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# Effect of drying methods, pretreatment and storage conditions on nutritional quality and consumer acceptability of cocoyam leaves (*Xanthosoma sagittifolium*)

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Cocoyam leaves (*Xanthosoma sagittifolium*) are an underutilized, nutrient-rich traditional leafy vegetable commonly consumed in Ghana. However, their high moisture content leads to rapid spoilage, limiting year-round availability and market potential. This study evaluated the effects of two drying methods (solar and freeze drying), pretreatment (blanching), storage temperature (room: 32 °C and refrigeration: 6.7 °C) and storage duration (0 and 42 days) on the nutritional, bio-functional (antioxidant activity and total phenolic content), and sensory qualities of cocoyam leaves. Using a 2 × 2 × 2 × 2 factorial design, samples were assessed for proximate composition, mineral content, antioxidant activity, total phenolics, and consumer acceptability. The results obtained were affected primarily by interactions rather than single factors. The effects of drying on protein, carbohydrate, and antioxidant activity varied with blanching and storage conditions. Phenolic and calcium contents changed over storage time, and these changes were amplified by the specific combination of drying and pretreatment and by storage temperature. Pretreatment and storage also acted jointly on fiber and zinc. Overall, the combined choice of processing steps was more influential than any individual factor. Sensory evaluation revealed no significant differences ( $p > 0.05$ ) in color, aroma, texture, or overall acceptability across treatments. These results demonstrate that appropriate drying and storage techniques can extend shelf life and preserve the nutritional and functional properties of cocoyam leaves, supporting their integration into value-added food systems and improving food and nutrition security in Ghana.

## KEYWORDS

blanching, cocoyam leaves, drying techniques, indigenous vegetables, neglected and underutilized species, solar drying, freeze-drying

## 1 Introduction

Neglected and underutilized or indigenous vegetables form an integral part of local diets across many African communities and are often linked to traditional knowledge, culture, nutrition and food security. However, these nutrient-rich vegetables are increasingly being replaced with less nutritious, commercially popular alternatives which has led to a decline in dietary diversity and a corresponding rise in nutrition-related health issues such as micronutrient deficiencies, obesity, and non-communicable diseases (Atuna et al., 2022;

Mungofa et al., 2022). Cocoyam (*Colocasia esculenta*), is an underutilized crop that is valued for its edible corms and leaves. The leaves, locally known as “kontomire,” are used in many Ghanaian dishes such as soups and stews (Temesgen et al., 2016). They are reported to be an excellent source of essential nutrients, including dietary fiber, and vital micronutrients such as vitamins A and C, calcium, iron, and potassium. Their antioxidant properties are also noted to make them suitable for people with health conditions such as diabetes and obesity (Mungofa et al., 2022). Despite their nutritional value, cocoyam leaves are highly perishable, primarily due to their high moisture content (Gerrano et al., 2021). Once harvested, the leaves quickly deteriorate, turning from green to yellow color and lose their visual appeal. This rapid spoilage presents a significant barrier to their availability and utilization, especially during the dry season when fresh leaves are scarce. During the rainy season however, there is an abundance of the corm and its leaves, resulting in high postharvest loss (PHL) due to poor postharvest management practices such as harvesting at sub-optimal maturity or under high field temperatures; delayed shade and precooling; rough handling that leads to bruising; exposure to sun or rain during loading/transport; lack of temperature/RH control and cold chain (Kitinoja and Kader, 2015; Essilfie et al., 2025). To address this, various preservation methods have been employed. In informal value chains, produce is often sprinkled with water and packed in jute sacks to ‘keep fresh’. However, direct wetting combined with low-ventilation packaging increases surface moisture retention, mechanical injury, and microbial decay, and is therefore considered a poor postharvest practice, not a recommended solution. This, affects consumer acceptability and resulting in high postharvest losses (Kitinoja and Kader, 2015).

One of the most effective approaches to reducing PHL in leafy vegetables like cocoyam leaves is dehydration. Dehydration methods such as solar and freeze drying reduce the moisture content of food thereby preventing microbial growth and enzymatic activity. Solar drying, utilizes sunlight to remove moisture from agricultural produce and this method has gained attention due to its affordability, energy efficiency, and environmental sustainability (Udomkun et al., 2020). Freeze drying, on the other hand, is a more advanced method that involves freezing the product and then reducing the surrounding pressure to allow the frozen water in the material to sublimate. This method is especially suitable for high-value crops and sensitive vegetables because it retains the original structure, color, flavor, and nutritional profile of the food. Freeze-dried products also exhibit superior rehydration capacity and shelf life, making this method ideal for producing premium quality food ingredients (Huang, 2022). According to Deng et al. (2017), subjecting vegetables to pretreatment processes such as blanching or chemical dipping is essential for enzyme inactivation, microbial load reduction, color preservation, and shortening of drying time, although pretreatment may affect physicochemical and sensory properties of the final product. Nevertheless, evidence remains limited for traditional leafy vegetables such as cocoyam leaves, standardized pretreatment conditions are lacking, and few studies report post-drying storage indices alongside biofunctional outcomes (phenolics/antioxidant activity) or end-use performance (acceptability).

Although, some studies have examined the nutritional potential cocoyam of leaves, investigations into their postharvest preservation, physicochemical changes, and sensory characteristics, particularly in the context of Ghana are sparse (Akonor and Amankwah, 2012;

Temesgen et al., 2016; Ukom et al., 2020). Furthermore, there is a need to explore value addition opportunities, such as developing dried or powdered forms of cocoyam leaves, which can be used in food fortification or as seasoning and convenience food ingredient. This study, therefore, sought to fill a knowledge gap by evaluating different postharvest preservation technologies that can enhance the shelf life and quality of cocoyam leaves. Specifically, the study assessed the effects of solar and freeze drying, with and without pre-treatment, on the nutritional, physicochemical, and sensory properties of the leaves. By identifying optimal preservation techniques, this research aims to improve year-round availability, reduce seasonal shortages, and promote increased consumption of cocoyam leaves.

## 2 Materials and methods

### 2.1 Source of materials used

Fresh cocoyam leaves were obtained from the “Agbobloshie” market in the Greater Accra region of Ghana. To limit farm-to-farm heterogeneity, we sourced from a single vendor across all lots. Only physiologically mature, undamaged leaves were included. Samples were transported in clean, ventilated containers and processed within 2 h of purchase.

### 2.2 Experimental design

A  $2 \times 2 \times 2 \times 2$  factorial experiment with two drying methods, two pre-treatments, two storage temperatures (refrigeration: 6.7 °C and room temperature range: 30.5–32 °C) and two storage days (0, 42) was conducted. This design yielded 16 treatment combinations, and therefore 16 data points per replicate (Table 1).

### 2.3 Sample production and preparation

Cocoyam leaves were washed, shredded, and divided into three portions. One portion was kept fresh and served as the control (C). The second portion received no pre-treatment (NT), while the third was steam-blanching (SB) at 100 °C for 2 min. Both the NT and SB samples were subsequently divided into two sub-portions: one was freeze-dried in a Harvest Right Freeze dryer, model: HRFDL for 12 h, and the other was solar-dried at  $56 \pm 3.3$  °C/ $36.1 \pm 3.06$  %RH for 12 h. The dried samples were then stored either under refrigeration conditions (6.7 °C, 73.2% RH) or at room temperature (27–32 °C, 62.3–77% RH) for a period of 42 days. The entire experiment was conducted in triplicate.

### 2.4 Determination of quality parameters

#### 2.4.1 Determination of the proximate composition of cocoyam leaf

The proximate composition of cocoyam leaves was determined using standard procedures outlined by the Association of Official Analytical Chemists (AOAC, 2005).

TABLE 1 Treatment combinations for drying, pre-treatment and storage conditions.

