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ORIGINAL RESEARCH ARTICLE

Comparative Effects of Air-Drying and Sun-Drying on the Nutritional and Anti-Nutritional Profile of Sweet Potato Flour in Kaduna State, Nigeria

Joshua Zamani Pius*[1], Aishatu Mohammed Aminu[2], Asiya Suleiman Adam[1], Umar Sa'ad[1], Buzu Sim Blessing [1], Turaki Maryam Ibrahim[3], Kabir Sani[1], Jamila, I. Abbas[1], Beatrice Hosea Ali[1] and Ishaq Shehu[1]
1Department of SLT-Chemistry and Biochemistry, Nuhu Bamalli Polytechnic, Zaria, Nigeria
2Department of SLT-Biology and Microbiology, Nuhu Bamalli Polytechnic, Zaria, Nigeria
3Department of Biology, School of Secondary Education, Federal College of Education Technical, Gusau, Zamfara State, Nigeria

ABSTRACT
This study evaluated the effects of air-drying and sun-drying on the nutritional and anti-nutritional composition of sweet potato (*Ipomoea batatas*) flour produced in Kaduna State, Nigeria. Fresh tubers (5 kg) were processed in triplicate (biological replicates), and each analysis was conducted in duplicate. Sliced samples were blanched at 80 °C for 3 min and dried to constant weight (<10% moisture) using either shade air-drying (24–26 °C) or direct sun-drying (34–38 °C). Proximate composition, mineral content, vitamins A and C, and selected anti-nutritional factors were determined using standard AOAC methods. Data were analyzed using an independent sample t-test at $p < 0.05$. Air-dried flour retained significantly higher levels of vitamin C (14.20 ± 0.30 vs 8.50 ± 0.15 mg/100 g), vitamin A (1.15 ± 0.05 vs 0.65 ± 0.02 mg/100 g), and iron (1.85 ± 0.04 vs 1.60 ± 0.03 mg/100 g). Conversely, sun-dried samples exhibited lower moisture content (7.45 ± 0.08%) and higher carbohydrate concentration (82.77 ± 0.50%). Anti-nutritional factors, including oxalate and phytates, were significantly reduced by both treatments and remained within safe limits. The findings demonstrate a clear processing trade-off: air-drying enhances micronutrient retention, whereas sun-drying improves moisture reduction and potential shelf stability.

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Sweet potato, drying methods, nutrient retention, anti-nutritional factors, Kaduna

INTRODUCTION
Sweet potato (*Ipomoea batatas*) is a critical staple in Kaduna State, Nigeria, prized for its carbohydrate density and potential as a source of provitamin A and vitamin C. However, substantial post-harvest losses and nutrient degradation during processing remain barriers to its contribution to local food security (Duan *et al.,* 2024; Onwude *et al.,* 2022). To mitigate these losses, drying is frequently employed; however, the choice of drying method significantly impacts final quality.

Conventional sun-drying often utilizes high temperatures and direct ultraviolet radiation, which can accelerate the degradation of heat- and light-sensitive nutrients. In contrast, air-drying (shade drying) may better preserve micronutrients due to reduced thermal and photochemical effects, although it is slower and may result in higher residual moisture content (Ntsowe *et al.,* 2024; Sturma *et al.*, 2023; Ahmad et al., 2022).

While the impact of drying on various crops is well-documented globally, there is a lack of location-specific evidence on the optimization of sweet potato flour processing in Kaduna State. Furthermore, many existing studies prioritize moisture content over the simultaneous analysis of nutritional and anti-nutritional profiles (Afeye *et al.,* 2021). This study fills this gap by comparing the effects of air-drying and sun-drying on the nutritional composition and anti-nutritional factors (specifically oxalate and phytates) in blanched sweet potato flour. By evaluating these parameters within the specific environmental context of Kaduna State, this research provides evidence-based data to optimize local processing techniques for improved nutritional outcomes (Badiora *et al.*, 2023; Ntsowe *et al.,* 2025).

Therefore, this study aimed to comparatively evaluate the effects of air-drying and sun-drying on the nutritional and anti-nutritional composition of sweet potato flour, with specific emphasis on micronutrient retention and reduction of anti-nutritional factors.

Correspondence: Joshua Zamani Pius. Department of SLT-Chemistry and Biochemistry, Nuhu Bamalli Polytechnic, Zaria, Nigeria. ✉ zamanijo2013@gmail.com.
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MATERIALS AND METHODS

2.1 Sample Collection and Identification

Approximately 5 kg of sweet potatoes (*Ipomoea batatas*) were purchased from local farmers in Zaria, Kaduna State, Nigeria. The samples were transported in chilled polyethylene bags to the Department of Chemistry and Biochemistry Laboratory, Nuhu Bamalli Polytechnic, Zaria. Taxonomic identification was confirmed at the Department of Biology, where voucher specimens were deposited.

