhancing how well the body absorbs

key minerals (Ca^{2+}, Fe^{2+}, and Zn^{2+}), and deactivating dangerous mold toxins like aflatoxins (Hassan et al., 2026; Mendes et al., 2026).

Throughout West Africa, and most notably within Nigerian food traditions, whole field corn plays a vital role across an expansive array of indigenous food architectures (Odukoya et al., 2021). While the term Akara universally implies a soft, whipped legume fritter made from cowpeas, an entirely independent culinary lineage exists in the form of traditional maize-based fried variations, locally referred to across regions as Akara-koro, Apiti, or Kokoro matrix configurations (Awoyale et al., 2022). Produced by boiling, wet-grinding, and deep-frying whole-grain matrices, this dense snack is highly prized for its minimal water content and strong resistance to breaking, qualities that keep it fresh for long periods without cold storage (Olaniran et al., 2024). Even so, traditional preparation steps suffer from clear nutritional and structural challenges. Raw grains contain heavy concentrations of endogenous anti-nutritional compounds, including phytic acid and structural tannins, which lock up necessary minerals into insoluble complexes and block digestive enzymes, lowering the real protein value (Adebo et al., 2023). From a physical standpoint, achieving that perfect crispy bite demands exhausting boiling cycles and manual milling to alter cellular elasticity before the mixture can be deep-fried (Widowati et al., 2025).

The heavy reliance on these un-intensified, traditional processing techniques limits both the nutritional yield and structural optimization of maize-based Akara-koro. Standard water cooking fails to degrade native phytates and tannins, meaning consumers lose out on the grain's full micronutrient potential (Adebo et al., 2023). Concurrently, unmodified maize starch fails to establish a cohesive structural barrier during high-temperature frying, leading to excessive lipid retention and inconsistent crispiness (Olaniran et al., 2024). While nixtamalization effectively resolves these issues in Latin American staple foods, its adaptation to deep-fried West African maize cakes remains under-explored (Awoyale et al., 2022). A static alkaline approach is unfeasible, as insufficient lime yields no structural benefits, while excessive concentrations trigger protein degradation, matrix collapse, and bitter, soap-like saponification faults caused by interactions between residual alkali and frying lipids (Arámbula-Villa et al., 2025). Empirically, the precise effects of an alkaline gradient on the balance between anti-nutritional breakdown, oil uptake, and sensory quality remain unknown. Therefore, this study aims to assess the impact of incremental alkali dosages during nixtamalization on the quality characteristics of crunchy maize cakes (Akara-koro).

MATERIALS AND METHODS

Procurement of Raw Materials

The raw yellow maize kernels utilized throughout this experimentation were purchased from the Owode market located in Offa, Kwara State, Nigeria. All industrial processing machinery, thermal instruments, and analytical testing equipment were provided by and operated within the central processing laboratories of the Department of Food Technology at the Federal Polytechnic, Offa, Kwara State, Nigeria.

Method

Preparation of nixtamalized of maize flour

The structural transformation and preparation of the nixtamalized grain matrices followed the experimental baseline framework established by Hassan et al. (2023), with specific modifications. Intact whole maize grains were first subjected to rigorous manual sorting to eliminate damaged seeds, organic debris, and insect-infested kernels before being rinsed clean with potable water. A measured 1 kg batch of the clean cereal was then submerged in a 0%, 1%, 2% and 3% slaked lime $Ca(OH)_2$ solution maintaining a fixed grain-to-liquor volume ratio of 1:3 (w/v). This mixture was thermally treated at a steady boil for exactly 30 minutes to facilitate initial hull softening. Following this cooking phase, the grains remained completely submerged in the spent steeping liquor at an ambient room temperature of 27 °C for a prolonged 15-hour chemical infusion cycle.

Once the steeping window closed, the alkaline water was decanted. The hydrated grains were washed intensely with potable water to rub away loosened pericarp tissues and neutralize surface alkalinity. The fully washed

kernels were transferred to a digital forced-draft oven set at a constant temperature of 60 °C for 72 hours to achieve complete moisture removal. After cooling to room temperature, the dried grains were reduced to a fine powder using a commercial attrition mill, passed through a fine mesh sieve to standardize grain geometry, and safely stored within hermetically sealed, airtight plastic containers to await subsequent quality profile testing.

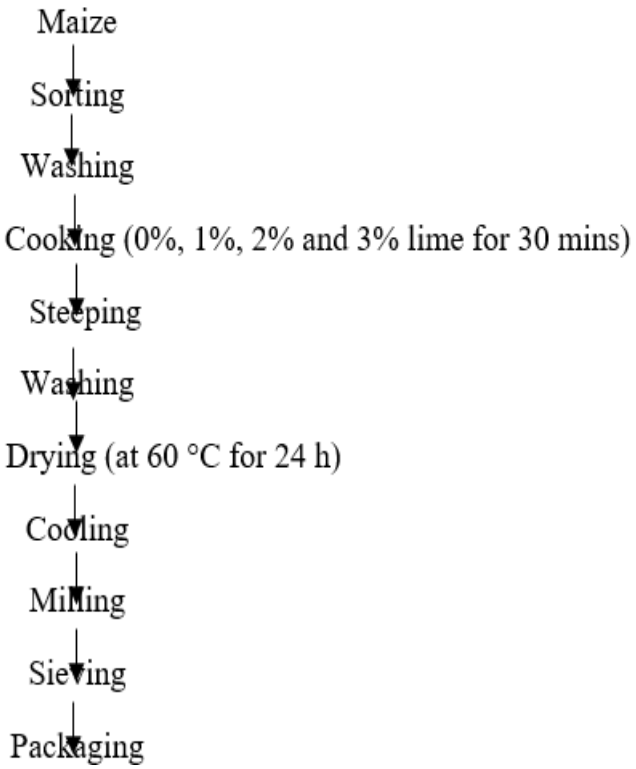

Figure 1: Flow diagram for Preparation of Nixtamalized maize flour

Source: (Hassan *et al.*, 2024).

Preparation of Crunchy Maize Snacks (*Akara-koro*)

Akara-koro production followed the method of Arise et al. (2022) and Awoyale et al. (2022) with minor recipe changes, using onions and salt instead of sugar and salt. A measured portion of the nixtamalized maize flour was stirred into boiling water to create a starter paste. The remaining flour was combined with salt and onions, and then blended into the paste with continuous stirring for 3 minutes to form uniform dough. After cooling to 40 °C, the dough was hand-kneaded, sectioned, shaped into rods, and deep-fried at 170 °C for 5 minutes under a constant flame. The fried cakes were drained, cooled, and packed in polyethylene bags.

