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Temperature-Dependent Changes in the Nutritional and Sensory Quality of Fermented African Oil Bean (Pentaclethra macrophylla Benth.) Slices

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ABSTRACT: African oil bean (Pentaclethra macrophylla Benth.) is an indigenous Nigerian legume valued for its nutritional potential but requires processing and fermentation before consumption. This study evaluated the effects of drying temperature on the quality of fermented African oil bean slices. Samples were dried at 65, 70, 75, and 80 °C, with an un-dried fermented sample serving as the control. Proximate composition, essential amino acid profile, mineral content, anti-nutritional factors, and sensory acceptability were evaluated using standard analytical methods. Moisture content decreased from 36.81% in the control to 5.04% at 80 °C, while protein increased from 10.13% to 24.10%. Fat decreased from 19.22% to 9.19%, whereas fibre and carbohydrate increased from 2.14% to 5.39% and 26.63% to 50.57%, respectively. Leucine remained the predominant essential amino acid, reducing slightly from 5.72 to 5.51 g/100 g protein, while methionine showed the greatest relative reduction. Mineral concentrations increased with drying temperature, largely reflecting moisture removal. Conversely, phytate, tannin, oxalate, saponin, and trypsin inhibitor contents decreased progressively. At 80 °C, their respective reductions were approximately 31%, 31%, 32%, 27%, and 35% relative to the control. Sensory overall acceptability decreased from 8.00 in the control to 7.30 at 80 °C, indicating good acceptance of the dried samples. The findings demonstrate that drying temperature influences the nutritional and sensory quality of fermented African oil bean. Drying at 75–80 °C offers potential for improved preservation through moisture reduction and decreased anti-nutritional factors, although temperature selection should balance nutrient retention and consumer acceptability.

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1. Introduction

Legumes are important components of food systems because they provide protein, dietary fibre, minerals, complex carbohydrates and a range of bioactive compounds. Their nutritional importance is particularly relevant in developing countries, where plant-based foods contribute substantially to dietary protein and micronutrient intake. However, many legumes also contain anti-nutritional factors, including phytate, tannins, oxalates, saponins, lectins and protease inhibitors, which may reduce nutrient digestibility and mineral bioavailability. Appropriate processing is therefore necessary to improve their nutritional quality and safety (Margier *et al.*, 2018; Samtiya *et al.*, 2020; Sharma, 2021).

African oil bean (*Pentaclethra macrophylla* Benth.) is an indigenous leguminous tree of West and Central Africa and is particularly important in southern Nigeria. The seeds are processed into the traditional fermented food commonly known as Ugba, Ukpaka or Apara. Recent molecular and ecological evidence confirms the broad distribution and cultural importance of *P. macrophylla* in Nigeria (Omonhinmin and Alonge, 2024). The seed is nutritionally valuable because it contains appreciable protein, lipid, fibre, minerals and amino acids. Comparative analysis of Nigerian lesser-known legumes has also shown African oil bean to be particularly rich in protein, fat, minerals, fibre and amino acids (James *et al.*, 2020). Traditional production of Ugba involves prolonged boiling, dehulling, slicing, further boiling or soaking, washing and spontaneous fermentation. Fermentation improves the sensory characteristics and nutritional quality of the seed while reducing several undesirable constituents. Obi and James (2019) reported substantial nutritional changes during thermal processing and fermentation of African oil bean, while Azi *et al.* (2019) demonstrated that processing conditions can modify protein quality, residual anti-nutritional factors and microbial characteristics. Oly-Alawuba and Anunukem (2018) similarly showed that boiling, soaking, drying and fermentation influence the nutritional and phytochemical characteristics of Ugba. Despite its nutritional potential, traditionally fermented Ugba has a short shelf life because its relatively high moisture content supports microbial growth and biochemical deterioration. Drying is therefore an attractive preservation technique because removal of water reduces water activity, limits microbial proliferation and slows many enzymatic and chemical reactions (Alp and Bulantekin, 2021; Fathi *et al.*, 2022). However, drying temperature is a critical processing variable. Excessive thermal exposure can promote nutrient degradation, protein denaturation, lipid oxidation and other undesirable changes, whereas inadequate drying may leave sufficient residual moisture for microbial deterioration (Hasan *et al.*, 2019; Tuly *et al.*, 2023).

The effect of drying on nutritional quality is not necessarily uniform. Removal of water can increase the concentration of nutrients expressed on a wet-weight basis, while thermal degradation or oxidation can decrease particular nutrients. Thus, apparent increases in protein, ash, fibre and minerals following drying may reflect concentration effects rather than synthesis or absolute nutrient gains. Conversely, heat-sensitive amino acids may decline with increasing temperature. The final nutritional profile is therefore determined by the interaction between moisture removal, concentration, thermal degradation and chemical transformations. Protein quality is particularly important in African oil bean because of its potential as a plant protein source. Essential amino acids such as histidine, threonine, valine, methionine, isoleucine, leucine, phenylalanine and lysine cannot be synthesized adequately by humans and must be supplied through the diet. Processing may alter their concentration through protein modification, degradation, leaching or concentration effects. Recent reviews emphasize that processing can influence both protein digestibility and amino acid availability in legumes (Ohanenye *et al.*, 2022).

Mineral composition is another important consideration. African oil bean contains appreciable levels of potassium, phosphorus, magnesium, calcium, iron and zinc (James *et al.*, 2020). Although minerals are generally more thermally stable than vitamins and some phytochemicals, their measured concentration can increase during drying because of water loss. Nevertheless, mineral bioavailability can remain limited by phytate, oxalate and tannins, which may bind mineral elements and reduce their absorption (Samtiya *et al.*, 2020; Ghosh *et al.*, 2021). Anti-nutritional factors deserve particular attention because their reduction can improve the nutritional value of processed legumes. Phytate can bind calcium, iron and zinc; tannins can interact with proteins and minerals; oxalate can form insoluble complexes with calcium; saponins may affect palatability and nutrient utilization at high concentrations; and trypsin inhibitors can interfere with protein digestion. Thermal processing can reduce several of these compounds, although the magnitude of reduction depends on the compound, food matrix, temperature and duration of treatment (Feizollahi *et al.*, 2021; Ojo, 2022; Huynh *et al.*, 2022; Suhag *et al.*, 2021).