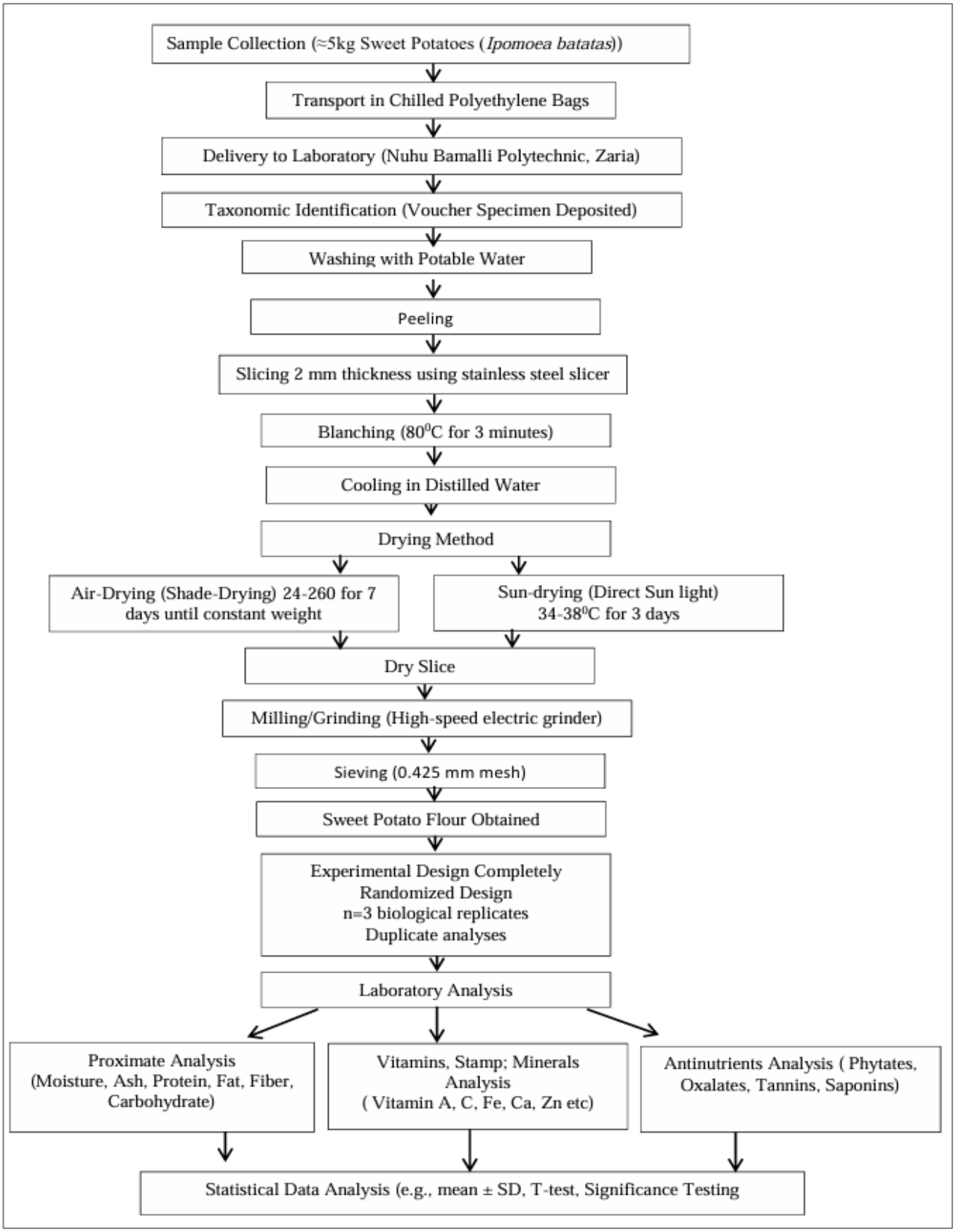

Figure 1: Process flow diagram illustrating the comparative preparation of air-dried and sun-dried sweet potato flour

2.2 Preparation of Sweet Potato Flour

The tubers were washed with potable water, peeled, and sliced into uniform circular shapes (2 mm thickness) using a stainless-steel slicer. The slices were immediately blanched in a water bath at 80°C for 3 minutes to inactivate polyphenol oxidase enzymes (Kolawole *et al.,* 2016). After blanching, the slices were cooled in distilled water and divided into two experimental groups:

Air-Drying (Shade-Drying): Slices were spread in a single layer on stainless steel trays and dried in a well-ventilated laboratory at an average temperature of 24–26°C for 7 days until a constant weight was achieved.

Sun-Drying: Slices were exposed to direct sunlight on stainless steel trays at an average ambient temperature of 34–38°C for 3 days.

The dried slices were pulverized using a high-speed electric grinder and sieved through a 0.425 mm mesh to obtain a uniform flour. The flour was stored in airtight plastic containers and refrigerated at 4°C prior to analysis (Boni *et al.,* 2018).

2.2.1 Experimental Design

The study was conducted using a completely randomized design. Sweet potato samples were processed in triplicate (n = 3 biological replicates)**,** and each laboratory analysis was performed in duplicate (technical replicates)**.** Figure 1 shows process flow diagram illustrating the comparative preparation of air-dried and sun-dried sweet potato flour.