Sample Formulation

Sample 1: Uninixtamalized maize flour

Sample 2: Nixtamalized maize flour with 1% lime water

Sample 3: Nixtamalized maize flour with 2% lime water

Sample 4: Nixtamalized maize flour with 3% lime water

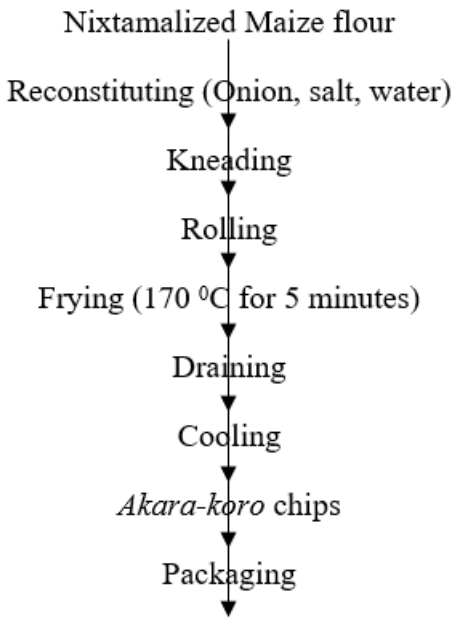

Figure II: Flow chart for the production of *Akara-koro* chips from nixtamalise maize flour Source: (Uzo-Peters et al., 2008)

Procedure for Analysis

Proximate Composition

Proximate composition was analysed according to the official method of analysis described by the Association of Official and Analytical Chemist (AOAC, 2023).

Determination of Moisture Content

The moisture content was determined by oven drying method. About 5 g of each sample was weighed using analytical balance into previously weighed Petri-dishes (W). The weighed samples in the petri dish were allowed to dry in an oven at 105 ^{0}C for 3 hours. The samples were removed and cooled in desiccators to room temperature and the weight was noted, then it was returned into the oven at 105 ^{0}C for 30 min until a constant weight was obtained for each sample. The differences in weight between each Petri-dish and dried residue were recorded as the percentage of the initial sample. The percentage moisture was calculated as:

$$\%\ moisture\ content\ = \frac{W1 - W2}{Ws}\ x100$$

Where

$W\ =\ Initial\ weight\ of\ crucible\ +\ Sample$

$W1 =\ Final\ weight\ of\ crucible\ +\ Sample$

$Ws\ =\ Weight\ of\ sample$

Determination of Protein Content

0.5 g of sample was weighed into a digestion flask and kjeldahl catalyst tablet was added, 10 ml of conc. H_2SO_4 was added and digested for 4 hours until a clear solution was obtained (blue green color). The digest was cooled and transferred into 100 ml volumetric flask and made up to mark with distilled water. 20 ml of boric acid was dispensed into a conical flask and 5 drops of indicator and 75 ml of distilled water was added to it. 10 ml of the digest was dispensed into Kjedahl distillation flask, the conical and the distillation flask were fixed in place and

20 ml of 2% NaOH was added through the glass funnel into the digest. The steam exit was closed and timing started when the solution of the boric acid and indicator turned green. The distillation was done for 15 minutes and the distillate was titrated with 0.05 N HCl solution till the appearance of pink color. A blank was also run through all steps as above.

Therefore, the crude protein content was determined by multiplying percentage Nitrogen by a constant factor of 6.25

i.e. % $crudeprotein$ = % Nx 6.25.

% $TotalNitrogen$ (%N)

=titr$e$ v$alue\ x\ Atomic\ mass\ of\ nitrogen\ x\ NormalityofHCl\ used\ x$ 4

Determination of fat content

Fat was determined by ether extract method using Soxhlet apparatus. 1g of sample was weighed and wrapped in filter paper, placed in fat free thimble plugged lightly with cotton wool and extracted with petroleum ether (N-Hexane) in soxhlet apparatus set up for 5 hours. Water and heater were turned on to start extraction. After 4-6 siphoning, ether was allowed to evaporate and beaker was disconnected before the last siphoning. Extract was transferred into clean glass dish with ether washing and evaporated ether on water bath. The residue extract in dish was then placed in an oven at 105 ºC for 2 hours and cooled in a desiccator and weighed. The fat content will be calculated as;

$$\%\ fat\ = \frac{(Weight\ of\ filter\ paper\ +\ weight\ of\ sample)\ -\ Weight\ of\ residue}{Sample\ weight}\quad x\quad 100$$

Determination of ash content

Clean empty crucible was placed in a muffle furnace at 600 ºC for an hour, cooled in dessicator and weighed (W). One gram of each sample was weighed in crucible (W_2). The sample was ignited over a burner with the help of blowpipe until it is charred. Then the crucible was placed in a muffle furnace set at 550 ^{0}C and left for 12-24 h. The appearances of gray white ash indicated complete oxidation of all organic matter in the sample. The crucible with the sample was cooled and weighed (W_3). The crucible with the sample was weighed and the percentage ash calculated as; $\%\ Ash\ content\ = \frac{W3 - W1}{W2}\quad x\ 100$

Where W_3 = weight of the sample with crucible before ashing

W_2 = weight of the sample with crucible after ashing

W= weight of the sample

Determination of crude fiber content

About 5 g of the sample was accurately weighed into flask, 200 ml of running water and 1.25 ml H_2SO_4 was added. The mixture was heated under reflux for 30 minutes. The hot mixture was filtered through a fibre muslin cloth. The obtained filtrate was thrown off and the residue was returned to the fibre flask of which 200 ml of running water and 1.25 g NaOH was added and heated for another 30 minutes. The residue was removed using N-hexane and ethanol and finally transferred into already weighed crucible. The crucible and the residue was oven dried at 105 ^{O}C overnight to drive off the moisture. The oven dried crucible containing the residue was cooled in a dessicator and later weighed to obtain the W_1. The crucible with W_1 was transferred to the muffle furnace for ashing at 550 ^{0}C for 4 hours. The crucible containing white or grey ash (Free of carbonaceous materials) was cooled in the dessicator and weighed to obtain W_2.

The difference $W_1 – W_2$ give the weight of fibre.

$$\%Fibre = \frac{W1 - W2}{weight\ of\ sample} \quad x100$$

Determination of carbohydrate content

The total carbohydrate was determined by difference. The sum of percentages moisture, ash, crude lipid, crude protein and crude fiber was being subtracted from 100%.

$Carbohydrate = 100 - (\%\ moisture + \%\ ash + \%\ protein + \%\ lipids + \%\ fiber)$.