Recent research has increasingly focused on drying technologies and their effects on food quality. Studies have shown that drying temperature and method can influence nutrient retention, phytochemical stability, texture, color and overall product quality (Mohammadi *et al.*, 2020; Zielinska *et al.*, 2020; Fathi *et al.*, 2022). However, information remains limited on the combined effects of controlled drying temperature on the proximate composition, essential amino acids, mineral composition

and anti-nutritional factors of fermented African oil bean slices. The present study therefore investigated the effect of drying temperatures of 65, 70, 75 and 80 °C on the nutritional and anti-nutritional composition of fermented African oil bean slices. The specific objectives were to determine the effects of drying temperature on proximate composition, essential amino acid composition, mineral profile, selected anti-nutritional factors and consumer acceptability of the product and to identify a drying temperature capable of improving preservation while retaining desirable nutritional characteristics.

2. Materials and Methods

2.1 Study Location

This study was conducted in the Food Microbiology Laboratory, Department of Food Science and Technology, university of agriculture and Environmental Sciences, Umuagwo, Imo state, Nigeria where the preparation, fermentation and analysis were carried out**.**

2.1 Raw material Collection

Matured African oil bean (*Pentaclethra macrophylla* Benth.) seeds were obtained from a local (Ekeikpa) market in Ihitte/Uboma, Imo State, Nigeria. The seeds were sorted to remove damaged, moldy and immature seeds and transported to the food processing laboratory for processing and analysis. Analytical-grade reagents were used throughout the study.

2.2 Processing of African Oil Bean Seeds

Preparation and Fermentation of African Oil Bean

The African oil bean seeds were processed following the traditional fermentation method described by Obi *et al.* (2023) shown in Figure 1. The seeds were thoroughly washed under running potable water to remove adhering dirt and foreign materials. Clean seeds were boiled in distilled water for 2–3 h to soften the hard seed coat and facilitate dehulling. After boiling, the seeds were allowed to cool to room temperature (28 ± 2°C), and the seed coats were manually removed using sterile stainless-steel knives. The dehulled cotyledons were sliced longitudinally into thin strips approximately 4–6 mm thick. The sliced cotyledons were boiled again for 1 h. After cooking, the slices were cooled and soaked in potable water for 10–12 h. Following soaking, the water was discarded and the slices were washed thoroughly five consecutive times using sterile potable water. The washed slices were drained under aseptic conditions and wrapped individually in sterile blanched plantain leaves and allowed to ferment naturally at ambient laboratory temperature (28 ± 2°C) for 72h, respectively.

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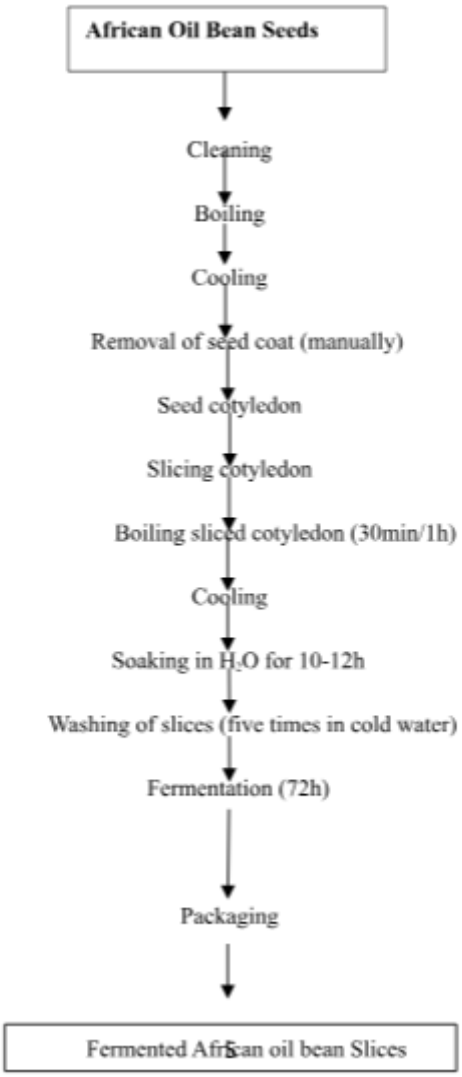

Figure 1: Flow chart for the Preparation of African Oil Bean Seed Slices (Source: Obi *et al.*, 2023)

2.3 Drying Treatments

Five hundred grams (500 g) of fermented African oil bean slices (2 mm thickness) were divided into five equal (100g) treatment groups and dried at 65, 70, 75 and 80 °C. The last group that was not dried served as a control. The drying treatments were conducted under controlled hot-air conditions till a constant weight was achieved. The samples were cooled to 40°C after drying and packaged in clean airtight containers before analysis.

2.4 Determination of Proximate Composition

Moisture, ash, crude protein, crude fat and crude fibre were each determined in duplicate using the standard procedures of AOAC (2023).

2.3.1 Moisture content determination

Two grams of each of the developed sample was weighed into dried weighed crucible. The samples were put into a moisture extraction oven at 105°C and heated for 3 h. The dried samples were put into desiccators, allowed to cool and reweighed. The process was reported until constant weights were obtained. The difference in weight was calculated as a percentage of the original sample.

$$\text{Percentage moisture (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times \frac{100}{1} \quad (1)$$

Where:

W_1 = Initial weight of empty dish

W_2 = Weight of dish + un-dried sample

W_3 = Weight of dish + dried sample

2.3.2 Fat content determination

Two grams of each of the sample was loosely wrapped with a filter paper and put into the thimble which was fitted to a clean round bottom flask, which has been cleaned, dried and weighed. The flask contained 120 ml of petroleum ether. The sample was heated with a heating mantle and allowed to reflux for 5 h. The heating was then stopped and the thimbles with the spent samples kept and later weighed. The difference in weight was received as mass of fat and is expressed in percentage of the sample.

$$\text{Percentage fat (\%)} = \frac{W_2 - W_1}{W_3} \times \frac{100}{1} \quad (2)$$

Where:

W_1 = weight of the empty extraction flask

W_2 = weight of the flask and oil extracted

W_3 = weight of the sample

2.3.3 Crude fibre determination

Two grams (2 g) of each sample and 1g asbestos was put into 200 ml of 1.25 % of H_2SO_4 and boiled for 30 minutes. The solution and content then poured into Buchner funnel equipped with muslin cloth and secured with elastic band. This were allowed to filter and residue were then put into 200 ml boiled NaOH and boiling continued for 30 minutes, then transferred to the Buchner funnel and filtered and washed thoroughly with hot distilled water. The precipitates were then rinsed twice with alcohol and thrice with petroleum ether. The residues obtained were scrapped into a clean weighed crucible and dried in the moisture extraction oven to a constant weight. The crucibles were removed, cooled in desiccators and re – weighed. Then, difference of weight (i.e. loss in ignition) is recorded as crucible fibre and expressed in percentage crude fibre

$$\text{Percentage Crude Fibre (\%)} = \frac{W_1 - W_2}{W_3} \times \frac{100}{1} \quad (3)$$

Where:

W_1 = weight of sample before incineration

W_2 = weight of sample after incineration

W_3 = weight of original sample

2.3.4 Crude protein determination

The micro kjeldahl method described by Onwuka (2018) was used. Two grams of each of the samples was mixed with 10ml of concentrated H_2SO_4 in a heating tube. One table of selenium catalyst was added to the tube and mixture heated inside a fume cupboard. The digest was transferred into distilled water. Ten-millimeter portion of the digest mixed with equal volume of 45 % NaOH solution and poured into a kjeldahl distillation apparatus. The mixture was distilled and the distillate collected into 4 % boric acid solution containing 3 drops of methyl red indicator. A total of 50 ml distillate was collected and titrated as well. The sample was duplicated and the average value taken. The Nitrogen content was calculated and multiplied with 6.25 to obtain the crude protein content. This is given as:

$$\text{Percentage Nitrogen (\%)} = \frac{(100 \times N \times VF)T}{100 \times V_a} \quad (4)$$

Where:

N= Normality of the titrate (0.1N)

VF= Total volume of the digest= 100 ml

T= Titre Value

Va= Aliquot Volume distilled

2.3.5 Ash content determination

Two grams of each of the samples was weighed into a crucible, heated in a moisture extraction oven for 3 h at 100°C before being transferred into a muffle furnace at 550°C until it turned white and free of carbon. The sample was then removed from the furnace, cooled in a desiccator to a room temperature and reweighed immediately. The weight of the residual ash was then calculated as ash Content.

$$\textbf{\textit{Percentage Ash}}\ (\%) = \frac{\textbf{\textit{Weight of Ash}}}{\textbf{\textit{Weight of original sample}}}\ \textbf{\textit{x}}\ \frac{\mathbf{100}}{\mathbf{1}} \quad 5$$

2.3.6 Carbohydrate Content Determination

The Nitrogen free method described by Onwuka (2018) was used. The carbohydrate was calculated as weight by difference between 100 and the summation of other proximate parameters as Nitrogen free Extract (NFE) percentage carbohydrate

Nitrogen Free Extract (%) = 100- (m +p + F_1 + A + F_2) 6

Where:

m = moisture

p = protein

F_1 = Fat

A = ash

F_2= Crude fibre

2.4 Determination of Essential Amino Acids

The essential amino acid composition of the samples was determined following acid hydrolysis and chromatographic analysis, with modifications based on the procedure of Weber (2022) and the HPLC workflow described by Xiao *et al.* (2024)]. Finely milled samples were hydrolyzed with 6 M hydrochloric acid at 110 °C for 24 h to release protein-bound amino acids. The hydrolysates were cooled, filtered and appropriately diluted before chromatographic analysis. Amino acids were separated and quantified by HPLC using appropriate amino acid standards and calibration curves. Individual amino acids were identified by comparison of their retention times with those of reference standards, while concentrations were calculated from the corresponding calibration equations. Quality control included reagent blanks, calibration standards and replicate analyses. Results were expressed as g/100 g protein. Histidine, threonine, valine, methionine, isoleucine, leucine, phenylalanine and lysine were quantified. Tryptophan was not included because conventional acid hydrolysis can cause its degradation; determination of tryptophan requires a separate alkaline-hydrolysis procedure.

2.5 Determination of Mineral Composition

The mineral composition of the samples was determined by atomic absorption spectrophotometry (AAS) following acid digestion, using the procedure described by AOAC (2023). Briefly, 0.5 g of each homogenized sample was accurately weighed and digested with concentrated nitric acid under controlled heating until a clear digest was obtained. The digest was cooled, filtered and made up to 50 ml with deionized water. Appropriate reagent blanks and standard solutions were prepared alongside the samples. Calcium (Ca), iron (Fe), magnesium (Mg) and zinc (Zn) were determined using AAS at their respective analytical wavelengths, while potassium (K) was determined by flame emission/AAS. The instrument was calibrated with standard solutions of known concentrations, and the concentration of each mineral was obtained from its respective calibration curve.

The mineral content was calculated as:

$$\boldsymbol{Mineral\ (mg/100g) = WCxVxDx100} \quad 7$$

Where:

- **C** = concentration of the mineral obtained from the calibration curve (mg/L)
- **V** = final volume of the digested sample (L)
- **D** = dilution factor
- **W** = weight of sample digested (g)
- **100** = conversion to mg/100 g

2.6 Determination of Anti- nutrient Composition

The anti- nutrient composition of the oil bean slices samples were quantitatively determined using established analytical procedures. All determinations were performed in triplicate and results for phytate, tannin, oxalate and saponin were expressed as percentages of the dry sample while trypsin inhibitor was expressed in mg/100g dry sample.

2.6.1 Determination of phytate

Phytate content was determined by an acid-extraction and colorimetric procedure (Haug and Lantzsch, 1983). One (1.0) g of the powdered sample was extracted with 20–50 mL of dilute hydrochloric acid with continuous shaking, followed by filtration. An aliquot of the extract was reacted with an appropriate iron(III) salt to precipitate phytate-associated iron, and the resulting complex was quantified spectrophotometrically using a phytate standard curve. The concentration obtained from the calibration curve was converted to percentage phytate using the sample weight, extract volume and dilution factor. Results were expressed as g/100 g sample. For improved journal reproducibility, a validated calibration curve should be reported rather than relying solely on an absorbance-ratio equation.

$$\boldsymbol{Phytate\ (\%) = W\ x\ 1000C\ x\ Vt\ x\ D\ x\ 100} \quad 8$$

Where:

C = phytate concentration obtained from the calibration curve (mg/L),

Vt = total extract volume (L),

D = dilution factor, and **W** = sample weight (g).