2.3 Proximate Composition

The proximate composition was determined in accordance with the standard methods of the Association of Official Analytical Chemists (AOAC, 2017). All analyses were performed in triplicate biological replicates, with each replicate analyzed in technical duplicate to ensure analytical precision.

2.3.1 Moisture Content

A clean crucible was dried to constant weight in an air oven at 105°C, cooled in a desiccator, and weighed (W1). Two grams (2 g) of sample were weighed into the crucible (W2). The sample was dried in an oven at 105°C until a constant weight (W3) was reached.

$$\%\, Moisture = \frac{(W1 - W2)}{W1} \times 100$$

Where: W1 = Initial weight of sample; W2 = Weight after drying

2.3.2 Determination of Ash Content

The porcelain crucible was dried in an oven at 100 °C for ten minutes, cooled in a desiccator and weighed (W_1). Two grams (2g) of the sample were placed into the previously weighed porcelain crucible and weighed (W_2). The samples were first ignited and transferred into a furnace, which was then set to 550 °C . The samples were left in the furnace for 8 hours to ensure proper ashing. The crucible containing the ash was removed, cooled in the desiccator, and reweighed (W_3). The percentage ash content was calculated as:

$$\%\, Ash = \frac{(W2 - W1)}{W3} \times 100$$

Where: W1 = Weight of empty crucible; W2 = Weight of crucible + ash; W3 = Weight of sample

2.3.3 Determination of Crude Lipid Content.

A clean, dried 500ml round-bottom flask containing a few anti-bumping granules was weighed (W_1), and 300ml of petroleum ether (40-60 °C) for extraction was poured into the flask fitted with a Soxhlet extraction unit. The extractor thimble containing 20g of the sample was fixed in the Soxhlet extraction unit. The round-bottom flask and condenser were connected to the Soxhlet extractor, and cold water circulation was started. The heating mantle was switched on, and the heating rate was adjusted until the solvent was refluxing steadily. Extraction were carried out for six hours. The solvent was recovered, and the oil was dried in the oven at 70 °C for one hour. The round-bottom flask containing the oil was cooled in the desiccator, and the weighed W_2. The lipid content was calculated thus:

$$\%\ \textbf{Crude Lipid Content} = \left[\frac{(W2 - W1)}{\text{Weight of Sample}}\right] \times 100$$

Where: W1 = Weight of empty flask; W2 = Weight of flask + lipid; W3 = Weight of sample

2.3.4 Determination of Crude Fiber

2g of sample will be weighed out into a round-bottom flask. 100 mL of 0.25 M sulphuric acid solution will be added, and the mixture will be boiled under reflux for 30 minutes. The hot solution will be quickly filtered under suction. The insoluble matter will be sieved several times with hot water until it is acid-free. It will be quantitatively transferred into the flask, 100 mL of hot 0.31 M sodium hydroxide solution will be added, and the mixture will be boiled again under reflux for 30 minutes, then quickly filtered under suction. The insoluble residue will be base-free. It will be dried to constant weight (C_1), then incinerated in a muffle furnace at 550 °C for 2 hours, cooled in the desiccator, and reweighted (C_2)

Calculation

$$\%\, \boldsymbol{Crude\ Fibre} = \frac{(W1 - W2)}{W3} \times 100$$

Where: W1 = Weight after digestion and drying; W2 = Weight after ashing; W3 = Weight of sample

2.3.5 Determination of Crude Protein

Exactly 1.5g of the defatted sample on ashless filter paper was dropped into a 300ml Kjeldahl flask. 25 ml of H2SO4 and 3g of digesting mixed catalyst (weighed separately into an ashless filter paper) will be dropped into the Kjeldahl

flask. The flask was then transferred to the Kjeldahl digestion apparatus. The sample was digested until a clear green colour will be obtained. The digest will be cooled and diluted to 100ml with distilled water.

2.3.6 Distillation of the digest

20ml of the diluted digest sample was measured into a 500ml Kjeldahl flask containing anti-bumping chips, and 40ml of 40% NaOH was slowly added along the side of the flask. A 250ml conical flask containing a mixture of 50ml of 2% Boric acid and 4 drops of indicator was used to trap the ammonia liberated. The conical flask and the Kjeldahl flask were then placed on the Kjeldahl distillation apparatus, with the tubes inserted into both. The flask was heated to distill out the NH_3 evolved. The distillate was collected into the boric acid solution. From the point at which the boric acid turned green, 10 minutes were allowed for complete distillation of the ammonia present in the digest. The distillate was then titrated with 0.1 M HCl.

Calculation

% N = [14 X M x V_t X T_v X 100]/[Weight of sample (mg) X V_a]

Where:

M = Actual molarity of acid

T_v = Titre volume of HCL used

V_t = Total volume of diluted digest

V_a = Aliquot volume distilled

% Crude protein = % Nitrogen (N_2) X 6.25

2.3.7 Determination of Carbohydrate

The total carbohydrate content was determined by difference, as described by Ibrahim et al. (2022). The sum of the percentage moisture; Ash, crude lipid, crude protein, and crude fiber will be subtracted from 100

Calculation:

% Total carbohydrate (CHO) = 100 – (%Moisture + % Ash + % Fat + % protein + % Fiber)

2.4 Determination of Mineral Content

The mineral content (Ca, Fe, and Zn) was determined using Atomic Absorption Spectrophotometry (AAS) in accordance with AOAC (2017) protocols.