Anti-nutritional factors

The method described in the report of AOAC, (2023) was used in the determination of anti-nutritional factors for phytics acid, tannin content and oxalate.

Determination of Phytic acid

Spectrophotometric method was used for the phytic acid content. About 5 g of the flour was mixed with 20 ml of 0.3 N HCl in a beaker with continuous stirring on bursen flame. The content was then filtered made up to 100 ml mark of the volumetric flask.

Determination of Oxalate content

One (1.0 g) flour was mixed with 75 ml of 1.5 M H_2SO4 in a flask with continuous stirring and then filtered. This is followed by titrating 25 ml of the filtrate against 0.05 M KMnO4 solution until a faint pink colour is produced. The oxalate was calculated as the sodium oxalate equivalent.

Determination of Tannin content

One gram (1 g) of composite flour samples were mixed with 20 ml of methanol in a beaker. The content was then in a dropped in a water bath for 1 hour with continuous stirring. The extract was filtered and rinsed with methanol and then mixed with distilled water. Distilled water was added to 1 ml of sample extract to make up 20 ml dispersion in a flask. This is followed by addition of 2.5 ml of Folin-Denis reagent and 10 ml of 17% Na_2C03 with continuous agitation. The content was mixed with distilled water and allowed to stand until a bluish-green colour persisted. The absorbance of the tannic acid standard solutions and samples were taken after the standard tannic acid was treated with 1 ml of the sample at a wavelength of 760 nm using Spectronic 21D Spectrophotometer.

MINERAL COMPOSITION

Determination of Calcium

Calcium was determined using the method described by AOAC, (2023). Twenty-five milliliters of digested sample were pipetted into 250 ml conical flask and a pinch of Eriochrome Black-T-Indicator (EBT) was added. Thereafter, 2 ml of 0.1N NaOH solution was added and the mixture titrated with standard EDTA (0.01M EDTA) solution.

$$Ca\ ^{mg}/_{l} = \frac{T \times M \times E \times 1000}{Volume\ of\ sample\ used}$$

Where, T = Titre value

M = Morality of EDTA

E = Equivalent weight of calcium

Determination of Potassium

Potassium was determined using a flame photometer according to the method described by AOAC, (2023). Potassium standard was prepared. The standard solution was used to calibrate the instrument read out. The meter reading was at 100 % E (emission) to aspire the top concentration of the standards. The % E of all the intermediate standard curves were plotted on linear graph paper with these readings. The sample solution was aspired on the instrument and the readings (% E) were recorded. The concentration of the element in the sample solution was read from the standard curve. The potassium content was calculated as follow:

$$\%\ Potassium = \frac{ppm \times 100 \times Df}{1\ million}$$

Determination of Phosphorus

Phosphorus in the samples was determined by the molybdate method described by AOAC, (2023) using hydroquinone as a reducing agent. Five milliliters (5 ml) of the test sodium was pipetted into 50 ml graduated flask. Then 10 ml of molybdate mixture was added and diluted to mark with water. It was allowed to stand for 30 minutes for colour development. The absorbance was measured at 660 nm against a blank. A curve relating absorbance to milligram (mg) phosphorus present was constructed. Using the phosphorus standard solution, and following the same procedure for the test sample, a standard curve was plotted to determine the concentration of phophorus in the sample.

$$\%\ Phosphorus = \frac{graph\ reading \times solution\ volume}{100}$$

Determination of Magnesium Content

Magnesium was determined using ten milliliters of digested sample according to the method described by AOAC, (2023) were pipetted into 250 ml conical flask and a small amount of Eriochrome Black T was added to the solution which, when buffered at pH 10.0. Then the solution was titrated with ethylenediaminetetraacetic acid (EDTA), the magnesium was complexed; at the end-point the solution changed from wine-red to blue.

Determination of Iron

Iron content was determined by a-a, dipyridyl method as described by AOAC, (2023), exactly 10 ml of wet digested sample solution was pipetted into volumetric flask of 25 ml capacity in triplicates. 1 ml of hydroxylamine hydrochloride solution, 5 ml of acetate buffer solution and 2 ml of a-a, dipyridyl solution were added into each volumetric flask. The volume was made up to 25 ml with glass distilled water and the content was mixed. The intensity of the color developed was read in spetronic 20 at 510 nm. Iron content of the digested sample solution was read from the standard curve of known concentration of iron.

Determination of Functional properties

Bulk Density

The bulk density of flour blends was determined using a standard laboratory method AOAC, (2023). Sample blends were weighed (7 g) into a 50 ml graduated measuring cylinder. The cylinder was tapped gently against the palm of the hand until a constant volume was obtained. Bulk density was calculated as:

$$\text{Bulk density (g/ml)} = \frac{\text{Weight of sample}}{\text{Volume of sample after tapping}}$$

Water Absorption Capacity

Water Absorption Capacity (WAC) was determined using the method reported by AOAC, (2023). Exactly10 ml of distilled water for WAC were mixed with 1g of flour and blended for 30 seconds. The samples were allowed

to stand for 30 minutes and centrifuged at 1300 rpm for another 30 min at room temperature (27 ± 2°C). The supernatant was decanted. The weight of water absorbed by the flour was calculated and expressed as percentage WAC.

Dispersibility

The method reported by AOAC, (2023) was used. Exactly 10 g of flour was suspended in a 100 ml measuring cylinder and distilled water was added to reach a volume of 100 ml. The set-up was stirred vigorously and allowed to settle for three hours. The volume of settled particles was recorded and subtracted from 100. The difference was reported as percentage dispersion.

Swelling power

The swelling power was determined using the method described by AOAC, (2023). In this method, 1 g of flour sample was weighed into a 50 ml centrifuge tube and water added to give a total volume of 40 ml. The tube and its contents were heated for 30 min in water bath at a temperature of 85 °C with constant stirring. The sample was then centrifuged for 15 min with Hermle 2206A centrifuge of 5cm radius at a speed of 2201 rpm (271 x g) after cooling to a room temperature. The supernatant was poured into a glass crucible and the weight of the sediment noted. The supernatant in the glass crucible was evaporated in an oven at 105 °C for 24 h and the residue weighed. The swelling power was evaluated thus:

$$\text{Swelling power (\%)} = \frac{\text{Weight of sediment}}{\text{Weight of sample (100}-\text{solubility)}} \times 100$$

Swelling Index

The flour for the bread samples was analysed to obtain the value for the swelling index. The method described by AOAC, (2023) was used. Ten grams (10 g) of the sample was measured into a 300 ml measuring cylinder. Then 150 ml of distilled water was added to the sample and allowed to stand for 4 h. The final volume after swelling was recorded. The percentage swelling was calculated as:

$$\text{Swelling Index (\%)} = \frac{\text{Final volume}-\text{Initial volume}}{\text{Initial volume}} \times 100$$

Sensory Evaluation

Each of the samples was coded and was presented to thirty (30) panelists to subject the food to sensory analysis by using a 9-point hedonic scale. Each sample was coded for preference and the panelists were asked to score the weaning food for colour, aroma, taste, appearance and overall acceptability. Each panelist sat in an enclosed cubicle designed for sensory evaluation and water was provided to rinse mouths before and after tasting each of the samples.