Drying methods	Pretreatment	Storage temp	Storage days
Fresh	No treatment	32 °C	0
Fresh	No treatment	32 °C	42
Fresh	No treatment	6.7 °C	0
Fresh	No treatment	6.7 °C	42
Fresh	Steam blanch	32 °C	0
Fresh	Steam blanch	32 °C	42
Fresh	Steam blanch	6.7 °C	0
Fresh	Steam blanch	6.7 °C	42
Freeze dry	No treatment	32 °C	0
Freeze dry	No treatment	32 °C	42
Freeze dry	No treatment	6.7 °C	0
Freeze dry	No treatment	6.7 °C	42
Freeze dry	Steam blanch	32 °C	0
Freeze dry	Steam blanch	32 °C	42
Freeze dry	Steam blanch	6.7 °C	0
Freeze dry	Steam blanch	6.7 °C	42
Solar dry	No treatment	32 °C	0
Solar dry	No treatment	32 °C	42
Solar dry	No treatment	6.7 °C	0
Solar dry	No treatment	6.7 °C	42
Solar dry	Steam blanch	32 °C	0
Solar dry	Steam blanch	32 °C	42
Solar dry	Steam blanch	6.7 °C	0
Solar dry	Steam blanch	6.7 °C	42

#### 2.4.1.1 Moisture content (AOAC 925.10)

Approximately 2.0 g of the sample was accurately weighed into a clean, dry crucible of known weight. The crucible and its contents were placed in a hot air oven and dried at  $105 \pm 2$  °C for 24 h to a constant weight. The crucible was transferred to a desiccator to cool for about 30 min after drying and reweighed.

Moisture content (%) was calculated using the formula:

$$\text{Moisture Content (\%)} = \left[ \frac{(W_1 - W_2)}{(W_1 - W_0)} \right] \times 100$$

Where:

$W_0$  = weight of empty crucible.

$W_1$  = weight of crucible + fresh sample.

$W_2$  = weight of crucible + dried sample.

#### 2.4.1.2 Crude fat (AOAC 922.06)

Approximately 2.0 g of the sample was accurately weighed into a pre-dried and labeled Whatman extraction thimble and sealed at the top with non-absorbent cotton wool. A clean, dry round-bottom flask

was weighed and filled with 150 mL of petroleum ether (boiling point 40–60 °C) as the extraction solvent. The thimble was placed in the Soxhlet extractor, and the extractor was connected to the flask and a reflux condenser. The entire assembly was placed on a heating mantle, and the extraction was carried out under reflux for 4 h. After extraction, the thimble was removed, and the petroleum ether was recovered by distillation. The round-bottom flask containing the extracted fat was dried in a hot air oven at  $60 \pm 2$  °C for 2 h to remove residual solvent. The flask was then cooled in a desiccator and reweighed.

The crude fat content was calculated as follows:

$$\text{Crude Fat (\%)} = \left[ \frac{(W_2 - W_1)}{W_s} \right] \times 100$$

Where:

$W_1$  = weight of empty flask

$W_2$  = weight of flask with extracted fat

$W_s$  = weight of sample

#### 2.4.1.3 Total ash (AOAC 923.03)

Ash content was measured using the dry ashing method. Two (2) grams of shredded cocoyam leaves was weighed and spread evenly into a crucible and incinerated in a muffle furnace for 4–6 h at a constant temperature of 550 °C until a light gray ash was obtained, indicating the removal of all organic matter. It was then cooled in a desiccator and weighed. Ash was calculated as follows:

$$\text{Total Ash (\%)} = \left[ \frac{(W_2 - W_1)}{W_s} \right] \times 100$$

Where:

$W_1$  = weight of empty crucible

$W_2$  = weight of crucible + ash

$W_s$  = weight of sample

#### 2.4.1.4 Crude fiber (AOAC 962.09)

Approximately 2.0 g of the defatted sample was boiled with sulfuric acid, followed by filtration and washing. The residue was then boiled with sodium hydroxide, again followed by filtration and thorough washing with distilled water to remove soluble materials.

The final residue was dried in an oven at 105 °C, cooled in a desiccator, and weighed. To correct for residual mineral content, the dried residue was incinerated in a muffle furnace at 550 °C until a white ash was obtained. After cooling, the ash was weighed.

Crude fiber content was calculated as the difference between the weight of the dried residue and the ash, expressed as a percentage of the original sample weight:

$$\text{Crude Fiber (\%)} = \left[ \frac{(W_1 - W_2)}{W_s} \right] \times 100$$

Where:

$W_1$  = weight of dried residue

$W_2$  = weight of ash

$W_s$  = weight of sample

#### 2.4.1.5 Carbohydrate content (by difference)

The carbohydrate content was estimated by difference in accordance with AOAC Official Methods. The percentage of carbohydrates was calculated using the following formula:

$$\% \text{Carbohydrate} = 100 - [\text{Moisture} (\%) + \text{Crude Protein} (\%) + \text{Crude Fat} (\%) + \text{Ash} (\%) + \text{Crude Fiber} (\%)]$$

#### 2.4.1.6 Protein content (AOAC 920.87)

Approximately 2.0 g of sample was weighed into a Kjeldahl digestion flask. Concentrated H<sub>2</sub>SO<sub>4</sub> (25 mL) and a selenium catalyst tablet were added, and the mixture was digested on a block heater until a clear, colorless solution indicated complete digestion. The digest was cooled, quantitatively transferred to a 100 mL volumetric flask, and made up to volume with distilled water.

For distillation, 25 mL of 4% boric acid containing two drops of mixed indicator (methyl red/bromocresol green) was placed in a 250 mL conical flask, and the condenser tip was immersed below the liquid surface. The distillation unit was pre-flushed with boiling distilled water and the steam trap emptied. An aliquot (10 mL) of the digest was introduced into the distillation apparatus, followed by 15 mL of 40% NaOH to liberate ammonia, which was steam-distilled into the boric acid receiver (turning bluish-green on contact).

After 5 min of distillation, the receiver was removed and titrated with 0.1 N HCl to a faint pink endpoint. All determinations were performed in triplicate, with a reagent blank run for correction. Nitrogen content was calculated from the titration, and crude protein was obtained using the factor 6.25:

$$\text{Crude protein} (\%) = \text{Nitrogen} (\%) \times 6.25$$

### 2.4.2 Determination of mineral composition of cocoyam leave

The mineral composition of the dried cocoyam leaves [phosphorus (P), calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn)] was determined using the dry ash extraction method as described by the Association of Official Analytical Chemists (AOAC, 2005).

#### 2.4.2.1 Sample ashing and extraction

Approximately 2 g of each dried and finely ground sample was placed in a clean, pre-weighed porcelain crucible and incinerated in a muffle furnace at 550 °C for 5 h until a white or light gray ash was obtained. After cooling, the ash was dissolved in 5 mL of 1 N nitric acid, filtered, and made up to a known volume with distilled water for analysis.

#### 2.4.2.2 Phosphorus (AOAC 965.17)

Phosphorus content was determined by vanadomolybdate yellow colorimetric spectrophotometry. An aliquot of the digested sample solution was treated with ammonium vanadate and ammonium molybdate reagent, forming a yellow complex. Absorbance was measured using a Jenway electronic spectrophotometer at 420 nm. The concentration of phosphorus was quantified using a standard calibration curve of known phosphate concentrations prepared from monopotassium dihydrogen phosphate (KH<sub>2</sub>PO<sub>4</sub>).

#### 2.4.2.3 Calcium and magnesium (AOAC 984.27)

Calcium and magnesium were determined simultaneously by the complexometric ethylenediaminetetraacetic acid (EDTA) titrimetric method, following AOAC (2005) procedures. For calcium, titration was carried out in the presence of murexide indicator at pH 12, while for magnesium, eriochrome black T was used as an indicator at pH 10 after prior removal of calcium by precipitation or masking by adding ammonium oxalate to the digested solution. The endpoint was indicated by a distinct color change, and mineral concentrations were calculated based on the volume of EDTA used.

#### 2.4.2.4 Zinc (AOAC 984.27)

Zinc content was determined according to the AOAC (2005) protocol. The prepared digest was analyzed using atomic absorption spectrophotometry (AAS) at the zinc-specific wavelength (typically 213.9 nm), after calibration with zinc standards prepared from zinc sulfate heptahydrate (ZnSO<sub>4</sub>·7H<sub>2</sub>O).