Approximately 2 g of each sweet potato variety was dried in a hot air oven at 100°C for 30 minutes. The dried samples were then placed on a hot plate until they became smoke-free. Subsequently, the samples were transferred to a muffle furnace set at 550°C for 3 hours until a white ash was obtained. The resulting ash was dissolved in 5 ml of 6 M HCl by warming the mixture on a hot plate for 2–3 minutes. This solution was transferred into a 50 ml volumetric flask, and 1 M HNO_3 was added to volume. Standard solutions for each mineral element were prepared by diluting stock standards with 0.3 M HCl to the required concentrations.

The AAS was calibrated using these standard solutions, and the sample solutions were then aspirated into the spectrophotometer. The minerals were quantified by measuring absorbance at element-specific wavelengths against the standard calibration curves. All determinations were performed in duplicate.

2.5 Vitamins Content Determination in Air and Sundried Potato Flour

2.5.1 Determination of Vitamin C

A modified version of the method described by Awolu et al. (2013) was used. The vitamin C content of the hydrophilic extracts from the samples was determined by spectrophotometry, with ascorbic acid as the reference standard.

Exactly 10.0 mL of the juice sample was measured and diluted with 10 mL of distilled water, after which the mixture was thoroughly homogenized. An aliquot of 200 µL (0.2 mL) of the extract was pipetted into a test tube and mixed with 300 µL (0.3 mL) of 13.3% trichloroacetic acid (TCA) and 75 µL (0.075 mL) of dinitrophenylhydrazine (DNPH).

The mixture was incubated in a water bath at 37°C for 3 hours. After incubation, 500 µL (0.5 mL) of 65% sulphuric acid was added to the mixture. The absorbance of the resulting solution was then measured at 520 nm using a spectrophotometer.

The concentration of vitamin C in the sample was calculated using the relationship:

$$\textbf{Vitamin C (mg/100 mL)} = \left(\frac{A_{sample}}{A_{standard}}\right) \times C_{standard} \times \left(\frac{V_{total}}{V_{sample}}\right)$$

Where:

Asample = Absorbance of the sample

Astandard = Absorbance of the standard (ascorbic acid)

Cstandard = Concentration of the standard solution (mg/mL)

Vtotal = Total volume of extract (mL)

Vsample = Volume of sample analyzed (mL)

2.5.2 Determination of Vitamin A

The AOAC (2017) method was used with slight modifications. Vitamin A was determined from the lipophilic extract obtained after saponification of the sample.

Exactly 1.0 mL of the extract was transferred into a centrifuge tube with a tight stopper, and 1.0 mL of potassium hydroxide (KOH) solution was added. The mixture was vigorously shaken for 1 minute and subsequently heated in a water bath at 60°C for 20 minutes

to achieve saponification. The tube was then cooled rapidly under running cold water.

Thereafter, 1.0 mL of xylene was added, and the mixture was shaken vigorously for another 1 minute to extract the unsaponifiable fraction. The mixture was centrifuged at 1500 × g for 10 minutes to facilitate phase separation. The upper organic layer was carefully collected and transferred into a second test tube made of sodium glass.

The absorbance (A_1) of the extract was measured at 335 nm using a spectrophotometer, with xylene as the blank. The extracts were then exposed to ultraviolet light for 30 minutes, after which the absorbance (A_2) was measured again at the same wavelength.

The concentration of vitamin A (µM) in the sample was calculated using the expression:

$$C = (A_1 - A_2) \times 22.23$$

$\mathbf{A_1}$ = Initial absorbance

$\mathbf{A_2}$ = Absorbance after UV irradiation

22.23 = Conversion factor based on the absorption coefficient of a 1% vitamin A (retinol) solution in xylene at 335 nm using a 1 cm cuvette

2.6 Phytochemicals Analysis of Air and Sundried Sweet Potato flour.

Tannins in the sweet potato flour were determined using the method described by Ooko (2020). About 10 ml of 70% acetone was mixed with 0.2 g of the powdered sample in a 50 ml bottle. The bottle was shaken in an ice shaker for 2 hours at 30 °C, then centrifuged; the supernatant was kept on ice. About 0.2 ml and 0.8 ml of the supernatant and distilled water were mixed in a test tube to obtain a 1 ml test solution. About 0.5 mg/ml of the standard tannate stock was diluted with 0.5 ml distilled water to make a 1 ml standard solution. 0.5 ml of Folin-Ciocalteu reagent and 2.5 ml of 20% Na_2CO_3 were added to both test and standard solutions, vortexed, and incubated at room temperature for 40 minutes. The absorbance was read at 725 nm, and the tannin concentrations were extrapolated from the calibration curve of standard tannate. For the determination of glycosides, the chloroform solution of the sample was filtered into a 100 ml flask, followed by the addition of 10 ml of pyridine and 2 ml of 29% sodium nitroprusside. The addition of 3 ml of 20% NaOH to the solution results in the development of brownish yellow color. The glycoside standard with a concentration within the range of 0-50 mg/mL was used to prepare a standard calibration curve; the absorbance of the sample and the standard was measured at 510 nm. Saponins and flavonoids were assessed using the method described by Bao (2005).