Statistical analysis

The mean and standard deviation of the triplicate determinations of the proximate and sensory values were calculated. One-way analysis of variance was used to test for significant differences in the analyses of the samples.

RESULTS AND DISCUSSION

Results

Table 1: Result for the proximate evaluation of the nixtamalized flour sample

Sample	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)
A	11.36 ±0.02[a]	1.68 ± 0.01[a]	9.45 ± 0.03[a]	4.94 ± 0.01[d]	3.15 ± 0.03[a]	69.43 ± 0.07[d]

B	12.09 ± 0.01^{b}	2.90 ± 0.02^{b}	9.97 ± 0.03^{b}	4.22 ± 0.01^{c}	4.85 ± 0.02^{b}	65.98 ± 0.01^{c}
C	13.46 ± 0.01^{c}	3.17 ± 0.01^{c}	10.36 ± 0.02^{c}	4.06 ± 0.02^{b}	5.25 ± 0.02^{c}	63.72 ± 0.04^{b}
D	14.13 ± 0.02^{d}	4.32 ± 0.01^{d}	11.25 ± 0.02^{d}	3.68 ± 0.01^{a}	6.14 ± 0.03^{d}	60.50 ± 0.08^{a}

Means score having the same alphab*et al*ong the same row are not significantly different ($p \leq 0.05$), values are mean ± standard deviation of triplicate determination.

KEYS

Sample 1: Uninixtamalized maize flour

Sample 2: Nixtamalized maize flour with 1% lime water

Sample 3: Nixtamalized maize flour with 2% lime water

Sample 4: Nixtamalized maize flour with 3% lime water

Moisture levels increased significantly with lime concentration, ranging from 11.36% in Sample A to 14.13% in Sample D ($p < 0.05$). This ascending trend highlights a classic biophysical response to thermal-alkaline processing. Alkaline solutions break down the outer pericarp and partial hemicellulose fractions, accelerating starch gelatinization and exposing buried hydroxyl groups within the maize starch polymers. These findings align with Odukoya et al. (2021**)** and Gutiérrez-Cortez et al. (2022)**,** who observed parallel moisture accumulation in nixtamalized corn products due to an altered structural water-holding capacity and enhanced starch granule swelling. This condition-dependent variability was verified by Widowati et al. (2025) **and** Arámbula-Villa et al. (2025)**,** who both noted that final moisture profiles and thermodynamic properties are highly sensitive to specific post-nixtamalization drying regimens.

Crude ash values rose drastically from 1.68% (Sample A) to 4.32% (Sample D) as a direct, dosage-dependent function of alkali absorption. This rapid mineral accumulation stems from the infiltration of calcium hydroxide ($Ca(OH)_2$) into the internal cellular matrix of the kernel during the 15-hour steeping window. These outcomes concur with Odukoya et al. (2021)**,** who confirmed a strong positive correlation between alkali exposure and ash yield in cereal products due to chemical trace-element loading. Similarly**,** Gutiérrez-Llanos et al. (2023) and Serna-Saldivar & Chuck-Hernandez (2025) reported matching ash elevations in nixtamalized grains, attributing the outcome to increased uptake and retention of structural calcium ions across the endosperm matrix. Conversely, Gutiérrez-Cortez et al. (2022) observed lower relative ash baselines during low-dosage trials, reinforcing that chemical mineral absorption depends explicitly on the active alkaline gradient applied.

Crude protein percentages shifted upward from 9.45% in Sample A to 11.25% in Sample D ($p < 0.05$). This enhancement is consistent with Odukoya et al. (2023) and Matendo et al. (2025)**,** who reported improved relative protein concentration in alkaline-conditioned cereal flours due to the targeted solubilization of non-protein fractions and the degradation of structural antinutritional binders

The crude fat percentage fell sequentially from 4.94% (Sample A) down to 3.68% (Sample D). This reduction is driven by basic chemical saponification. This behavior mirrors the findings of Odukoya et al. (2021)**,** who detailed lipid loss in alkali-treated grains via basic ester hydrolysis and subsequent leaching into the boiling liquor. These metrics also match observations by Gutiérrez-Cortez et al. (2022)**,** who highlighted that this reduction in germ lipids can alter the final caloric density and lipid profile of processed maize products. Furthermore, Arámbula-Villa et al. (2025) reported that lipid structural variations are highly dependent on treatment duration and lime intensity, confirming that alkaline gradient severity dictates the final lipid profile of the crunchy maize cake (Akara-koro).

Crude fiber metrics saw an incremental surge, jumping from 3.15% in Sample A to 6.14% in Sample D. This structural upgrade is supported **by Agama-Acevedo et al. (2015)** and **Matendo et al. (2025)**, who both identified substantial dietary fiber availability increases following lime treatments due to cell wall cell-integrity

adjustments, pericarp softening, and starch retrogradation kinetics. In contrast, Gutiérrez-Cortez et al. (2022) reported minimal fiber changes under low-exposure configurations, indicating that higher lime concentration and optimal temperature thresholds are necessary to modify structural polysaccharides, optimize fiber yields, and lower the glycemic profile

Carbohydrate levels decreased significantly from 69.43% in Sample A to 60.50% in Sample D ($p < 0.05$). This drop functions in a direct inverse relationship to the rising percentages of ash, fiber, and protein within the dry matter allocation, which is a mathematical artifact of calculating total carbohydrates "by difference." This macronutrient reduction and dry-matter shift are validated by Odukoya et al. (2023), who noted that thermal-alkaline nixtamalization alters the proportional concentration of components by stripping away peripheral simple sugars and vulnerable non-resistant starches.