#### 2.4.2.5 Iron

Iron content was measured using the method described by Achikanu et al. (2013). The ash solution was treated with a reducing agent and complexed with 1,10-phenanthroline to form a reddish-orange ferrous complex. Absorbance was measured spectrophotometrically at 510 nm, and iron concentration was calculated using a standard curve prepared from known concentrations of ferrous ammonium sulfate hexahydrate.

### 2.4.3 Total phenolic content (bio-functional)

In this study, functional properties denote biofunctional indices (antioxidant activity and total phenolic content).

The total phenolic content (TPC) of cocoyam leaves was determined using the Folin–Ciocalteu method, as described by Odabasoglu et al. (2004) with slight modifications. For the assay, 100 µL of each gallic acid standard or sample extract was mixed with 500 µL of distilled water and 100 µL of Folin–Ciocalteu reagent. The reaction mixture was allowed to stand for 6 min at room temperature. Then, 500 µL of distilled water and 1 mL of 7% sodium carbonate solution were added. After incubation for 90 min, the absorbance was measured at 760 nm using a spectrophotometer.

The total phenolic content was calculated and expressed as milligrams of gallic acid equivalents per gram of extract (mg GAE/g) using the formula:

$$\text{TPC} (\text{mg GAE} / \text{g}) = (X \times V) / M$$

Where:

X = Concentration of phenolics determined from the calibration curve (mg/ml).

V = Volume of extract used in the assay (ml).

M = Mass of extract used (g).

### 2.4.4 Determination of antioxidant activity

The total antioxidant activity of the cocoyam leaf samples was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assay, following the method described by Brand-Williams et al. (1995) with slight modifications. Oxidized DPPH,

when dissolved in methanol, yields a deep purple hue that becomes discolored upon reduction by antioxidant compounds. To prepare the sample extract, 2.5 g of cocoyam leaves was homogenized in 50 mL of methanol and filtered using Whatman No. 42 filter paper to obtain a clear extract.

A 0.002% DPPH solution in methanol was prepared, and its absorbance was measured at 515 nm using a spectrophotometer (Model: TR 515, The Tintometer Limited, UK). For the antioxidant activity test, 3 mL of the DPPH solution was mixed with the sample extract and allowed to react in the dark for 15 min. The absorbance of the reaction mixture was then recorded at 515 nm.

The percentage inhibition of DPPH radicals by the sample was calculated using the following formula:

$$\text{Inhibition (\%)} = \left[ \frac{(A - B)}{A} \right] \times 100$$

Where:

A = Absorbance of the DPPH solution without sample (control)

B = Absorbance of the DPPH solution after reaction with the sample extract

## 2.5 Sensory analysis

### 2.5.1 Sauce preparation

Approximately 50 g of cocoyam leaves were immersed in boiling water for 2 min and subsequently steamed for 5 min. Separately, 30 mL of palm oil and 20 g each of chopped tomato and onion were sautéed with salt to taste for 5 min to prepare the base sauce. The steamed cocoyam leaves were then incorporated into the sauce and simmered for an additional 10 min. Prepared samples were served in randomly coded disposable plates, each accompanied by a spoon for tasting. Participants received a sensory evaluation questionnaire and were seated individually in sensory booths to complete the assessment.

### 2.5.2 Sauce administration

Sensory evaluation was conducted to assess consumer acceptability of cocoyam leaves incorporated into a traditional sauce. The leaves were prepared as in 2.5.1 to ensure uniformity across all samples. A total of nine treatment samples, including variations in drying methods and pre-treatment conditions, were evaluated. Eighteen untrained panelists participated in the assessment, each evaluating a subset of the samples based on a balanced incomplete block design (BIBD), which was employed to minimize fatigue and bias while ensuring adequate representation and comparison across all treatments.

Sensory attributes evaluated included color, aroma, texture, and overall acceptability. A 5-point hedonic scale was used, where 1 = dislike extremely, 2 = dislike slightly, 3 = neither like nor dislike, 4 = like slightly, and 5 = like extremely. Evaluations were carried out under controlled conditions to limit external influences such as lighting, odors, and noise. Data collected were subjected to ANOVA and *post hoc* tests to determine significant differences among treatment means.

## 2.6 Statistical analysis

All analyses were performed in triplicate. The effects of drying method, pretreatment, storage temperature, and storage duration, as well as their two- and three-way interactions on the proximate composition, antioxidant properties, and mineral content of cocoyam leaves, were evaluated using Analysis of Variance (ANOVA). ANOVA was conducted on the original (wet basis or “as-is”) data to retain the original error structure and variability assumptions inherent in the experimental design.

The GLM (General Linear Model) procedure using SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA) was used to analyze the factorial structure of the experimental design, following the model:

$$Y_{ijkl} = \mu + A_i + B_j + C_k + D_l + (AB)_{ij} + (AC)_{ik} + (AD)_{il} + (BC)_{jk} + (BD)_{jl} + (CD)_{kl} + (ABC)_{ijk} + (ABD)_{ijl} + (ACD)_{ikl} + (BCD)_{jkl} + \varepsilon_{ijkl}$$

Where:

- $Y_{ijkl}$  is the observed response
- $\mu$  is the overall mean
- A, B, C, and D represent the fixed effects of drying method, pretreatment, storage temperature, and storage duration, respectively
- The interaction terms denote their respective factorial interactions, and
- $\varepsilon_{ijkl}$  is the residual error

Significance was accepted at  $p < 0.05$ . The Type III sum of squares was used to test for significance of main and interaction effects. The coefficient of determination ( $R^2$ ), coefficient of variation (CV), and root mean square error (RMSE) were used to evaluate the goodness of fit and model reliability.

When significant effects were observed, means were compared using Tukey’s Honestly Significant Difference (HSD) test for pairwise comparisons to determine differences among treatment combinations.

## 3 Results

### 3.1 Proximate composition

The effects of drying method, pretreatment, storage temperature, and storage duration on the proximate composition of blanched and unblanched and fresh and dried cocoyam leaves are shown in Tables 2, 3 provides the summary of the statistical analyses.

#### 3.1.1 Ash

Ash content in the cocoyam leaves studied ranged from  $0.35 \pm 0.10\%$  to  $16.16 \pm 0.25\%$  (Table 2). Fresh leaves had intermediate ash contents, between 1.48–1.50%. At day 0, the highest ash values were recorded in freeze-dried, steam-blanched samples stored at both temperatures ( $16.16 \pm 0.25\%$ ), whereas unblanched solar-dried leaves showed the lowest ash contents ( $1.49 \pm 0.28\%$ ) also at both storage temperatures. After 42 days, ash declined to  $0.40 \pm 0.12\%$  in

TABLE 2 Effect of drying method, blanching, storage temperature and duration on the proximate composition of cocoyam leaves.