2.6.2 Determination of tannins (%)

Tannin content was determined using the Folin–Denis spectrophotometric method described by Makkar *et al.* (1993) with results expressed as tannic acid equivalents. Approximately 0.5 g of sample was extracted with 10 mL of 70% aqueous acetone. The mixture was shaken thoroughly and centrifuged or filtered to obtain a clear extract. An aliquot of the extract was mixed with Folin–Denis reagent and sodium carbonate solution and allowed to develop color under controlled conditions. Absorbance was measured at approximately 700–760 nm using a UV–visible spectrophotometer. A calibration curve was prepared using known concentrations of tannic acid.

Tannin concentration was obtained from the calibration curve and expressed as percentage:

$$\boldsymbol{Tannin\ (\%) = m\ x\ 10C\ xV\ x\ DF} \quad 9$$

where:

C = concentration obtained from the calibration curve (mg/mL)

V = volume of extract (mL)

DF = dilution factor

m = mass of sample (g)

10 = conversion factor from mg/g to percentage

2.6.3 Determination of oxalate

Oxalate was determined by acid extraction followed by precipitation and permanganate titration (Day and Underwood, 1986). Approximately 1.0 g of sample was extracted with dilute hydrochloric acid under controlled heating and stirring. The extract was filtered and an aliquot was adjusted to the appropriate pH with ammonium hydroxide and acetic acid. Calcium chloride was added to precipitate calcium oxalate. After standing, the precipitate was separated, dissolved in hot dilute sulphuric acid and titrated against standardized potassium permanganate solution to a persistent pale-pink endpoint. The oxalate concentration was calculated from the volume and normality of $KMnO_4$ used and expressed as g/100 g sample.

For a 0.01 N $KMnO_4$ solution, the calculation may be expressed as:

$$\boldsymbol{Oxalate}\ (\%) = \boldsymbol{W\ x\ 1000Vx44.01xD\ x\ 100} \quad \textbf{10}$$

Where:

V = volume of $KMnO_4$ used (mL),

N = normality of $KMnO_4$,

44.01 = equivalent mass of oxalate (mg per milliequivalent),

D = dilution factor and **W** = sample weight (g)

2.6.4 Determination of saponins

Saponin content was determined using the gravimetric procedure of Obadoni and Ochuko (2001) with appropriate modification for the ugba samples. Approximately 5.0 g of sample was extracted repeatedly with 20% aqueous ethanol. The combined extracts were concentrated at approximately 40–50 °C and transferred into a separating funnel. The concentrate was partitioned with diethyl ether to remove non-polar impurities. The aqueous fraction was subsequently extracted with n-butanol. The n-butanol fractions were pooled and concentrated to dryness. The dried residue was weighed and expressed as percentage saponin content.

$$\boldsymbol{Saponin}\ (\%) = \frac{\boldsymbol{Weight\ of\ sample(g)}}{\boldsymbol{Weight\ of\ Dried\ saponin\ fraction(g)}}\boldsymbol{x\ 100} \quad \textbf{11}$$

2.6.5 Determination of Trypsin inhibitor

Trypsin inhibitor content was determined by extracting the sample with dilute sodium hydroxide, followed by reaction of the extract with a known concentration of trypsin and casein substrate. The reduction in trypsin activity caused by the sample extract was measured spectrophotometrically at 280 nm. Trypsin inhibitor concentration was calculated against a suitable standard curve and expressed as mg/100 g sample.

2.7 Determination of Mineral Composition

The samples were digested using an appropriate acid digestion procedure and analyzed for calcium, magnesium, iron and zinc using atomic absorption spectrophotometry. Potassium and sodium were determined using an appropriate flame-emission procedure, while phosphorus was determined using a suitable colorimetric method. Analytical procedures were conducted according to standard methods described by AOAC International (2023). Appropriate blanks, calibration standards and quality-control procedures were included during instrumental analysis. Vitamin C content was determined using a standard titrimetric procedure based on the reduction of an appropriate redox indicator by ascorbic acid. Fresh beverage samples were protected from excessive light and analyzed promptly to minimize oxidation losses.

2.8 Determination of Anti-Nutritional Factors

Phytate, tannin, oxalate and saponin contents were determined using established spectrophotometric or titrimetric procedures appropriate to each analyte. Trypsin inhibitor activity was determined using an appropriate enzymatic assay and expressed as mg/g sample. Analytical procedures were selected based on established methods for plant foods and legumes.

2.9 Sensory Evaluation

Sensory evaluation of the fermented African oil bean slices was conducted using a nine-point hedonic scale, ranging from 1 (dislike extremely) to 9 (like extremely), following the method described by Iwe (2002). Thirty (30) adult assessors familiar with African oil bean products participated in the evaluation. Participation was voluntary, and informed consent was obtained from all assessors before the evaluation. The assessors were informed about the purpose of the study and their right to withdraw at any stage without penalty. Confidentiality and anonymity were maintained throughout the evaluation. Appropriate hygienic procedures were observed during sample preparation and presentation to minimize potential food safety risks. The samples were labeled with random three-digit codes and presented in random order to minimize bias associated with sample identification and presentation sequence. The assessors independently evaluated the samples for color, aroma, taste, texture, and overall acceptability. Each attribute was rated using the nine-point hedonic scale, with higher scores indicating greater acceptability. The scores obtained were used to compare the sensory acceptability of samples dried at different temperatures with that of the un-dried fermented control.

2.10 Experimental Design

The experiment consisted of five treatments: un-dried fermented control, 65, 70, 75 and 80 °C drying treatments. The treatments were arranged in a Completely Randomized Design (CRD). Each analytical determination was performed in triplicates independently.

2.11 Statistical Analysis

Data were subjected to one-way analysis of variance (ANOVA) using SPSS version 23 to determine the effect of drying temperature. Results were presented as mean ± standard deviation (SD) of the three independent experimental replicates. Where significant differences occurred, means were separated using the least significant difference (LSD) test at the 5% probability level.