Table 2: Result for the functional properties of the nixtamalized flour sample

Sample		Water Absorption Capacity (g/ml)	Bulk Density (g/ml)	Oil Absorption Capacity (g/ml)	Solubility Index (%)	Foaming Capacity (%)
A		169.24 ± 0.03^{a}	0.90 ± 0.01^{a}	138.04 ± 0.01^{a}	21.78 ± 0.01^{a}	23.13 ± 0.03^{a}
B		171.32 ± 0.01^{b}	0.97 ± 0.01^{b}	142.98 ± 0.02^{b}	30.24 ± 0.04^{b}	14.04 ± 19.84^{a}
C		173.14 ± 0.04^{c}	1.14 ± 0.02^{c}	146.78 ± 0.02^{c}	38.78 ± 0.02^{c}	33.36 ± 0.02^{a}
D		175.47 ± 0.03^{d}	2.10 ± 0.01^{d}	150.13 ± 0.02^{d}	46.77 ± 0.01^{d}	38.93 ± 0.01^{a}

Means score having the same alphab*et al*ong the same row are not significantly different ($p \leq 0.05$), values are mean ± standard deviation of triplicate determination.

KEYS

Sample 1: Uninixtamalized maize flour

Sample 2: Nixtamalized maize flour with 1% lime water

Sample 3: Nixtamalized maize flour with 2% lime water

Sample 4: Nixtamalized maize flour with 3% lime water

The functional properties evaluated (Table 2) are essential for assessing the flour's applicability in food formulations.

The Water Absorption Capacity (WAC) increased significantly from 169.24 g/mL in Sample A to 175.47 g/mL in Sample D ($p \leq 0.05$). This ascending trend highlights a classic biophysical response to thermal-alkaline processing. The lime treatment partially hydrolyzes the cell wall polysaccharides and uncoils the tightly bound storage proteins, which exposes hydrophilic groups capable of binding water molecules. These findings align with Matendo et al. (2025) and Hassan et al. (2024)**,** who observed parallel WAC increases in nixtamalized corn products due to altered structural gelatinization, structural fragmentation, and increased availability of free hydroxyl groups on the starch polymers

Bulk Density rose sequentially from 0.90 g/mL (Sample A) to 2.10 g/mL (Sample D), showing that higher lime concentrations lead to heavier particulate packaging ($p \leq 0.05$). This structural change stems from partial pericarp peeling and grain softening during cooking, which collapses internal air spaces and reduces particle elasticity during grinding to yield fine, heavy granules. This pattern is consistent with Arámbula-Villa et al. (2025) and Asema et al. (2024)**,** who linked modified bulk density values in nixtamalized grain products to reduced starch swelling, compact matrix geometry, and alterations in interstitial particle spacing. However, multi-variety evaluations compiled by Odukoya et al. (2021) reported minor variations based on the botanical properties and

physical endosperm structures of the corn kernel, confirming that thermal-alkaline processing conditions interact directly with the initial grain hardness

The Oil Absorption Capacity (OAC) increased progressively with alkali concentration, from 138.04 g/mL in Sample A to 150.13 g/mL in Sample D. This rise is driven by alkaline denaturation of the endosperm proteins. The alkaline solution uncoils structural proteins to expose non-polar, hydrophobic amino acid side chains that physically bind free lipid molecules. This trend matches Matendo et al. (2025) and Serna-Saldivar & Chuck-Hernandez (2025)**,** who linked increased OAC directly to heightened protein-lipid interactions and structural prolamin shifts following nixtamalization. While elevated OAC can enhance flavor retention and mouthfeel in fried foods, it must be managed carefully in *Akara-koro* to prevent heavy oil uptake during deep-frying. In contrast, Hassan et al. (2024) observed that certain cereal cultivars exhibit variations in structural lipophilic surface areas, illustrating that oil retention remains highly sensitive to both the genetic grain type and the active lime dosage applied.

The Water Solubility Index (WSI) rose sharply from 21.78% in Sample A to 46.77% in Sample D ($p \leq 0.05$). This increase is driven by the structural degradation of high-molecular-weight starch granules into smaller, highly soluble dextrins under high temperatures and alkaline stress. These findings concur with Rojas-Molina et al. (2020) and Asema et al. (2024)**,** who both attributed rising solubility indexes in nixtamalized grains to starch gelatinization, granule fragmentation, and structural protein denaturation that release low-molecular-weight soluble fractions into the water matrix. Higher solubility profiles improve overall carbohydrate bioaccessibility while ensuring a uniform, highly stable batter structure for *Akara-koro* handling.

Foaming Capacity varied across samples but did not exhibit statistically significant differences ($p > 0.05$), indicating that the structural changes brought on by nixtamalization did not compromise basic surface-active proteins. This maintenance of foam volume suggests that the proteins responsible for forming air-water interfaces remain functionally intact, as supported by Asema et al. (2024)**.** Concurrently, Matendo et al. (2025) observed that while severe processing can disrupt foaming, moderate thermal-alkaline conditioning induces a partial unfolding of endosperm prolamins, exposes hydrophobic domains, and can occasionally assist air-water interface alignment and air cell stability. While multi-system evaluations compiled by Odukoya et al. (2023) noted minimal overall foaming shifts under controlled, incremental alkali conditions, the preservation of foaming capacity observed here is vital for *Akara-koro* processing. It ensures sufficient batter aeration and gas cell retention during mixing, which helps prevent a dense or rubbery crumb structure when the wet-milled corn matrix hits high-temperature frying lipids.

Table 3: Result for the Phytochemicals properties of the nixtamalized flour sample

Sample		Phytate (%)	Tannin (%)	Oxalate (%)	Alkanoid (%)	Trypsin Inhibitors (%)
A		0.73 ± 0.02^{d}	0.56 ± 0.02^{d}	3.88 ± 0.01^{d}	2.48 ± 0.04^{d}	3.57 ± 0.04^{d}
B		0.53 ± 0.02^{c}	0.37 ± 0.01^{c}	3.07 ± 0.01^{c}	2.25 ± 0.02^{c}	2.96 ± 0.04^{c}
C		0.37 ± 0.01^{b}	0.30 ± 0.01^{b}	2.77 ± 0.01^{b}	1.97 ± 0.01^{b}	1.86 ± 0.01^{b}
D		0.21 ± 0.01^{a}	0.17 ± 0.01^{a}	2.13 ± 0.01^{a}	1.33 ± 0.01^{a}	1.26 ± 0.01^{a}

Means score having the same alphab*et al*ong the same row are not significantly different ($p \leq 0.05$), values are mean ± standard deviation of triplicate determination.