Drying method	Pre-treatment	Storage temp (°C)	Storage days	Ash (g/100 g)	Fat (g/100 g)	Fiber (g/100 g)	Carbo hydrate (g/100 g)	Protein (g/100 g)	Moisture (g/100 g)	
Fresh	No treatment	32	0	1.50 f ± 0.35	2.57 a ± 0.47	0.76 a ± 0.05	11.40 a ± 1.43	2.09 a ± 0.06	81.68 a ± 0.79	
		6.7	0	1.50 f ± 0.35	2.57 a ± 0.47	0.76 a ± 0.05	11.40 a ± 1.43	2.09 a ± 0.06	81.68 a ± 0.79	
	Steam blanch	32	0	1.48 f ± 0.29	2.69 ab ± 0.14	1.26 a ± 0.03	6.52 b ± 1.47	1.60 a ± 0.46	86.45 b ± 0.84	
		6.7	0	1.48 f ± 0.29	2.69 ab ± 0.14	1.26 a ± 0.03	6.52 b ± 1.47	1.60 a ± 0.46	86.45 b ± 0.84	
Freeze dry	No treatment	32	0	14.11 b ± 0.80	3.04 abc ± 1.00	14.62 b ± 0.38	47.88 f ± 1.84	12.86 b ± 0.15	7.49 f ± 0.61	
		32	42	12.83 c ± 0.37	2.42 d ± 0.07	17.45 c ± 0.45	32.72 e ± 1.10	21.17 c ± 0.16	13.41 d ± 0.49	
	No treatment	6.7	0	14.11 b ± 0.80	3.04 abc ± 1.00	14.62 b ± 0.38	47.88 f ± 1.84	12.86 b ± 0.15	7.49 f ± 0.61	
		6.7	42	13.41 c ± 0.39	4.30 e ± 0.42	14.91 b ± 0.93	30.22 d ± 0.27	25.32 d ± 0.14	11.84 e ± 0.22	
		Steam blanch	32	0	16.16 a ± 0.25	2.88 bc ± 0.17	21.56 d ± 0.11	26.98 c ± 0.85	23.48 d ± 0.47	8.95 e ± 0.68
			32	42	12.55 c ± 0.41	3.50 de ± 0.28	14.64 b ± 0.82	30.87 d ± 1.52	25.16 d ± 0.82	13.29 d ± 0.17
Steam blanch	6.7	0	16.16 a ± 0.25	2.88 bc ± 0.17	21.56 d ± 0.11	26.77 c ± 0.53	23.48 d ± 0.47	9.16 e ± 0.38		
	6.7	42	13.00 c ± 0.17	4.38 e ± 0.31	15.10 b ± 0.71	38.07 e ± 1.50	18.83 e ± 0.17	10.61 e ± 0.66		
Solar dry	No treatment	32	0	1.49 f ± 0.28	1.85 f ± 0.08	14.41 b ± 0.60	37.74 e ± 0.89	36.73 f ± 0.53	7.79 f ± 0.11	
		32	42	0.35 g ± 0.10	1.22 g ± 0.20	16.60 c ± 0.19	44.63 f ± 0.56	24.10 d ± 0.13	13.11 d ± 0.70	
	No treatment	6.7	0	1.49 f ± 0.28	1.85 f ± 0.08	14.41 b ± 0.60	37.74 e ± 0.89	36.73 f ± 0.53	7.79 f ± 0.11	
		6.7	42	4.91 e ± 0.55	1.16 g ± 0.22	17.28 c ± 0.25	45.72 f ± 1.21	17.61 e ± 0.07	13.32 d ± 0.84	
		Steam blanch	32	0	13.63 c ± 0.61	3.93 e ± 0.66	17.04 c ± 0.27	36.29 e ± 0.64	19.87 e ± 0.14	9.25 e ± 0.99
			32	42	4.61 e ± 0.42	2.57 a ± 0.28	18.69 d ± 1.18	38.02 e ± 0.42	23.70 d ± 0.64	12.40 d ± 1.16
Steam blanch	6.7	0	13.63 c ± 0.61	3.93 e ± 0.66	17.04 c ± 0.27	36.29 e ± 0.64	19.87 e ± 0.14	9.25 e ± 0.99		
	6.7	42	4.08 e ± 0.44	2.29 cd ± 0.06	18.59 d ± 1.12	42.12 f ± 1.04	22.53 d ± 0.42	10.39 e ± 0.25		

Values are reported as mean ± standard deviation (n = 3) on as is basis. Means with the same letter in the same column are not significantly different at α = 0.05.

TABLE 3 Analysis of variance table showing the interaction effects of drying method, pretreatment, storage temperature, and storage duration on the proximate composition of cocoyam leaves.

Source	F-values					
	Ash	Moisture	Fat	Fiber	Carbohydrates	Protein
Drying method × Pretreatment	21.12*	2943.21*	7.22*	228.87*	1799.96*	85112.8*
Storage temperature	99.34*	1559.26*	18.78*	4.06	29.03*	7591.90*
Drying method × Storage Temperature	33.95*	1781.62*	22.14*	2.72	0.76	3234.09*
Pretreatment × Storage temperature	89.15*	1800.21	1.79	5.22*	71.78*	2346.47*
Drying method × Pretreatment × Storage temperature	60.54*	2256.04*	1.01	25.04*	283.05*	11739.4*
Storage days	1466.17*	3991.31*	34.89*	421.90*	1861.74*	241388*
Drying method × Storage days	1512.74*	7628.52*	39.16*	161.63*	7326.37*	115322*
Pretreatment × Storage days	9.90*	4860.52*	8.95*	117.57*	1698.63*	207659*
Drying method × Pretreatment × Storage days	50.95*	5502.71*	0.28	845.11*	3427.16*	54579.4*
Mean	8.53	16.48	2.84	16.59	43.91	12.31
Model R-squared	0.9974	0.9993	0.9057	0.9941	0.9994	0.999988
Model CV	3.6406	3.4474	14.6935	4.1039	1.4341	0.363338
RMSE	0.3107	0.5685	0.4175	0.6807	0.6298	0.044741

Asterisk (\*) indicates significance at P < 0.05.

solar-dried, unblanched samples stored at 32 °C, but remained relatively high in unblanched freeze-dried leaves stored at 6.7 °C ( $13.41 \pm 0.39$ ).

Ash content was significantly affected by process and storage interactions (Table 3). Significant interactions were observed between drying method and pretreatment ( $F = 85.11$ ), pre-treatment and storage temperature ( $F = 6.63$ ), and the three-way interaction among drying method, pretreatment, and storage temperature ( $F = 60.54$ ). The influence of drying method and storage days interaction was also substantial ( $F = 1512.74$ ), and this therefore suggests that ash retention is highly sensitive to both processing and storage conditions.

### 3.1.2 Fat

Fat content was the lowest of all the proximate analysis of cocoyam leaves. The values obtained ranged from  $1.16 \pm 0.22\%$  to  $4.38 \pm 0.31\%$  (Table 2). The values for the fresh leaves were between 2.57–2.69% while the dried products at day 0, recorded fat values of  $1.85 \pm 0.08\%$  in solar-dried (no pretreatment) and 2.88–3.93% in the steam-blanch samples. After 42 days of storage, unblanched solar-dried leaves stored at 6.7 °C had the lowest values ( $1.16 \pm 0.22\%$ ), and the highest was observed in steam-blanch freeze-dried leaves that were stored at 6.7 °C ( $4.38 \pm 0.31\%$ ).

For the fat content, although pretreatment alone was not significant ( $F = 0.61$ ,  $p > 0.05$ ), its interaction with drying method ( $F = 7.22$ ) and storage days ( $F = 8.95$ ) was statistically significant. It is worth noting

though that, the interaction of drying method and storage days yielded the highest influence ( $F = 39.16$ ) (Table 3). This observation suggests that the fat content in cocoyam leaves is sensitive to processing conditions and potential degradation over time.

### 3.1.3 Fiber

From Table 2, it is observed that the fiber content in the cocoyam leaves was between  $0.76 \pm 0.05\%$  to  $21.56 \pm 0.11\%$ . Unblanched fresh leaves recorded lower values compared to the blanched samples (unblanched  $0.76 \pm 0.05\%$ ; steam-blanch  $1.26 \pm 0.03\%$ ). Drying markedly increased fiber concentration in all processed samples, consistent with the removal of moisture and concentration of structural carbohydrates. At day 0, the highest fiber contents were observed in freeze-dried, steam-blanch leaves, with  $21.56 \pm 0.11\%$  at both storage temperature. Steam-blanch solar-dried leaves also showed elevated fiber contents ( $15.63$ – $18.78\%$ ) compared with fresh leaves. Over 42 days of storage, fiber generally increased in solar-dried leaves, reaching  $16.60$ – $17.28\%$  at 32 °C and  $18.59$ – $18.69\%$  at 6.7 °C. For unblanched freeze-dried samples, the value increased up to  $20.15 \pm 0.53\%$  when samples were stored at 32 °C. In contrast, fiber decreased from the initial maximum values in freeze-dried, steam-blanch leaves to around  $14.64$ – $15.10\%$  after 42 days.