DATA ANALYSIS

Data were expressed as Mean ± Standard Deviation of triplicate biological determinations. Statistical significance was evaluated using an independent samples Student's t-test to compare the two drying treatments (Air-drying vs. Sun-drying). The t-test was justified as the study compared two independent experimental groups under controlled conditions. All analyses were performed using SPSS version 25.0, with significance set at $p < 0.05$.

RESULTS

The nutritional and anti-nutritional profiles of sweet potato flour as influenced by drying methods are presented in the tables below. Statistical analysis revealed that the drying method significantly affected ($p < 0.05$) almost all parameters evaluated, except for certain mineral and phytochemical traces.

4.1 Proximate Composition

The proximate composition of air-dried and sun-dried sweet potato flour is presented in Table 1 and Figure 2. Air-dried samples recorded higher values for crude protein (4.82 ± 0.14%), ash (2.45 ± 0.05%), crude fiber (3.12 ± 0.05%), and crude lipid (1.25 ± 0.02%) than sun-dried samples. Sun-dried samples showed lower moisture content (7.45 ± 0.08%) and higher total carbohydrate content (82.77 ± 0.50%) relative to air-dried samples.

Table 1: Proximate Composition of Air-Dried and Sun-Dried Sweet Potato Flour (%).

Parameters (%)	Air-Dried (Shed)	Sun-Dried
Moisture	9.15±0.12^a	7.45±0.08^b
Ash	2.45±0.05^a	2.10±0.03^b
Crude Protein	4.82±0.14^a	3.95±0.10^b
Crude Lipid	1.25±0.02^a	0.88±0.01^b
Crude Fibre	3.12±0.05^a	2.85±0.04^b
Total Carbohydrate	79.21±0.45^b	82.77±0.50^a

Results are means of duplicate determinations. Values on the same rows with the same super subscripts do not differ significantly at P<0.05.

Table 2. Vitamin and Mineral Composition of Sweet Potato Flour (mg/100 g).

Parameters	Air-Dried (Shed)	Sun-Dried
Vitamin A (RE)	1.15±0.05^a	0.65±0.02^b
Vitamin C	14.20±0.30^a	8.50±0.15^b
Iron (Fe)	1.85±0.04a	1.60±0.03b
Zinc (Zn)	1.12±0.01^a	1.09±0.01^a
Calcium (Ca)	32.40±1.10^a	28.15±0.90^b

Results are mean±SD of duplicate determinations. Values on the same rows with the same super subscripts do not differ significantly at P<0.05.

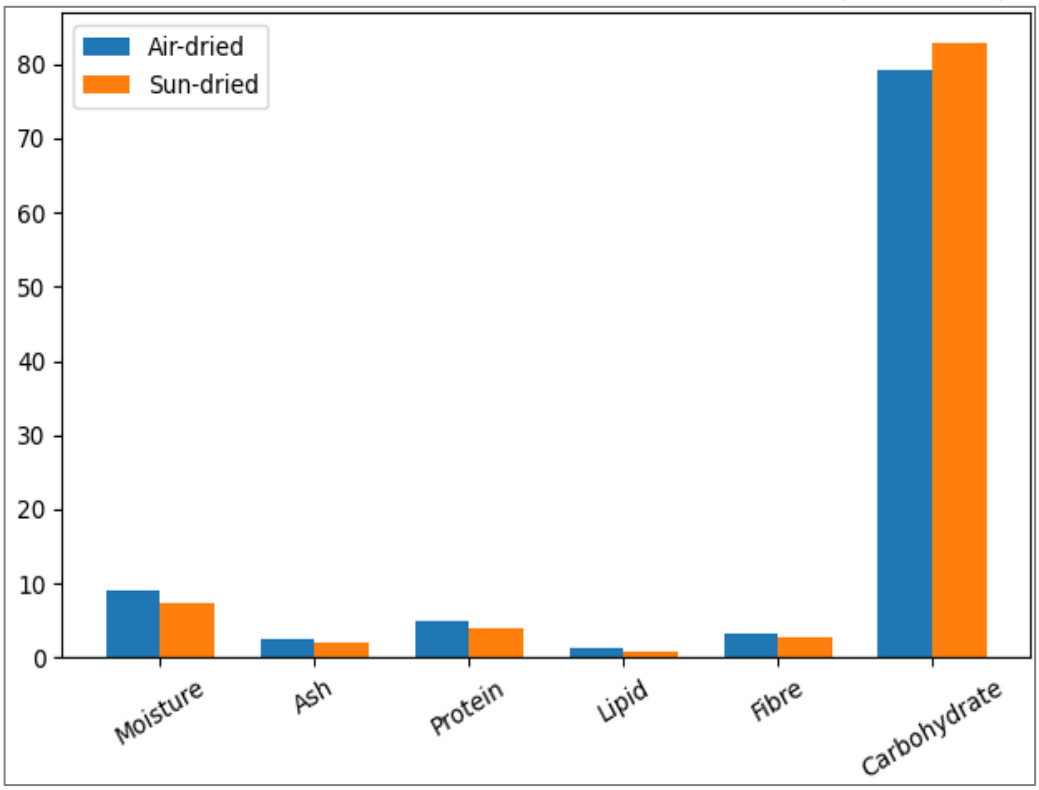

Figure 2: Proximate Comparison for Air-Dried and Sun-Dried Sweet Potatoes Flour (%).