KEYS

Sample 1: Uninixtamalized maize flour

Sample 2: Nixtamalized maize flour with 1% lime water

Sample 3: Nixtamalized maize flour with 2% lime water

Sample 4: Nixtamalized maize flour with 3% lime water

Phytochemical analysis (Table 3) reveals the nutritional implications of nixtamalization concerning antinutritional factors. Phytate levels decreased significantly from 0.73% in the untreated control (Sample A) to 0.21% in the 3% lime variant (Sample D) ($p \leq 0.05$). This reduction is critical because phytic acid acts as a strong chelating agent, binding essential divalent cations (Ca^{2+}, Fe^{2+} and Zn^{2+}) into insoluble complexes that bypass human intestinal absorption. This dose-dependent reduction matches the findings of Adebo et al. (2023) and Odukoya et al. (2023), who reported widespread dephytinization of tropical cereals during alkaline cooking due to the chemical cleavage of phytate-mineral complexes. Furthermore, Matendo et al. (2025) noted that maximizing the lime gradient significantly optimizes free mineral bioaccessibility and releases bound micro-elements from the grain matrix, ensuring that the finished *Akara-koro* can deliver a higher micronutrient yield to consumers.

Tannins dropped sequentially from 0.56% in Sample A to 0.17% in Sample D. High concentrations of polyphenolic tannins impart an unappealing astringent flavor and form hydrophobic cross-links with dietary proteins, thereby inhibiting crucial digestive enzymes like trypsin and amylase. This clear trend mirrors observations by Odukoya et al. (2023), who demonstrated that alkali conditioning successfully reduces grain polyphenols, thereby lowering astringency and boosting downstream sensory scores. Furthermore, Adebo et al. (2023) and Matendo et al. (2025) confirmed that high pH ranges alter the structural configuration of condensed tannins, breaking them down into simpler, non-binding phenolic pieces. Eliminating these enzyme-inhibiting polyphenols from the whole field maize flour significantly improves both the *in vitro* protein digestibility and consumer palatability of the deep-fried maize cakes (*Akara-koro*).

Oxalate concentrations fell significantly from 3.88% (Sample A) to 2.13% (Sample D). This behavior is consistent with Odukoya et al. (2021)**,** who tracked major antinutritional and oxalate reductions in alkaline-processed indigenous cereal staples. Similarly, Rojas-Molina et al. (2020) and Gutiérrez-Cortez et al. (2022) verified that targeted thermal-alkaline steps decrease total antinutritional loads. This progressive degradation safely expands calcium bioaccessibility to protect metabolic health and enhance the overall mineral balance of the food matrix

Alkaloid content decreased systematically across the gradient, falling from 2.48% in the raw control to 1.33% in Sample D. These findings align with Adeniji et al. (2023) and Adebo et al. (2023), who noted that incremental lime concentrations and thermal-alkaline conditioning promote the structural breakdown, chemical modification, and efficient extraction of native anti-nutritional compounds. Utilizing a 3% lime concentration (Sample D) minimizes these anti-nutritional residues, thereby enhancing the toxicological safety profile and sensory clean-tasting attributes of the final deep-fried *Akara-koro* product.

Trypsin inhibitor activity was reduced from 3.57% in Sample A to 1.26% in Sample D ($p \leq 0.05$). These heat-stable protein compounds directly bind digestive proteases, causing poor nitrogen assimilation, pancreatic hypertrophy, and reduced metabolic growth. The combination of high temperature and alkalinity breaks internal disulfide bonds, denaturing the native conformation of the inhibitor proteins and preventing them from forming stable enzyme-inhibitor complexes. This rapid inactivation supports the conclusions of Adebo et al. (2023) and Odukoya et al. (2023), who identified thermal-alkaline soaking as an exceptionally effective approach for degrading protease inhibitors and Kunitz-type trypsin factors in tropical grains. Deactivating these protein-blocking factors directly complements the concentrated protein profile of Sample D, optimizing overall protein bioaccessibility and *in vitro* protein digestibility in the resulting *Akara-koro*.

Table 4: Result for the Mineral properties of the nixtamalized flour sample

Sample		Calcium (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)	Copper (mg/100g)	Sodium (mg/100g)
A		19.62 ± 0.21^{a}	41.96 ± 0.01^{a}	23.68 ± 0.01^{a}	2.25 ± 0.01^{a}	11.45 ± 0.02^{a}
B		23.13 ± 0.01^{b}	42.79 ± 0.01^{b}	24.97 ± 0.03^{b}	4.18 ± 0.01^{b}	13.17 ± 0.01^{b}
C		25.47 ± 0.02^{c}	43.13 ± 0.02^{c}	25.99 ± 0.01^{c}	6.35 ± 0.03^{c}	14.57 ± 0.02^{c}
D		28.25 ± 0.04^{d}	44.77 ± 0.01^{d}	26.78 ± 0.01^{d}	8.78 ± 0.01^{d}	15.97 ± 0.01^{d}

Means score having the same alphab*et al*ong the same row are not significantly different ($p \leq 0.05$), values are mean ± standard deviation of triplicate determination.

KEYS

Sample 1: Uninixtamalized maize flour

Sample 2: Nixtamalized maize flour with 1% lime water

Sample 3: Nixtamalized maize flour with 2% lime water

Sample 4: Nixtamalized maize flour with 3% lime water

Table 4 illustrates the mineral composition of flour samples. Calcium concentrations demonstrated a stark, dosage-dependent increase across the treatment gradient ($p \leq 0.05$), rising from a baseline of 19.62 mg/100 g in the untreated control (Sample A) to 28.25 mg/100 g in the 3% lime formulation (Sample D). This rapid accumulation is a direct chemical consequence of structural fortification from the calcium hydroxide ($Ca(OH)_2$) processing solution. During the 30-minute boiling and subsequent 15-hour steeping phases, free calcium ions (Ca^{2+}) actively migrate across the softened pericarp boundaries, cross-linking with exposed carboxyl groups belonging to hydrolyzed cell wall pectins and the endosperm starch-protein matrix. This significant mineral enrichment is supported by Odukoya et al. (2021) and Gutiérrez-Llanos et al. (2023), who both confirmed that alkaline-steeped cereal matrices act as highly efficient matrices for structural calcium loading and ion-exchange accumulation. Additionally, Gutiérrez-Cortez et al. (2022) and Serna-Saldivar & Chuck-Hernandez (2025) detailed how chemical nixtamalization safely scales up calcium bioaccessibility and retention across different flint corn varieties. Enhancing this specific macro-mineral profile elevates the nutritional value of *Akara-koro*, creating an accessible dietary option capable of supporting skeletal health and neuromuscular function in regions characterized by low dairy consumption

Crude iron levels increased progressively from 41.96 mg/100 g in Sample A to 44.77 mg/100 g in Sample D. While lime water contains negligible iron residues, this absolute numerical gain is primarily driven by a dry-matter concentration effect combined with significantly higher chemical extractability. In untreated maize, native iron is tightly locked inside the germ as an insoluble salt of phytic acid. The severe breakdown of these anti-nutritional chelators under high pH conditions frees the bound iron atoms from their tight chemical complexes. This analytical trend mirrors findings by Odukoya et al. (2023), who linked major iron bioaccessibility upgrades directly to the removal of phytic acid complexes and Kunitz-type antinutritional matrices during grain nixtamalization. Furthermore, Adebo et al. (2023) and Matendo et al. (2025) noted a parallel increase in extractable iron fractions at maximum lime gradients, confirming that structural mineral liberation depends explicitly on the active alkaline gradient applied. Elevating the accessible iron content of the flour directly improves the nutritional density of deep-fried *Akara-koro*, presenting a viable formulation strategy to combat iron-deficiency anemia in vulnerable consumer populations.