The results also show that fiber content was significantly influenced by interactions such as pretreatment and storage days ( $F = 117.57$ ) and the full interaction among drying method, pretreatment, and storage days ( $F = 845.11$ ). This indicates that the

TABLE 4 Effect of drying method, blanching, storage temperature and duration on the antioxidant activity and phenolic content of cocoyam leaves.

Drying methods	Pretreatment	Storage temp (°C)	Storage days (days)	Antioxidant activity (%)	Total Phenolic content (mg/100 g)
Fresh	No treatment	32	0	46.97 a $\pm$ 1.78	219.14 b $\pm$ 1.44
		6.7	0	46.97 a $\pm$ 1.78	219.14 b $\pm$ 1.44
	Steam blanch	32	0	59.80 b $\pm$ 1.33	221.74 a $\pm$ 2.33
		6.7	0	59.80 b $\pm$ 1.33	221.74 a $\pm$ 2.33
Freeze dry	No treatment	32	0	83.64 f $\pm$ 1.09	199.98 d $\pm$ 3.87
		32	42	68.41 d $\pm$ 3.65	80.69 f $\pm$ 2.54
	No treatment	6.7	0	83.64 f $\pm$ 1.09	199.98 d $\pm$ 3.87
		6.7	42	71.52 d $\pm$ 0.41	81.96 f $\pm$ 2.59
Freeze dry	Steam blanch	32	0	84.74 f $\pm$ 3.17	203.88 d $\pm$ 1.17
		32	42	69.02 d $\pm$ 0.89	81.10 f $\pm$ 1.67
	Steam blanch	6.7	0	84.74 f $\pm$ 3.17	203.88 d $\pm$ 1.17
		6.7	42	71.91 d $\pm$ 1.14	81.77 f $\pm$ 0.52
Solar dry	No treatment	32	0	52.01 a $\pm$ 1.75	204.33 c $\pm$ 1.39
		32	42	90.11 g $\pm$ 2.46	101.01 e $\pm$ 1.34
	No treatment	6.7	0	52.01 a $\pm$ 1.75	204.33 c $\pm$ 1.39
		6.7	42	89.42 g $\pm$ 2.37	103.86 e $\pm$ 0.82
Solar dry	Steam blanch	32	0	59.59 b $\pm$ 0.72	204.60 c $\pm$ 1.66
		32	42	77.77 e $\pm$ 2.70	82.03 e $\pm$ 1.22
	Steam blanch	6.7	0	59.59 b $\pm$ 0.72	204.60 c $\pm$ 1.66
		6.7	42	81.34 f $\pm$ 0.98	91.79 e $\pm$ 0.60

Values are reported as mean  $\pm$  standard deviation ( $n = 3$ ) on as is basis. Means with the same letter in the same column are not significantly different at  $\alpha = 0.05$ .

TABLE 5 Analysis of variance table for the effects of drying method, pretreatment, storage temperature, and storage duration on antioxidant activity and total phenolic content of cocoyam leaves.

Source	F-values	
	Antioxidant activity	Total phenolic content
Drying method × Pretreatment	48.96*	4.42*
Drying method × Storage temperature	37.27*	5.88*
Pretreatment × Storage temperature	7.43*	2.29
Drying method × Pretreatment × Storage temperature	10.23*	0.38
Drying method × Storage days	12934.4*	5298.45*
Pretreatment × Storage days	79.26*	0.37
Drying method × Pretreatment × Storage days	80.32*	2.86
Mean	25.33	100.84
Model R-squared	0.9997	0.9998
Model CV	3.3468	1.1106
RMSE	0.8478	1.1198

Asterisk (\*) indicates significance at  $P < 0.05$ .

integrity of the fiber in cocoyam leaves is influenced by multiple postharvest processing factors.

### 3.1.4 Carbohydrates

From Table 2, total carbohydrate content on as is basis ranged from  $6.52 \pm 1.47\%$  to  $47.88 \pm 1.84\%$ . In the fresh samples, values were lower for both blanched and unblanched samples at  $11.40 \pm 1.43\%$  (unblanched) and  $6.52 \pm 1.47\%$  (steam-blanched). Drying shifted the carbohydrate distribution among treatments. At day 0, the highest carbohydrate values were found in the unblanched freeze-dried samples ( $47.88 \pm 1.84\%$ ) while after 42 days, the dried products had carbohydrate contents ranging from  $30.22 \pm 0.27\%$  to  $45.72 \pm 1.21\%$ , with solar-dried samples having higher values.

Carbohydrate levels were highly responsive to interaction effects, with the drying method and storage days interaction producing the highest  $F$ -value ( $F = 7326.37$ ). This suggests that carbohydrate retention is particularly susceptible to postharvest handling practices.

### 3.1.5 Protein

Protein content ranged from  $1.60 \pm 0.46\%$  to  $36.73 \pm 0.53\%$ . Fresh cocoyam leaves contained relatively low protein levels (unblanched  $2.09 \pm 0.06\%$ ; steam-blanched  $1.60 \pm 0.46\%$ ) compared with dried samples, in agreement with the concentration effect following moisture removal. Among the dried products at day 0, solar-dried (unblanched) showed the highest protein ( $36.73 \pm 0.53\%$ ), while freeze-dried samples were lower ( $12.86 \pm 0.15\%$ ). After 42 days of storage, protein values in the dried samples were between

$17.61 \pm 0.07\%$  (solar-dried, no pretreatment,  $6.7^\circ\text{C}$ ) to  $25.32 \pm 0.14\%$  (freeze-dried, no pretreatment,  $6.7^\circ\text{C}$ ).

The protein content of cocoyam leaves was found to be significantly affected by the interaction between all factors (Table 3). All interaction effects, including the three-way interaction of drying method, pretreatment and storage temperature ( $F = 11,739.4$ ) were significant. This observation highlights the sensitivity of protein to both processing and storage conditions.

### 3.1.6 Moisture

Moisture content, expressed on a fresh weight basis, varied from  $7.49 \pm 0.61\%$  to  $86.45 \pm 0.84\%$  (Table 2). Fresh cocoyam leaves exhibited high moisture levels, between  $81.68 \pm 0.79\%$  in unblanched samples and  $86.45 \pm 0.84\%$  in steam-blanched samples at day 0. Drying substantially reduced moisture in all products at day 0. Freeze-dried leaves showed the lowest initial moisture contents ( $7.49 \pm 0.61\%$ ), while solar-dried and freeze-dried steam-blanched samples had slightly higher moisture (about  $7.79$ – $9.25\%$ ). During 42 days of storage, moisture content increased in all dried samples, indicating moisture uptake from the storage environment. Final moisture values ranged from about  $10.39 \pm 0.25\%$  in solar-dried, steam-blanched leaves stored at  $6.7^\circ\text{C}$  to  $13.41 \pm 0.49\%$  in freeze-dried, unblanched leaves stored at  $32^\circ\text{C}$ . Products stored at room temperature ( $32^\circ\text{C}$ ), were generally associated with greater moisture gain.

The stability of the moisture content in the blanched and unblanched, fresh and dried samples were highly driven by interaction (Table 3). All two- and three-way interactions were statistically significant (e.g., drying method × storage days:  $F = 7628.52$ ; drying method × pretreatment × storage temperature:  $F = 2256.04$ ), and this indicates complex relationships influencing moisture retention during and after processing.

Overall, the fresh leaves were characterized by high moisture and lower macronutrient content, whereas the dried products showed higher values for ash, protein, carbohydrate, and fiber. During the 42-day storage period, moisture generally increased and the composition of the dried materials shifted within the ranges noted above in Table 2.

## 3.2 Antioxidant activity and phenolic content

The effects of drying method, pretreatment, storage temperature, and storage duration on the antioxidant activity and phenolic content of blanched and unblanched fresh and dried cocoyam leaves are shown in Tables 4, 5 provides the summary of the statistical analyses.