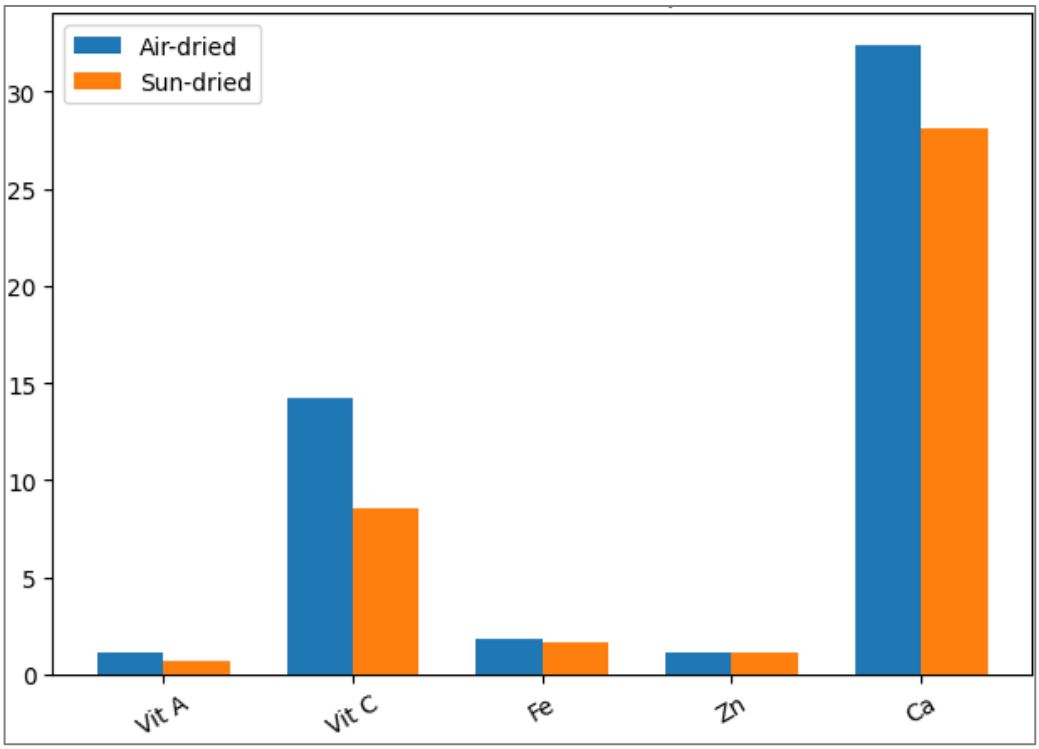

Figure 3: Vitamins and Mineral Comparison in Air-Dried (Shade) and Sun-Dried Sweet Potatoes flour (Mg/100g)

Table 3: Anti-nutritional Composition of Sweet Potato Flour (mg/100 g)

Phytochemical	Air-Dried (Shed)	Sun-Dried	Safe Limit
Oxalate	22.50±0.45[a]	18.30±0.30[b]	<250
Phytates	1.12±0.05[a]	0.95±0.03[b]	<20
Tannins	0.23±0.02[a]	0.19±0.01[a]	<10
Saponins	0.87±0.01[a]	0.07±0.01[b]	Negligible

Results are mean±SD of duplicate determinations. Values on the same rows with the same super subscripts do not differ significantly at P<0.05.