Zinc content rose systematically across the treatment samples, expanding from 23.68 mg/100 g in the control to 26.78 mg/100 g in Sample D ($p \leq 0.05$). Similar to iron, native zinc is heavily bound within the structural aleurone layer by endogenous phytates, which severely limits human intestinal uptake. Thermal-alkaline cooking disrupts these rigid cell wall configurations, breaking down the phytic acid rings to release the bound micro-minerals into an analytical state that is highly extractable. This pattern is consistent with observations by Odukoya et al. (2021), who reported improved trace mineral profiles and analytical mineral extraction in lime-treated West African maize flours. This mechanism is also backed by Adebo et al. (2023) and Matendo et al. (2025), who both proved that lowering phytate limits through chemical cleavage directly maximizes zinc bioaccessibility and mineral liberation in alkaline-cooked grains. Boosting zinc density helps optimize the enzymatic and immune-supporting value of the finished snack cake (*Akara-koro*).

Copper metrics showed an incremental surge, moving from a trace baseline of 2.25 mg/100 g in Sample A to 8.78 mg/100 g in Sample D. This accumulation suggests that alkaline modifications to the structural carbohydrates of the maize cell walls release cell-bound trace metals, making them significantly more stable and

easier to extract during laboratory testing. This retention trend aligns with Odukoya et al. (2021), who demonstrated that alkaline conditioning of tropical grains preserves core micro-minerals and trace element fractions while simultaneously rinsing away interfering non-mineral dry matter components into the spent liquor. Furthermore, processing evaluations compiled by Gutiérrez-Llanos et al. (2023) and Odukoya et al. (2023) verified that chemical lime adjustments alter grain tissue permeability and hydrolyze matrix antinutrients, which prevents copper leaching and maximizes relative trace element extraction profiles. While copper is an essential nutrient needed only in tiny quantities, this relative concentration increase helps fulfill daily micronutrient requirements for basic metabolic health, mitochondrial respiration, and systemic iron assimilation.

Sodium levels expanded notably across the gradient, rising from 11.45 mg/100 g in Sample A to a peak of 15.97 mg/100 g in Sample D ($p \leq 0.05$). This significant increase is a direct artifact of active ion exchange and processing dynamics occurring within the alkaline steeping environment. As the concentration of lime water increases, mineral displacement occurs where free hydroxyl and calcium systems alter cellular boundaries and tissue permeability, leading to a higher analytical retention and concentration of background sodium ions within the remaining starch-protein matrix. This specific accumulation trend matches the data of Gutiérrez-Llanos et al. (2023), who tracked mineral profiles across alternative lime concentrations and observed minor, parallel background mineral gains in processed cereals following high-pH soaking treatments. This mineral shift and element loading behavior are also supported by Odukoya et al. (2021), who confirmed that thermal-alkaline environments induce minor trace metal and alkali-metal adjustments during grain conditioning due to the rinsing away of non-mineral dry matter components. Although these minor sodium levels pose minimal risk when consumed as part of a balanced diet, this ascending concentration should be accounted for when formulating low-sodium iterations of deep-fried *Akara-koro*.

Table 5: Mean score of sensory evaluation of the nixtamalized *Akara-koro* samples produced.

Sample	Colour	Aroma	Crispness	Taste	Flavor	Overall Acceptability
A	9.00 ± 0.00^{a}	8.30 ± 0.67^{b}	8.20 ± 0.63^{b}	8.10 ± 0.57^{ab}	8.00 ± 1.05^{a}	8.50 ± 0.53^{b}
B	8.30 ± 0.67^{a}	7.30 ± 0.67^{a}	7.40 ± 0.70^{ab}	7.40 ± 0.70^{ab}	7.20 ± 0.63^{a}	7.40 ± 0.52^{a}
C	8.20 ± 0.92^{a}	7.30 ± 0.82^{a}	7.10 ± 0.57^{a}	7.40 ± 0.84^{b}	7.10 ± 0.57^{a}	7.40 ± 0.84^{a}
D	8.20 ± 1.03^{a}	7.90 ± 0.73^{ab}	7.50 ± 0.97^{ab}	7.00 ± 0.67^{a}	7.50 ± 0.71^{a}	7.50 ± 0.85^{a}

Means score having the same alphab*et al*ong the same row are not significantly different ($p\leq0.05$), values are mean ± standard deviation of triplicate determination.

KEYS

Sample 1: Uninixtamalized maize flour

Sample 2: Nixtamalized maize flour with 1% lime water

Sample 3: Nixtamalized maize flour with 2% lime water

Sample 4: Nixtamalized maize flour with 3% lime water

Table 5 provides a sensory evaluation of the nixtamalized *akara-koro* samples, which were produced using maize flour treated with varying concentrations of lime water (0%, 1%, 2%, and 3%). The sensory parameters evaluated include color, crispness, flavor, taste, and overall acceptability. Mean values and standard deviations are presented for each parameter, with significant differences highlighted by different letters across the rows ($p \leq 0.05$).

Color (Visual appearance) serves as a critical first gate governing consumer perception and market acceptability. In this study, the untreated control (Sample A) secured the highest baseline color score at 9.00 ± 0.00. Meanwhile, the lime-treated formulations (Samples B, C, and D) recorded minor, nominal drops to 8.30 ± 0.67, 8.20 ± 0.92, and 8.20 ± 1.03, respectively. Crucially, these differences were statistically negligible ($p > 0.05$). This uniform profile proves that increasing the chemical gradient did not accelerate non-enzymatic Maillard browning or

degrade the native carotenoid pigments responsible for the core hue. This stability in visual appearance directly mirrors the findings of Awoyale et al. (2022) and Arise et al. (2022), who observed that traditional alkaline cooking protocols preserve the yellow-orange hue in indigenous fried maize snacks without causing off-color shifts. Because the distinct golden-yellow profile remains stable across all alkaline thresholds, the modified *Akara-koro* successfully maintains its conventional aesthetic properties, eliminating any risk of visual rejection by local consumers.