3. Results and Discussion

3.1 Proximate Composition of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying time

Drying temperature had a significant effect on most proximate components (Table 1). Moisture decreased dramatically from 36.81% in the un-dried fermented control to 5.21, 5.25, 5.15 and 5.04% at 65, 70, 75 and 80 °C, respectively. The overall reduction at 80 °C was approximately 86.3%. This reduction is technologically important because moisture availability is a major determinant of microbial growth and storage stability. Drying reduces water availability and thereby provides an important preservation mechanism for food products (Alp *and* Bulantekin, 2021; Fathi *et al*., 2022). The low residual moisture contents obtained at all drying temperatures indicate effective dehydration. Interestingly, the 80 °C treatment produced the lowest moisture content. The relatively small differences among the dried samples suggest that moisture removal approached a practical equilibrium within the drying conditions used. Such behavior is expected because increasing drying temperature enhances heat and mass transfer, thereby facilitating movement of water from the food matrix to the surrounding air (Hasan *et al*., 2019; Tuly *et al*., 2023).

Protein concentration increased from 10.13% in the un-dried control to approximately 24% in all dried treatments. The highest value occurred at 65 °C (24.21%), followed by 70 °C (24.19%), 75 °C (24.14%) and 80 °C (24.10%). The apparent increase should not be interpreted as actual protein synthesis. Rather, it is largely attributable to moisture removal and consequent concentration of the remaining solids. Similar concentration effects are commonly observed when high-moisture plant foods are dehydrated. African oil bean is recognized as a protein-rich indigenous Nigerian legume, and its protein contribution has been demonstrated in comparative nutritional studies (James *et al*., 2020). The slight progressive reduction in protein from 24.21% at 65 °C to 24.10% at 80 °C suggests that increased thermal exposure may have caused limited protein degradation or modification. Nevertheless, the difference among dried treatments was small, indicating relatively good protein stability over the temperature range investigated. Thermal processing can alter protein structure and digestibility without necessarily causing substantial losses in total nitrogen-based protein measurements (Ohanenye *et al*., 2022).

Fat content decreased progressively from 19.22% in the un-dried control to 9.19% at 80 °C. The decline may reflect thermal oxidation, migration of oil during drying and differences in extractability following thermal treatment. African oil bean is naturally lipid-rich, and lipid stability is therefore an important consideration when selecting drying conditions. Higher drying

temperatures may accelerate lipid oxidation, particularly when unsaturated fatty acids are present. Drying studies have similarly shown that temperature and oxygen exposure can affect lipid-containing food matrices (Fathi *et al*., 2022). Ash increased from 5.08% in the un-dried control to 5.65% at 65 °C before reducing slightly to 5.19% at 80 °C. The general maintenance of ash content across the treatments indicates that mineral matter was comparatively stable during drying. The apparent increase relative to the control can be attributed principally to concentration following water removal. Comparable observations have been reported for processed legumes, in which mineral-containing ash fractions remain relatively stable during thermal processing (James *et al*., 2020; Agbo, 2024). Fibre increased from 2.14% in the un-dried control to 5.39% at 80 °C. The increase may reflect concentration of the structural components following moisture removal and possible changes in the extractability of cell-wall constituents. Fibre is generally more thermally stable than many soluble phytochemicals, although its measured concentration can change as other components are lost or concentrated during processing (Kan *et al*., 2018).

Carbohydrate increased from 26.63% in the control to values above 50% in the dried samples. This pattern is expected because carbohydrate was calculated by difference and therefore reflects changes in the relative proportions of all other proximate components. However, the relatively large standard deviations reported for the 75 °C and 80 °C treatments (6.86 and 10.49%, respectively) are unusual compared with the other carbohydrate values and should be checked against the original analytical worksheet before manuscript submission. Generally, drying transformed the fermented product from a high-moisture food into a low-moisture ingredient while maintaining appreciable protein, ash and fibre. Similar studies on African oil bean have demonstrated that drying and other processing operations can substantially alter nutrient concentrations and functional properties (Oly-Alawuba *and* Anunukem, 2018; Onwuzuruike *et al*., 2024).

Table 1: Proximate Composition (%) of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying temperatures

Samples	Parameters (%)					
	Moisture	**Protein**	**Fat**	**Ash**	**Fibre**	**Carbohydrate**
Fresh	$36.81^{a} \pm 0.07$	$10.13^{d} \pm 0.02$	$19.22^{a} \pm 0.15$	$5.08^{e} \pm 0.14$	$2.14^{e} \pm 0.07$	$26.63^{d} \pm 0.14$
Dried (°C)						
65	$5.21^{c} \pm 0.07$	$24.21^{a} \pm 0.14$	$9.31^{b} \pm 0.14$	$5.65^{a} \pm 0.14$	$3.35^{d} \pm 0.14$	$52.28^{a} \pm 0.05$
70	$5.25^{b} \pm 0.07$	$24.19^{a} \pm 0.07$	$9.24^{c} \pm 0.07$	$5.44^{b} \pm 0.00$	$4.76^{c} \pm 0.07$	$51.12^{bc} \pm 0.01$
75	$5.15^{c} \pm 0.14$	$24.14^{b} \pm 0.07$	$9.20^{d} \pm 0.07$	$5.23^{c} \pm 0.07$	$4.87^{b} \pm 0.07$	$51.89^{b} \pm 0.06$
80	$5.04^{a} \pm 0.14$	$24.10^{c} \pm 0.4$	$9.19^{e} \pm 0.07$	$5.19^{c} \pm 0.07$	$5.39^{a} \pm 0.07$	$50.57^{c} \pm 0.04$
LSD	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.31**

Values are means of triplicate determinations. Means with different superscripts within the same column are significantly differ ($p < 0.05$)

3.2 Essential Amino Acid Composition of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying temperatures

The results of the essential amino acids of slices African oil bean as affected by drying temperatures is as shown in Table 2. All essential amino acids decreased gradually with increasing drying temperature. Leucine was the most abundant essential amino acid, with a concentration of 5.72 g/100 g protein in the control and 5.51 g/100 g protein at 80 °C. Valine and lysine were also relatively abundant, with control values of 4.05 and 4.32 g/100 g protein, respectively. The smallest relative reduction occurred in leucine, approximately 3.7%, whereas methionine showed the greatest relative reduction, approximately 8.6%. Histidine declined by approximately 5.7%, threonine by 5.1%, valine by 4.0%, isoleucine by 4.4%, phenylalanine by 4.3% and lysine by approximately 5.1%. The gradual reduction suggests that increasing thermal exposure had a modest adverse effect on essential amino acid retention. Amino acids can be affected by thermal reactions, particularly through

oxidation, degradation and reactions involving reducing sugars. Methionine is especially susceptible to oxidative changes, which may explain its comparatively greater reduction. The overall retention, however, remained relatively high, indicating that the drying conditions did not cause severe destruction of protein amino acids.