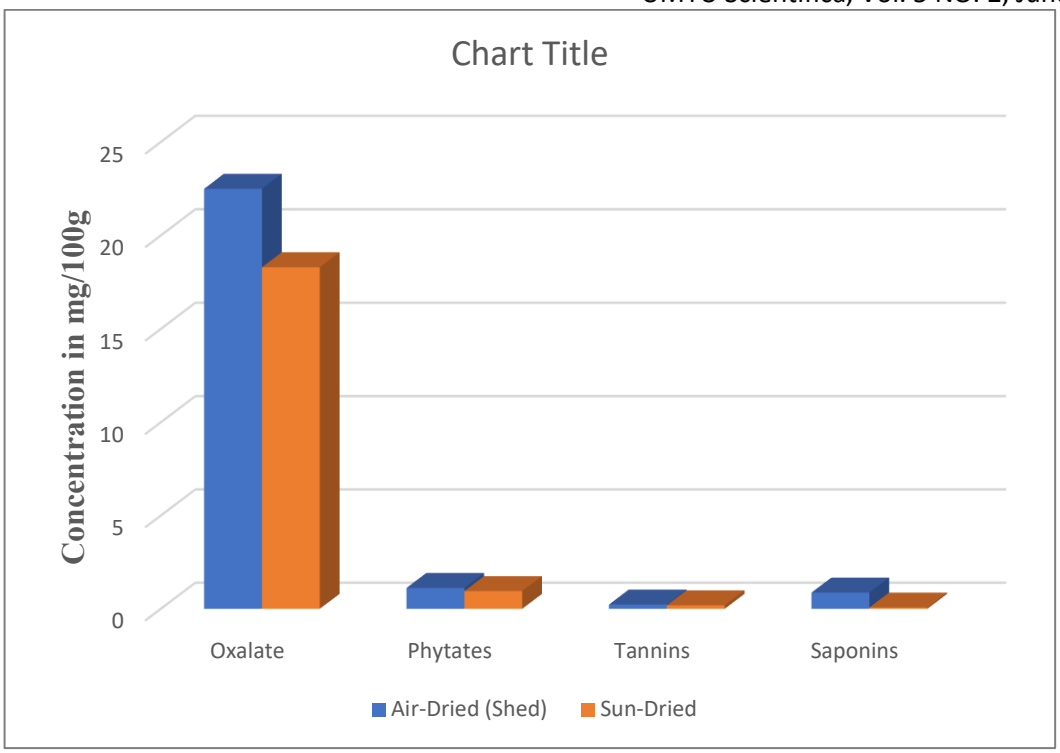

Figure 4:Anti-nutrient profile showing oxalate, phytate, tannin, and saponin levels by drying method.

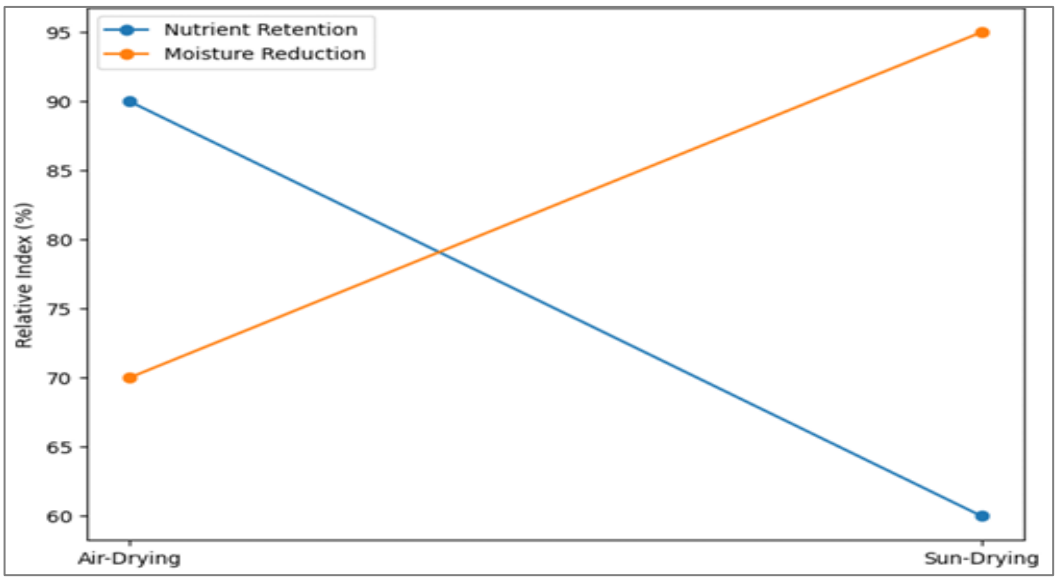

Figure 5: Nutrient Retention and Moisture Reduction Index on the overall processing effect

4.2 Vitamin and Mineral Composition

The vitamin and mineral composition is presented in Table 2 and Figure 3. Air-dried samples recorded higher concentrations of vitamin A (1.15 ± 0.05 mg/100 g), vitamin C (14.20 ± 0.30 mg/100 g), iron (1.85 ± 0.04 mg/100 g), and calcium (32.40 ± 1.10 mg/100 g) compared to sun-dried samples. Zinc levels were similar between the two drying methods.

4.3 Phytochemical and Anti-nutritional Factors

The anti-nutritional composition is shown in Table 3 and Figure 4. Sun-dried samples recorded lower values of oxalate (18.30 ± 0.30 mg/100 g), phytates (0.95 ± 0.03 mg/100 g), and saponins (0.07 ± 0.01 mg/100 g) compared to air-dried samples. Tannin levels were similar between the two drying methods.

The trade-off analysis of Figure 5 below revealed that air-drying retained a higher proportion of nutrients (~90%), whereas sun-drying achieved superior moisture reduction (~95%). This indicates that while sun-drying enhances shelf stability, it compromises nutritional quality.

Figure 6 below clearly shows that Air-drying retained the maximum nutrients (100%) but had lower shelf stability (81.4%). In contrast, sun-drying achieved ***the*** highest shelf stability (100%) but reduced nutrient retention (67.6%). This inverse relationship highlights a trade-off between nutritional quality and drying efficiency, indicating that method selection depends on whether nutrient preservation or storage stability is prioritized.