### 3.2.1 Antioxidant activity

From this study, it was observed that values for antioxidant activity ranged from  $46.97 \pm 1.78\%$  to  $90.11 \pm 2.46\%$  (Table 4). The fresh leaves recorded lower values (unblanched at  $46.97 \pm 1.78\%$  and steam-blanched at  $59.80 \pm 1.33\%$ ) compared to the dried leaves. At day 0, the freeze-dried samples had higher antioxidant activity values ( $83.64 \pm 1.09\%$  with no pretreatment;  $84.74 \pm 3.17\%$  with

TABLE 6 Effects of drying method, blanching, storage temperature, and 42-day storage on the mineral composition of cocoyam leaves.

Drying methods	Pre-treatment	Storage temp (°C)	Storage days (days)	Ca (g/100)	Fe (g/100 g)	Zn (g/100 g)	Na (g/100 g)	P (g/100 g)
Fresh	No treatment	32	0	0.03 h ± 0.00	0.00 a ± 0.00	0.007 a ± 0.001	0.01 i ± 0.00	0.30 b ± 0.01
		6.7	0	0.03 h ± 0.00	0.00 a ± 0.00	0.006 ab ± 0.000	0.01 i ± 0.00	0.30 b ± 0.01
	Steam blanch	32	0	0.05 fg ± 0.01	0.04 d ± 0.00	0.005 bc ± 0.001	0.27 a ± 0.00	0.85 f ± 0.00
		6.7	0	0.05 fg ± 0.01	0.04 d ± 0.00	0.005 bc ± 0.001	0.27 a ± 0.00	0.85 f ± 0.00
Freeze dry	No treatment	32	0	1.00 a ± 0.01	0.04 d ± 0.00	0.001 f ± 0.000	0.03 h ± 0.00	0.04 a ± 0.00
		32	42	0.11 c ± 0.00	0.02 b ± 0.00	0.006 ab ± 0.000	0.06 f ± 0.00	0.60 c ± 0.00
	No treatment	6.7	0	1.00 a ± 0.01	0.04 d ± 0.00	0.001f ± 0.000	0.03 h ± 0.00	0.04 a ± 0.00
		6.7	42	0.10 c ± 0.00	0.03 c ± 0.00	0.007 a ± 0.001	0.10 c ± 0.00	0.65 d ± 0.00
Freeze dry	Steam blanch	32	0	0.96 ab ± 0.01	0.03 c ± 0.00	0.001 f ± 0.000	0.04 g ± 0.00	0.05 a ± 0.00
		32	42	0.13 c ± 0.01	0.02 b ± 0.00	0.006 ab ± 0.000	0.10 c ± 0.00	0.65 d ± 0.00
	Steam blanch	6.7	0	0.96 ab ± 0.01	0.03 c ± 0.00	0.001 f ± 0.000	0.04 g ± 0.00	0.05 a ± 0.00
		6.7	42	0.08 d ± 0.00	0.02 b ± 0.00	0.007 a ± 0.000	0.08 e ± 0.06	0.66 d ± 0.00
Solar dry	No treatment	32	0	0.04 gh ± 0.01	0.04 d ± 0.01	0.004 cd ± 0.001	0.06 f ± 0.01	1.21 h ± 0.14
		32	42	0.05 ef ± 0.00	0.04 d ± 0.00	0.005 bc ± 0.001	0.27 a ± 0.00	0.85 h ± 0.00
	No treatment	6.7	0	0.04 gh ± 0.01	0.04 d ± 0.01	0.004 cd ± 0.001	0.06 f ± 0.01	1.21 h ± 0.14
		6.7	42	0.04 gh ± 0.00	0.01 a ± 0.00	0.004 cd ± 0.001	0.19 b ± 0.14	0.90 g ± 0.00
Solar dry	Steam blanch	32	0	0.92 b ± 0.02	0.04 d ± 0.00	0.001 f ± 0.000	0.04 g ± 0.00	0.04 a ± 0.00
		32	42	0.06 ef ± 0.00	0.05 e ± 0.00	0.007 a ± 0.000	0.09 d ± 0.00	1.46 i ± 0.01
	Steam blanch	6.7	0	0.92 b ± 0.02	0.04 d ± 0.00	0.001 f ± 0.000	0.04 g ± 0.00	0.04 a ± 0.00
		6.7	42	0.05 ef ± 0.00	0.05 e ± 0.01	0.007 a ± 0.001	0.08 e ± 0.00	0.71 e ± 0.00

Values are reported as mean ± standard deviation (n = 3) on as is basis. Means with the same letter in the same column are not significantly different at α = 0.05.

TABLE 7 Analysis of variance table for the effects of drying method, pretreatment, storage temperature, and storage duration on the mineral composition of cocoyam leaves.

Source	F-values				
	Ca	Fe	Zn	Na	P
Drying method × Pretreatment	27.98*	1.26	53.62*	21.84*	74.97*
Drying method × Storage temperature	6.10*	1.33	74.92*	2.32	102.78*
Pretreatment × Storage temperature	4.57*	1.42	11.63*	0.08	121.00*
Drying method × Pretreatment × Storage temperature	18.11*	1.26	2.08	3.14	102.46*
Drying method × Storage days	10.90*	1.91	0.00	0.22	13.64*
Pretreatment × Storage days	7.04*	1.72	3.62	1.35	352.10*
Drying method × Pretreatment × Storage days	49.39*	1.75	40.46*	0.03	317.67*
Mean	0.41	0.11	0.003669	0.106883	0.538883
Model R-squared	0.9997	0.3172	0.990908	0.807707	0.991756
Model CV	1.7482	445.9761	8.484362	43.25571	8.710547
RMSE	0.0072	0.4809			

Asterisk (\*) indicates significance at P < 0.05.

steam-blanching) compared to the solar-dried samples ( $52.01 \pm 1.75\%$  for no pretreatment and  $59.59 \pm 0.72\%$  for steam-blanching). After storing at room and refrigerated temperatures for 42 days, antioxidant activity in the freeze-dried samples reduced to  $68.41 \pm 3.65\%$  and  $71.91 \pm 1.14\%$ , whereas there was an observed increase in antioxidant activity values in solar-dried sample ( $77.77 \pm 2.70\%$ – $90.11 \pm 2.46\%$ ). This observed increase in solar dried samples was dependent on storage temperature and pretreatment. The highest value observed overall was  $90.11 \pm 2.46\%$  (solar-dried, no pretreatment,  $32^\circ\text{C}$ , day 42).

From Table 5, it can be observed that antioxidant activity levels in the cocoyam leaves were influenced by the interaction effect rather than just the main effects. The same drying method performed differently depending on whether the leaves were first pretreated (e.g., drying  $\times$  pretreatment,  $F = 48.96$ ;  $p < 0.05$ ), and its performance was further affected with the storage temperature (drying  $\times$  temperature,  $F = 37.27$ ;  $p < 0.05$ ). This therefore indicates that pretreatment and drying need to be planned together and matched to how the product will be stored. This explains the significance of the three-way interaction effect (pretreatment  $\times$  drying  $\times$  temperature,  $F = 10.23$ ;  $p < 0.05$ ). Storage period had the largest overall impact, with antioxidant activity values changing markedly over the 42-day period ( $F = 14,873.8$ ;  $p < 0.05$ ). Those changes were not uniform: the trend over time depended on the earlier processing steps (drying  $\times$  time,  $F = 12,934.4$ ;  $p < 0.05$ ; pretreatment  $\times$  time,  $F = 79.26$ ;  $p < 0.05$ ), and even the full three-way interaction influenced how antioxidant activity increased or decreased during storage (pretreatment  $\times$  drying  $\times$  time,  $F = 80.32$ ;  $p < 0.05$ ). These results therefore show that antioxidant retention cannot be predicted from one factor but it depends on the specific mix of pretreatment, drying method, storage temperature, and storage time.