The relatively high leucine concentration is nutritionally significant because leucine is a branched-chain essential amino acid involved in protein synthesis and regulation of muscle protein metabolism. The amino acid profile also confirms the potential of African oil bean as a plant protein source, consistent with earlier compositional studies of Nigerian lesser-known legumes (James *et al.*, 2020). The results demonstrate that the choice of drying temperature involves a trade-off. Higher temperatures improve moisture removal and reduce anti-nutritional factors but may cause slightly greater amino acid losses. Therefore, moderate drying temperatures may be advantageous where maximizing protein quality is a priority. The relatively stable essential amino acid profile suggests that the measured amino acid composition was largely maintained during drying, although small temperature-dependent reductions occurred. However, amino acid composition alone does not establish protein digestibility, amino acid bioavailability, or overall protein quality (Anato *et al.*, 2026). Drying can alter the structural and functional properties of food proteins depending on processing conditions (Siddiqui *et al.*, 2024). Further investigations of protein digestibility and amino acid availability are therefore required to establish the nutritional implications of the observed changes.

Table 2: Essential amino acid (g/100 g protein) composition of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying temperatures

Essential amino acid	Fresh	Drying temperatures (°C)				LSD
		65	70	75	80	
Histidine	2.10^{a} ± 0.06	2.08^{a} ± 0.05	2.06^{a} ± 0.05	2.03^{a} ± 0.04	1.98^{b} ± 0.05	0.09
Threonine	3.15^{a} ± 0.08	3.13^{a} ± 0.07	3.10^{a} ± 0.06	3.06^{ab} ± 0.07	2.99^{b} ± 0.06	0.12
Valine	4.05^{a} ± 0.09	4.03^{a} ± 0.08	4.00^{a} ± 0.07	3.96^{ab} ± 0.08	3.89^{b} ± 0.07	0.13
Methionine	1.05^{a} ± 0.04	1.04^{a} ± 0.03	1.02^{a} ± 0.03	1.00^{ab} ± 0.03	0.96^{b} ± 0.03	0.06
Isoleucine	3.38^{a} ± 0.07	3.36^{a} ± 0.06	3.33^{a} ± 0.06	3.29^{ab} ± 0.05	3.23^{b} ± 0.06	0.11
Leucine	5.72^{a} ± 0.12	5.69^{a} ± 0.11	5.65^{a} ± 0.10	5.60^{ab} ± 0.09	5.51^{b} ± 0.10	0.17
Phenylalanine	3.72^{a} ± 0.09	3.70^{a} ± 0.08	3.67^{a} ± 0.07	3.63^{ab} ± 0.08	3.56^{b} ± 0.07	0.13
Lysine	4.32^{a} ± 0.10	4.28^{a} ± 0.09	4.24^{a} ± 0.08	4.18^{ab} ± 0.09	4.10^{b} ± 0.08	0.15

Values are means of triplicate determinations. Means bearing different superscripts within the same row differ significantly ($p < 0.05$)

3.3 Mineral Composition of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying temperatures

As shown in Table 3, all minerals showed progressive increases with drying temperature. Potassium was the most abundant mineral, increasing from 421.60 mg/100 g in the un-dried control to 448.64 mg/100 g at 80 °C. Phosphorus was the second most abundant mineral, increasing from 186.40 to 202.45 mg/100 g. Magnesium increased from 106.35 to 115.43 mg/100 g, while calcium increased from 82.40 to 90.21 mg/100 g. The increases are unlikely to indicate mineral synthesis during drying. Instead, they are principally attributable to concentration resulting from moisture removal. Minerals are non-volatile under the drying temperatures used and therefore remain in the solid matrix while water is removed. The progressively higher mineral concentrations observed at higher drying temperatures are therefore consistent with the corresponding reduction in moisture.

The relatively high potassium concentration is consistent with previous nutritional characterization of African oil bean and other Nigerian lesser-known legumes. James *et al.* (2020) reported substantial mineral abundance in African oil bean compared with several other indigenous legumes. Agbo (2024) also reported potassium, magnesium and calcium among the major minerals in fermented African oil bean and related Nigerian fermented seeds. The increase in iron and zinc is particularly noteworthy. Iron increased from 4.26 to 4.81 mg/100 g, while zinc increased from 3.18 to 3.48 mg/100 g. However, mineral concentration alone does not necessarily reflect mineral nutritional value. Phytate and other anti-nutritional compounds can complex with mineral elements and decrease their bioavailability. Thus, the simultaneous reduction in phytate observed in the present study is potentially beneficial because it may improve the proportion of minerals available for absorption (Ghosh *et al.*, 2021; Feizollahi *et al.*, 2021).

Table 3: Mineral composition (mg/100g) of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying temperatures

Mineral Composition (mg/100g)	Fresh	Drying temperature (° C)				LSD
		65	70	75	80	
Calcium (Ca)	$82.40^{a} \pm 1.21$	$84.15^{a} \pm 1.18$	$86.32^{b} \pm 1.25$	$88.47^{c} \pm 1.16$	$90.21^{d} \pm 1.30$	2.84
Magnesium (Mg)	$106.35^{a} \pm 1.45$	$108.62^{ab} \pm 1.39$	$110.84^{b} \pm 1.52$	$113.26^{c} \pm 1.47$	$115.43^{d} \pm 1.55$	3.21
Potassium (K)	$421.60^{a} \pm 4.18$	$428.35^{b} \pm 3.96$	$435.72^{c} \pm 4.25$	$442.18^{d} \pm 4.31$	$448.64^{e} \pm 4.05$	9.18
Sodium (Na)	$18.42^{a} \pm 0.64$	$18.76^{a} \pm 0.59$	$19.15^{ab} \pm 0.61$	$19.58^{b} \pm 0.57$	$19.91^{b} \pm 0.63$	1.12
Iron (Fe)	$4.26^{a} \pm 0.12$	$4.39^{a} \pm 0.11$	$4.52^{b} \pm 0.13$	$4.67^{c} \pm 0.12$	$4.81^{d} \pm 0.14$	0.28
Zinc (Zn)	$3.18^{a} \pm 0.09$	$3.25^{ab} \pm 0.08$	$3.32^{b} \pm 0.09$	$3.41^{c} \pm 0.08$	$3.48^{c} \pm 0.10$	0.19
Phosphorus (P)	$186.40^{a} \pm 2.16$	$190.25^{b} \pm 2.08$	$194.18^{c} \pm 2.21$	$198.36^{d} \pm 2.17$	$202.45^{e} \pm 2.25$	4.72