DISCUSSION

4.1 Proximate Composition and Moisture

The observed reduction in moisture content in sun-dried samples confirms the greater drying efficiency of direct solar radiation, which provides higher thermal energy for rapid water removal. Similar trends have been reported by Boni et al. (2018) and Badiora et al. (2023), who noted that sun-drying accelerates dehydration but may compromise nutrient integrity. While the lower moisture content (7.45%) enhances shelf stability and reduces microbial susceptibility, it also concentrates macronutrients, such as carbohydrates, which explains the higher values observed in sun-dried flour.

However, the higher retention of crude protein, ash, and fiber in air-dried samples suggests that milder drying conditions help preserve structural and heat-sensitive components. This aligns with Kolawole et al. (2016), who reported reduced protein denaturation under controlled drying conditions. These findings highlight a clear processing trade-off: sun-drying optimizes shelf-life through moisture reduction, whereas air-drying better preserves nutritional quality.

4.2 Vitamin Retention and Mechanisms of Degradation

The significantly higher retention of vitamin C and provitamin A in air-dried samples is consistent with established degradation pathways of thermolabile and photosensitive compounds. Vitamin C losses in sun-dried samples can be attributed to combined thermal degradation and photo-oxidation, as previously demonstrated by Gyamfi et al. (2016). Likewise, the reduction in vitamin A content reflects the susceptibility of β-carotene to ultraviolet-induced isomerization and oxidative cleavage (Bechoff et al., 2010).

Importantly, the magnitude of vitamin loss observed in this study is comparable to earlier reports in sweet potato processing, where sun-drying caused substantial carotenoid degradation compared with controlled-drying methods (Bechoff et al., 2010; Kolawole et al., 2016). This supports the conclusion that light exposure, rather than temperature alone, is a critical driver of micronutrient loss.

Nevertheless, while air-drying offers superior micronutrient retention, its higher residual moisture content may limit storage stability in humid tropical environments. Therefore, its practical application must consider post-processing storage conditions or integration with improved drying technologies, such as solar dryers with UV shielding.

4.3 Mineral Content and Anti-nutritional Factors: Implications for Bioavailability

Although air-dried samples retained slightly higher mineral concentrations, the nutritional relevance of these differences depends on mineral bioavailability rather than total content. The reductions in oxalates and phytates observed in both treatments are primarily attributable to the blanching pre-treatment, which facilitates leaching of soluble anti-nutrients, as also reported by Amagloh et al. (2022).

While sun-drying showed marginally greater reductions in anti-nutritional factors, the absolute differences between treatments were relatively small. Given that all measured values were already far below established safety thresholds, the extent of reduction may not translate into a substantial improvement in mineral bioavailability under typical dietary conditions. This observation is consistent with Agubosi et al. (2022), who emphasized that modest reductions in phytate levels do not always result in biologically significant increases in mineral absorption.

Furthermore, it is important to note that some anti-nutritional compounds, particularly phenolics, may contribute beneficial antioxidant properties. Excessive degradation during high-temperature drying could therefore reduce potential health benefits, as suggested by Mohanraj and Sivasankar (2014). Thus, the goal of processing should not be complete elimination but rather optimization to safe and functional levels.

4.4 Practical Implications for Processing in Kaduna State

The findings of this study demonstrate that the intended use of the flour should guide the choice of drying method. Air-drying is preferable when the objective is to maximize micronutrient retention, particularly vitamins A and C, which are critical for addressing deficiencies in vulnerable populations. In contrast, sun-drying offers advantages in terms of moisture reduction, shelf stability, and processing speed, making it more suitable for large-scale or resource-limited settings.

A balanced approach may involve adopting improved drying systems, such as indirect or solar dryers, which can reduce drying time while minimizing nutrient losses. Such technologies could help reconcile the trade-off between nutrient preservation and storage stability identified in this study.

CONCLUSION

This study confirms that while both methods achieve safe moisture levels, air-drying is significantly superior for preserving heat-sensitive and photo-labile nutrients. Air-dried flour retained higher concentrations of Vitamin C, Vitamin A, and crude protein, avoiding the oxidative degradation caused by direct UV exposure in sun-drying. Additionally, blanching effectively reduced oxalates and phytates, enhancing mineral bioavailability. Although not a total mineral source, the flour provides a nutrient-dense, safe energy base. For Nigerian smallholders, controlled air-drying is recommended to combat micronutrient deficiencies. Future adoption of UV-shielded solar dryers could optimize drying speed without compromising nutritional quality.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest related to this work.

AUTHOR CONTRIBUTIONS

In accordance with international standards for authorship, the individual contributions of the authors are outlined below:

Joshua Zamani Pius: Conceptualization, Methodology, Supervision, and Writing – Original Draft.

Aminu, A.M. & Rhoda Dallatu Yakubu: Investigation, Data Curation, and Laboratory Analysis.

Buzu Sim Blessing & Turaki, Maryam Ibrahim: Validation, Formal Analysis, and Software (SPSS).

Kabir Sani & Jamila, I. Abbas: Project Administration and Sample Collection.

Beatrice Hosea Ali & Ishaq Shehu: Writing – Review & Editing, and Literature Search.

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