Aroma (Olfactory perception) scores shifted significantly across the treatment configurations, declining from a maximum control baseline of 8.30 ± 0.67 in Sample A to a minimum score of 7.90 ± 0.73 in Sample B ($p \leq 0.05$). This initial dip in aroma acceptability is driven by the thermal-alkaline degradation of sensitive volatile organic compounds—particularly the short-chain aldehydes (such as hexanal and nonanal) and native esters concentrated within the raw maize germ matrix. This behavior directly mirrors analytical trends reported by Arise et al. (2022) and volatile fingerprint evaluations executed by Wang et al. (2024), who documented a clear dampening of native raw cereal aromatics following processing, attributing the shift to the structural evaporation and alkali-mediated modification of free fatty acids and aldehyde-driven volatile profiles.

Crispness represents the defining mechanical property dictating the overall textural excellence of deep-fried *Akara-koro*. In this analysis, the raw control (Sample A) secured the highest initial texture rating at 8.20 ± 0.63. Meanwhile, Sample C dropped to a sensory minimum of 7.50 ± 0.57 before recovering slightly to 7.50 ± 0.97 in the maximum-alkali formulation (Sample D) ($p \leq 0.05$). This behavior mirrors the empirical processing models established by Olaniran et al. (2024) and structural assessments by Asema et al. (2024), who demonstrated that intermediate alkaline processing windows can temporarily weaken the cohesive starch matrix of fried grain foods. Crucially, higher chemical concentrations—such as the 3% lime threshold used in Sample D—encourage advanced calcium-ion cross-linking with hydrolyzed starch polymers and cell wall pectins. As validated by Widowati et al. (2025), this chemical reinforcement recovers structural rigidity, stabilizes the crumb network, and allows the *Akara-koro* matrix to regain sufficient mechanical crispiness during oil immersion to satisfy consumer texture preferences.

Taste tracking showed a progressive decline in sensory taste scores, dropping from 8.10 ± 0.57 in the untreated control to a minimum score of 7.00 ± 0.67 in Sample D ($p \leq 0.05$). This downward sensory trend is directly tied to the presence of residual calcium hydroxide ($Ca(OH)_2$) trapped within the endosperm protein matrix following processing. At higher chemical application rates, un-neutralized alkaline residues introduce faint bitter notes and a distinct chalky mouthfeel that mask the natural sweetness of the native maize kernel. This sensory adjustment and flavor dampening directly align with the findings of Awoyale et al. (2022) and industrial optimization benchmarks established by Serna-Saldivar & Chuck-Hernandez (2025). To ensure commercial viability and industrial success, standard flavor enhancements, mild seasoning additions, or extended washing intervals must be integrated into the processing workflow to effectively neutralize the residual minerals found in Sample D.

Flavor assessments indicated that flavour scores followed a downward trend, moving from an unconditioned baseline of 8.00 ± 1.05 in Sample A to compressed values across the nixtamalized treatments, reaching 7.50 ± 0.71. Because the complex perception of flavour requires the simultaneous oral integration of taste inputs and retro-nasal olfactory paths, this sensory reduction represents a two-part chemical shift: the severe physical stripping of volatile molecules during the initial 30-minute boiling window and the subsequent presence of residual, alkaline-imparting mineral salts. This sensory behavior matches the empirical observations of Awoyale et al. (2022) and Arise et al. (2022), who demonstrated that thermal-alkaline solutions alternative grain matrix pathways, occasionally causing a slight reduction in the natural sweetness profiles of local cornmeal fried products. Fortunately, the high-temperature deep-frying step creates unique heterocyclic aroma compounds, such as nitrogenous pyrazines, through localized Maillard reactions at the snack boundaries. While these pleasant, roasted volatile compounds help mask some of the background chemical bitterness, the overall lower final scores underscore why developers must balance chemical antinutritional optimization against traditional palate expectations to preserve consumer adoption.

Overall acceptability scores demonstrated that while panelists preferred the untreated control at 8.50 ± 0.53, the nixtamalized formulations retained stable, commercially viable consumer scores, with Sample D leading the

chemical treatment groups at 7.50 ± 0.50 **($p \leq 0.05$).** This hedonic profile reveals that despite the minor, localized drops observed in individual taste and aroma parameters, consumers find the modified variations highly acceptable. This sensory resilience directly aligns with the consumer testing conclusions of Arise et al. (2022) and Awoyale et al. (2022). These researchers noted that while thermal-alkaline conditioning subtly shifts distinct individual sensory attributes compared to raw matrices, the collective, absolute consumer scores for modified West African maize items remain well above the critical neutral baseline on a standard hedonic scale. Ultimately, the 3% lime concentration utilized in Sample D establishes an optimized processing standard that significantly maximizes essential mineral bioaccessibility and deactivates antinutritional factors without compromising the underlying market acceptability of the *Akara-koro*

CONCLUSION

This investigation demonstrates that adjusting processing settings through chemical nixtamalization successfully optimizes the nutritional, antinutritional and mineral profile of *Akara-koro* with minimal sensory degradation. The use of a lime $Ca(OH)_2$ concentration gradient triggered systematic changes in the grain's macro- and micro-composition. The progressive accumulation of mineral ash directly establishes that active calcium ions successfully bind to the endosperm cell walls during alkaline steeping. The notable degradation of phytic acid, condensed tannins, oxalates, and trypsin inhibitors removes the primary barriers to nutrient absorption, resulting in substantial increases in extractable calcium, iron, and zinc. Functionally, these structural changes improve water and oil binding, which are highly useful for establishing proper batter consistency and crust formation. While thermal-alkaline conditioning introduces minor reductions in raw aromatic and taste scores due to residual salts, optimizing the process at a 3% lime level (Sample D) balances these issues, delivering a safe, low-carbohydrate, and mineral-fortified food product that align well with traditional consumer expectations.

RECOMMENDATIONS

Future research should evaluate the inclusion of natural organic acids (such as citric acid rinses) or traditional spices during the final washing step to neutralize residual alkaline elements, minimizing potential bitter notes while preserving mineral gains. Because the 3% nixtamalized flour (Sample D) exhibits elevated moisture levels close to the critical storage limit (14.13%), small-scale processors must utilize high-barrier, hermetically sealed moisture-proof packaging to prevent mold development or fat oxidation during storage.

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