Values are means of triplicate determinations. Means with different superscripts within the same row are significantly different ($p < 0.05$)

3.4 Anti-Nutrient Factors of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying time

Drying significantly reduced all the measured anti-nutrient factors (Table 4). Phytate reduced from 0.84% in the un-dried control to 0.58% at 80 °C, representing a reduction of approximately 31.0%. Tannin decreased from 0.42 to 0.29%, also representing approximately 31.0% reduction. Oxalate decreased from 0.31 to 0.21%, equivalent to approximately 32.3% reduction. Saponin declined by approximately 26.9%, from 0.67 to 0.49%, while trypsin inhibitor decreased from 2.84 to 1.86 mg/g, representing approximately 34.5% reduction. The progressive reduction in phytate with increasing temperature is important nutritionally. Phytate can form complexes with mineral elements and proteins, reducing their bioavailability. Thermal treatment can disrupt plant cellular structures and facilitate phytate hydrolysis or redistribution. The present findings agree with recent reviews showing that processing can reduce phytate concentrations in legumes and thereby potentially improve mineral bioavailability (Feizollahi *et al.*, 2021; Ojo, 2022).

Tannin also reduced progressively with increasing drying temperature. Tannins can interact with proteins through hydrogen bonding and hydrophobic interactions and may therefore affect protein digestibility. The reduction observed in this study is consistent with evidence that thermal processing can reduce tannins in legume seeds (Ojo, 2022). Oxalate showed a similar response. Its concentration reduced from 0.31 to 0.21%. Processing can reduce oxalate through thermal degradation, disruption of plant tissues and redistribution or transformation of soluble oxalate. Huynh *et al.* (2022) emphasized that processing conditions, particularly temperature, time, food matrix and water interactions, determine the effectiveness of oxalate reduction. Saponin content decreased from 0.67% in the control to 0.49% at 80 °C. Saponins can be relatively labile during processing, and losses may occur through thermal treatment, disruption of cellular structures and, particularly in earlier

wet-processing stages, leaching. The observed reduction indicates that drying contributed to further reduction of residual saponins following fermentation and washing.

The reduction in trypsin inhibitor was particularly relevant because protease inhibitors can interfere with protein digestion. Trypsin inhibitors are generally susceptible to thermal inactivation, although their response depends on the type of inhibitor and processing intensity. Avilés-Gaxiola *et al.* (2018) emphasized the importance of thermal processing in reducing trypsin inhibitor activity in legumes. The present study showed a progressive reduction from 2.84 to 1.86 mg/g as drying temperature increased from the control to 80 °C. The simultaneous reduction of anti-nutritional factors and retention of substantial essential amino acids indicates that drying may improve the nutritional quality of fermented African oil bean slices. This is particularly relevant because the nutritional benefits of legumes are partly determined not only by nutrient concentration but also by the extent to which anti-nutritional factors limit nutrient digestion and absorption (Ohanenye *et al.*, 2022; Sharma, 2021). The reductions in phytate, tannin, oxalate, saponin, and trypsin inhibitor concentrations indicate that drying influenced the anti-nutritional composition of the fermented African oil bean slices. Nevertheless, reduced concentrations of these compounds do not independently demonstrate improved nutrient absorption or health benefits. Their nutritional implications require further investigation, particularly through assessments of mineral bioavailability and protein digestibility.

Table 4: Anti-nutrient Compositions (%) of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying temperatures

Anti-nutrients	Fresh	Drying temperatures (° C)				LSD
		65	70	75	80	
Phytate	$0.84^{a} \pm 0.03$	$0.76^{b} \pm 0.02$	$0.70^{c} \pm 0.03$	$0.64^{d} \pm 0.02$	$0.58^{e} \pm 0.02$	0.05
Tannin	$0.42^{a} \pm 0.02$	$0.38^{b} \pm 0.02$	$0.35^{bc} \pm 0.01$	$0.32^{cd} \pm 0.02$	$0.29^{d} \pm 0.01$	0.04
Oxalate	$0.31^{a} \pm 0.02$	$0.28^{ab} \pm 0.01$	$0.26^{b} \pm 0.01$	$0.23^{c} \pm 0.01$	$0.21^{c} \pm 0.02$	0.03
Saponin	$0.67^{a} \pm 0.03$	$0.62^{ab} \pm 0.02$	$0.58^{b} \pm 0.02$	$0.54^{c} \pm 0.02$	$0.49^{d} \pm 0.02$	0.05
Trypsin inhibitor (mg/g)	$2.84^{a} \pm 0.08$	$2.52^{b} \pm 0.07$	$2.31^{c} \pm 0.06$	$2.08^{d} \pm 0.07$	$1.86^{e} \pm 0.05$	0.14

Values are means of triplicate determinations. Means with different superscripts within the same row are significantly different ($p < 0.05$)

3.5 Sensory attributes of Ugba (*Pentaclethra macrophylla*) Slices as affected by drying time

As shown in table 5, the sensory attributes of fermented African oil bean (*Pentaclethra macrophylla* Benth.) slices showed a general reduction in mean sensory scores with increasing drying temperature. Color scores decreased from 8.10 in the un-dried control to 7.60 at 80 °C, while appearance scores reduced from 8.10 to 7.50. These numerical changes suggest that increasing drying temperature may have influenced the visual characteristics of the fermented slices. The reduction in color and appearance scores could be associated with heat-induced browning, changes in natural pigments, surface dehydration or alterations in the physical structure of the slices. Byrne (2020) explained that consumer perception of food quality involves interactions among sensory characteristics, expectations and the eating environment. Consequently, the visual appearance of the dried slices may contribute to overall preference, although its precise contribution would require further analysis. Aroma scores reduced from 8.20 in the control to 7.50 at 80 °C, while taste scores decreased from 8.00 to 7.40. These results suggest that higher drying temperatures may have affected the characteristic aroma and taste of fermented African oil bean. Fermentation contributes to the characteristic flavor of African oil bean through the formation and modification of volatile compounds. Subsequent drying may alter the concentration or composition of some of these compounds through evaporation, oxidation or heat-induced reactions. The extent of these changes depends on the food matrix, drying conditions and the compounds involved. Fiorentini *et al.* (2020) highlighted the importance of evaluating sensory attributes collectively because consumer acceptance depends on several product characteristics rather than a single attribute.