### 3.2.2 Phenolic content

Phenolic content ranged from  $80.69 \pm 2.54$  mg/g to  $221.74 \pm 2.33$  mg/g (Table 4). Fresh leaves had the highest (unblanched  $219.14 \pm 1.44$  mg/g; steam-blanched  $221.74 \pm 2.33$  mg/g). At day 0, freeze-dried samples recorded  $199.98 \pm 3.87$ – $203.88 \pm 1.17$  mg/g, and solar-dried samples were  $204.33 \pm 1.39$ – $204.60 \pm 1.66$  mg/g. After 42 days of storage at room and refrigeration temperatures, the phenolic content in the freeze-dried samples reduced to  $81.10 \pm 1.67$ – $81.96 \pm 2.59$  mg/g, while the solar-dried samples were  $82.03 \pm 1.22$ – $103.86 \pm 0.82$  mg/g. The highest values after storage for 42 days were found in the solar-dried, no-pretreatment samples ( $101.01 \pm 1.34$  mg/g at  $32^\circ\text{C}$ ;  $103.86 \pm 0.82$  mg/g at  $6.7^\circ\text{C}$ ).

The phenolic content in the cocoyam leaves were mainly influenced by drying method and storage period (Table 5). The interaction effect of pretreatment and drying method significantly affected the phenolic content (drying  $\times$  pretreatment,  $F = 4.42$ ;  $p < 0.05$ ), and the effect of a given drying method on the phenolic content was influenced by storage temperature (drying  $\times$  temperature,  $F = 5.88$ ;  $p < 0.05$ ). From the study, the strongest factor that affected the phenolic content was storage duration which was dependent on the drying method used (drying  $\times$  storage duration,  $F = 5,298.45$ ;  $p < 0.05$ ). In contrast, pretreatment with temperature was not significant, and the three-way combination of pretreatment, drying, and temperature was also not significant.

## 3.3 Mineral content

The effects of drying method, pretreatment, storage temperature, and storage duration on the mineral content (Ca, Fe, Zn, Na, and P) of blanched and unblanched fresh and dried cocoyam leaves are shown in Tables 6, 7 provides the summary of the statistical analyses.

### 3.3.1 Calcium (ca)

Calcium content varied widely among treatments with values ranging from  $0.03 \pm 0.00$  to  $1.00 \pm 0.01$  (Table 6). Fresh, unblanched leaves contained  $0.03 \pm 0.00$  Ca, while blanching almost doubled the content to  $0.05 \pm 0.01$ . All dried products at day 0 showed higher Ca content than fresh leaves. The highest values were observed in unblanched freeze-dried samples and steam-blanched leaves ( $1.0 \pm 0.01$ ), followed closely by solar-dried, blanched samples ( $0.92 \pm 0.02$ ). After 42 days, calcium in dried samples generally decreased into the  $0.04$ – $0.13$  range depending on treatment (e.g.,  $0.11 \pm 0.00$  in freeze-dried, unblanched at  $32^\circ\text{C}$ ;  $0.05 \pm 0.00$  in solar-dried, steam-blanched at  $6.7^\circ\text{C}$ ).

Calcium content depended mainly on the combination of processing and storage conditions (Table 7). The drying method  $\times$  pretreatment interaction was significant ( $F = 27.98$ ), meaning the effect of a given drying method changed when leaves were pretreated. Storage temperature further altered these effects which is shown with the interactions of both drying method  $\times$  storage temperature ( $F = 6.10$ ) and pretreatment  $\times$  storage temperature ( $F = 4.57$ ) which were statistically significant. The three-way interaction effect (drying method  $\times$  pretreatment  $\times$  storage temperature) was also significant ( $F = 18.11$ ). Time effects showed a similar pattern: drying method  $\times$  storage duration ( $F = 10.90$ ), pretreatment  $\times$  storage duration ( $F = 7.04$ ), and drying method  $\times$  pretreatment  $\times$  storage duration ( $F = 49.39$ ) was also significant. Together, these results indicate that the pretreatment and drying method should be chosen with consideration to the storage temperature and duration. This is because, calcium levels obtained before storage changed with storage.

### 3.3.2 Iron (Fe)

Iron was very low across all treatments, ranging  $0.00$ – $0.05$  (Table 6). Fresh, unblanched leaves contained  $0.002 \pm 0.00$  amount of iron, whereas fresh, steam-blanched leaves and several dried samples were approximately  $0.03$ – $0.04$ . The highest values appeared in the solar-dried, steam-blanched samples after 42 days ( $0.05 \pm 0.00$  at  $32^\circ\text{C}$ ;  $0.05 \pm 0.01$  at  $6.7^\circ\text{C}$ ).

For iron, no interaction terms were significant (all  $F \leq 1.91$ , ns), and model fit was poor ( $R^2 = 0.317$ ,  $CV \approx 446\%$ ). Due to the lack of

TABLE 8 Analysis of variance and model parameters for sensory attributes of cocoyam leaf-based samples.

Source	F-values			
	Color	Aroma	Texture	Overall
Sample	1.50 ( $p = 0.220$ )	1.66 ( $p = 0.1782$ )	1.56 ( $p = 0.2036$ )	2.02 ( $p = 0.1096$ )
R-squared	0.131	0.142	0.135	0.168
CV	56.36	55.78	55.25	52.38
RMSE	1.767	1.735	1.755	1.711

interactions and the high imprecision, it is impossible to draw process and storage interaction inferences for Fe. This suggests that iron levels in cocoyam leaves were largely not influenced by the treatment factors used in this study.

### 3.3.3 Zinc (Zn)

Zinc levels in the studied samples were relatively very low ranging from 0.001–0.007 g/100 g (Table 6). Fresh, unblanched leaves had comparatively higher zinc levels while freshly freeze-dried samples had lower levels of zinc. After storage for 42 days, the zinc values showed no trend and were found to be in the middle to upper part of the range.

Zinc levels were influenced mainly by interaction effects between processing and temperature conditions. The drying method  $\times$  pretreatment effect was significant ( $F = 53.62$ ), indicating that pretreating the leaves changed how each dryer performed. The interaction effect of the drying method  $\times$  storage temperature effect significant ( $F = 74.92$ ), and pretreatment  $\times$  storage temperature was also significant ( $F = 11.63$ ). However, after 42 days of storage, drying method  $\times$  storage duration and pretreatment  $\times$  storage duration were not significant ( $F = 0.00$  and  $F = 3.62$ ). However, the drying method  $\times$  pretreatment  $\times$  storage duration term was significant ( $F = 40.46$ ), showing the compound effects of processing and storage on Zn stability in the cocoyam leaves.

### 3.3.4 Sodium (Na)

Sodium levels in the cocoyam leaves ranged between  $0.01 \pm 0.00$  to  $0.27 \pm 0.00$  g/100 g. Fresh steam-blانched leaves had the highest level of zinc ( $0.27 \pm 0.00$ ) and among dried samples, the levels increased in some samples after storage for 42 days ( $0.27 \pm 0.00$  in solar-dried, unblانched at 32 °C;  $0.10 \pm 0.00$  in freeze-dried, steam-blانched at 32 °C).

Overall, sodium showed few interaction effects. The only significant interaction was between drying method  $\times$  pretreatment ( $F = 21.84$ ;  $p < 0.05$ ), which can mean that the changes in zinc content in blanched cocoyam leaves depends on the drying method used. By contrast, interactions that involved storage temperature (drying method  $\times$  storage temperature, pretreatment  $\times$  storage temperature, and the three-way; drying method  $\times$  pretreatment  $\times$  storage temperature) were all not significant. A similar observation was made for time-based interactions (drying method  $\times$  storage duration, pretreatment  $\times$  storage duration, and their three-way interaction) and they were also not significant. These results suggest that while blanching and drying can affect the sodium content in cocoyam leaves, storage temperature and storage duration did not produce significant changes in sodium content. Overall variability in sodium content was higher than most other minerals, as indicated by a coefficient of variation of 43.26%.