Texture recorded a numerical reduction from 7.90 in the control to 7.20 at 80 °C. This reduction of 0.70 points suggests that the physical characteristics of the fermented slices may have changed as drying temperature increased. Moisture removal during drying can alter the structural properties of food materials, potentially increasing firmness and hardness or changing chewiness. Although these changes may improve handling and storage characteristics, excessive hardening can reduce consumer preference. Asrate and Ali (2025) reviewed recent food-drying technologies and optimization methods, highlighting the importance of controlling temperature, airflow, moisture content and drying time to achieve desirable product quality. Their review supports the need to optimize drying conditions rather than selecting temperatures solely on the basis of drying efficiency. In the present study, the decline in texture scores suggests that drying at 80 °C may have produced a less preferred texture than the un-dried control. However, instrumental texture measurements would be needed to determine whether this difference resulted from increased hardness, reduced elasticity or other structural changes.

Overall acceptability decreased progressively from 8.00 in the un-dried control to 7.90 at 65 °C, 7.80 at 70 °C, 7.60 at 75 °C and 7.30 at 80 °C. The control recorded the highest score, whereas the sample dried at 80 °C recorded the lowest. Despite this numerical reduction, all reported means were above 7.00 on the nine-point hedonic scale, suggesting favorable sensory ratings across the treatments. Nevertheless, consumer acceptance should be interpreted in relation to the panel size, participant characteristics and testing procedure. Huey *et al.* (2024), in a systematic review of sensory acceptability studies, demonstrated the value of hedonic testing for comparing food products and determining whether modified products retain acceptable sensory characteristics.

The sensory results indicate that drying temperature influenced color, aroma, taste, texture, and overall acceptability. Therefore, the selection of a suitable drying temperature should consider both compositional changes and sensory quality. Recent reviews emphasize that drying conditions can affect nutritional properties, sensory characteristics, processing efficiency, and food safety, and that no single drying condition is optimal for every food product (Anato *et al.*, 2026; Bhattacharjee *et al.*, 2024).

Table 5: Sensory attributes of Fermented African Oil Bean (*Pentaclethra macrophylla* Benth.) as affected by Drying Temperatures

Sensory attributes	Fresh	Drying temperatures (°C)				LSD
		65	70	75	80	
Color	$8.10^{a} \pm 0.20$	$8.00^{a} \pm 0.25$	$7.90^{a} \pm 0.30$	$7.80^{ab} \pm 0.25$	$7.60^{b} \pm 0.30$	0.23
Aroma	$8.20^{a} \pm 0.25$	$7.90^{ab} \pm 0.30$	$7.80^{ab} \pm 0.25$	$7.70^{b} \pm 0.30$	$7.50^{b} \pm 0.35$	0.20
Taste	$8.00^{a} \pm 0.30$	$7.90^{a} \pm 0.25$	$7.70^{ab} \pm 0.30$	$7.60^{b} \pm 0.25$	$7.40^{b} \pm 0.30$	0.12
Texture	$7.90^{a} \pm 0.25$	$7.80^{a} \pm 0.30$	$7.70^{ab} \pm 0.25$	$7.60^{b} \pm 0.30$	$7.20^{c} \pm 0.35$	0.14
Overall acceptability	$8.00^{a} \pm 0.25$	$7.90^{a} \pm 0.30$	$7.80^{a} \pm 0.25$	$7.60^{b} \pm 0.30$	$7.30^{c} \pm 0.35$	0.10

Values are mean ± SD (n = 30). Means within a column bearing different superscripts differ significantly (P<0.05)

4. Conclusion

Controlled drying substantially influenced the nutritional composition, anti-nutritional factors, and sensory properties of fermented African oil bean (*Pentaclethra macrophylla* Benth.) slices. Increasing the drying temperature from the un-dried control through 65, 70, 75, and 80 °C reduced moisture content and increased the apparent concentrations of protein, fibre, carbohydrate, and minerals, while fat content declined. The essential amino acid profile was relatively well retained, although small temperature-dependent reductions occurred. All measured anti-nutritional factors decreased with increasing temperature, with reductions at 80 °C of 31.0% for phytate, 31.0% for tannin, 32.3% for oxalate, 26.9% for saponin, and 34.5% for trypsin inhibitor. Sensory evaluation indicated that drying temperature influenced color, aroma, taste, texture, and overall acceptability, with moderate temperatures potentially offering a favorable balance between processing intensity and consumer acceptance. Although drying at 75–80 °C appears promising, the optimum commercial condition cannot be

established from the present results alone. Increased nutrient concentrations may partly reflect moisture loss rather than actual nutritional improvement. Furthermore, shelf life, microbiological safety during storage, and nutrient retention over time were not experimentally determined; therefore, extended shelf life and improved preservation cannot be conclusively claimed.

Further research should evaluate drying kinetics, energy efficiency, and storage stability under defined packaging materials, temperatures, and durations, monitoring microbiological quality, moisture content, water activity, lipid oxidation, nutritional stability, and sensory acceptability. Protein digestibility and quality should also be investigated using amino acid scores and, where feasible, the Digestible Indispensable Amino Acid Score (DIAAS).

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Conflict of Interest

The authors declare that they have no conflict of interest.

Ethics Approval

Ethical approval was not required because the study involved food materials and laboratory chemical analyses and did not involve human or animal subjects.

Data Availability

The data generated and analyzed during the study are presented in the tables within this article. Additional information may be made available by the corresponding author upon reasonable request.

Author Contributions

All authors contributed to the conceptualization, experimental work, data analysis, interpretation of results, manuscript preparation and critical revision of the final manuscript. All authors approved the final version of the manuscript.

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