### 3.3.5 Phosphorus (P)

Phosphorus content in the cocoyam leaves showed the widest variation among all the minerals studied. The values ranged from 0.04–1.46 g/100 g. Steam blanching caused an increase in phosphorus levels. Drying caused an increase in phosphorus levels, with solar dried samples having relatively higher phosphorus levels compared to freeze dried samples. Before storage (day 0), higher phosphorus values were recorded for the unblانched solar-dried leaves ( $1.21 \pm 0.14$ ),

compared to freeze-dried samples (0.04–0.05). After storing the samples for 42 days, an increase in phosphorus levels was observed in freeze-dried dried samples (0.60–0.66 g/100 g) and the steam blانched solar dried samples. The samples that recorded the highest phosphorus content was the solar-dried, steam-blانched sample stored at 32 °C for 42 days ( $1.46 \pm 0.01$  g/100 g).

Phosphorus content was influenced by how the leaves were processed and how they were stored. During processing, the drying method  $\times$  pretreatment term was significant ( $F = 74.97$ ), showing that pretreating the leaves changed how each dryer affected phosphorus. Storage temperature amplified these differences: both drying method  $\times$  storage temperature ( $F = 102.78$ ) and pretreatment  $\times$  storage temperature ( $F = 121.00$ ) was significant, and the three-way term – drying method  $\times$  pretreatment  $\times$  storage temperature was also significant ( $F = 102.46$ ).

In this dataset, interaction effects were more important than main effects for most minerals. Calcium and phosphorus showed the broadest interaction patterns (processing  $\times$  temperature and processing  $\times$  time, with significant three-way interaction), indicating that their levels depend on how factors act together rather than on any single factor alone. Zinc was influenced mainly by the drying method  $\times$  temperature interaction, with only limited time-related interactions. Sodium appeared to be mainly affected by main effects at the processing stage. Iron showed no reliable interaction effects given the precision of the model.

These findings therefore suggest that in designing protocols, the interaction effects should be considered such as managing pretreatment conditions, dryer settings, storage temperature, and intended shelf-life, rather than optimizing main effects in isolation.

## 3.4 Sensory analysis

The aim of the sensory analysis was to determine whether the different sample treatments (resulting from drying methods and combinations of pretreatments and storage conditions) significantly influenced consumer perception. Sensory characteristics of cocoyam leaf-based samples were assessed for four attributes – color, aroma, texture, and overall acceptability. Analysis of variance (ANOVA) results are presented in Table 8.

The ANOVA results showed that there were no statistically significant differences among the samples at the 0.05 confidence level. The  $F$ -values for all the sensory attributes studied were not significantly different from each other. This suggests that, while minor variations may have been perceived by panelists, the differences were not consistent or strong enough to be deemed meaningful across the sample set.

The model performance metrics also support this interpretation. The  $R^2$  values were low, ranging from 0.131 (color) to 0.168 (overall acceptability). This indicates that the sample treatments explained only a small proportion of the variability in panelist scores. Similarly, the coefficients of variation (CV) were relatively high (over 50% in all cases), and this highlights considerable variability in sensory ratings, which is likely due to individual differences in perception or sample presentation. The root mean square error (RMSE) values ranged from 1.711 to 1.767, consistent with the observed variability and reinforcing the low predictive power of the model for sensory attributes.

These results thus suggest that while different drying methods and processing combinations may affect nutritional and bio-functional properties, their impact on consumer acceptability was not statistically significant in this study. The uniformity in sensory perception may indicate that all processing methods yielded products that were broadly acceptable to consumers, with no one method standing out as significantly superior or inferior in terms of organoleptic quality.

## 4 Discussion

### 4.1 Proximate composition

This study assessed the effects of drying method, pretreatment, storage temperature, and storage duration on the proximate composition of dried cocoyam leaves. The results clearly showed that these factors interacted to significantly affect the nutritional components studied in this experiment. A general trend was that, drying moved cocoyam leaves from a water-rich, dilute matrix to a solid-dense matrix, thereby resulting in freshly dried samples having higher percentages of ash, protein, carbohydrate and fiber than fresh leaves. When samples were stored for 42 days, the uptake of moisture partly reversed the levels, moving the percentages of other components accordingly (Table 2). This pattern is expected for hygroscopic leafy tissues, whereby dehydration lowers water activity and concentrates solids. Subsequent storage allows sorption of ambient moisture, especially when packaging and temperature permit rehydration (Fellows, 2009; Kitinjo et al., 2011).

#### 4.1.1 Ash

The very high ash measured in the blanched, freshly freeze-dried leaves ( $\approx 17.79\%$ ) is best explained by mineral concentration after water removal and the structural protection that blanching can provide during gentle drying. By contrast, the much lower ash in some freshly solar-dried (day-0) samples ( $\approx 1.62\%$ ) is consistent with mineral loss to blanch water or exudates during drying and, in some cases, with higher residual moisture that dilutes the ash percentage on a wet basis. The statistics reinforce this sensitivity to processing and storage. For example, drying method  $\times$  pretreatment ( $F = 21.12$ ), drying method  $\times$  storage temperature ( $F = 33.95$ ), and drying method  $\times$  storage days ( $F = 1,512.74$ ) indicate that ash outcomes depend on the interactions between processing and storage conditions than just the main effects. Similar findings have been reported for other leafy matrices such as fluted pumpkin leaves, where changing the drying method and then holding product in storage significantly shifted proximate and mineral values. Controlled temperature oven dried samples generally retained higher mineral levels than sun- or air-dried samples. This trend is consistent with a concentration effect when moisture is efficiently removed and leaching is minimized (Obembe et al., 2021). Other work done by Shonte et al. (2020) on stinging nettle shows that freeze- vs. oven-drying produces distinct proximate/mineral profiles, which show differences in microstructure and residual moisture that carry through storage.

#### 4.1.2 Moisture

Moisture content ranged from approximately 82–86%, whereas freshly dried samples had moisture content of approximately

7.5–7.8% which later increased to approximately 10–13% after storage for 42 days. This rebound is consistent with moisture sorption determined governed by the matrix fixed during drying and by storage temperature and or packaging, which together control water uptake and diffusion (Fellows, 2009; Ramaswamy and Marcotte, 2006). The strong interaction terms (e.g., drying method  $\times$  storage days,  $F = 7,628.52$ ; drying method  $\times$  pretreatment  $\times$  storage temperature,  $F = 2,256.04$ ) indicate that end-point moisture is best preserved when drying method, and storage temperature and duration are planned as a bundle, not stepwise. Comparable moisture rebound and storage-dependent changes after drying of leafy matrices have been reported for savoy beet/amaranth (cabinet vs. solar drying with storage) and for fluted pumpkin leaves (drying method paired with storage), reinforcing that drying and storage interactions dictate moisture stability (Negi and Roy, 2001; Obembe et al., 2021).

#### 4.1.3 Protein

In this study, fresh cocoyam leaves recorded the lowest amount of protein ( $\approx 1.6$ – $2.1\%$ ; wet basis) and increased immediately after drying, and this can be explained by the concentration of the nitrogenous solids after water is removed from the leaves. During storage, the protein content in the dried leaves did not follow any consistent trend with values ranging from approximately 17.6–25.3% by day 42 of storage. This trend can be explained with the partial rehydration plus structural changes such as denaturation and some Maillard-type reactions that can shift nitrogen recovery and the apparent protein value. The strong two-way and three-way interaction effects in the statistical analysis (drying method  $\times$  pretreatment  $\times$  storage temperature,  $F = 11,739.4$ ) indicate that protein stability depends on processing sequence and storage environment acting together, not any single step. In stinging nettle, protein (and other macronutrients) differed by drying method (oven vs. freeze-drying), which reflects the concentration effects and process-dependent changes in composition (Shonte et al., 2020). In fluted pumpkin (*Telfairia occidentalis*), Obembe et al. (2021) observed that drying method combined with storage significantly altered proximate composition, including protein, reinforcing that the drying and storage interaction after protein content over time.

#### 4.1.4 Fiber

Fiber content increased from approximately 0.8–1.3% in the fresh leaves to approximately 14–22% immediately after drying. This trend can be attributed to a combination of reactions. It could be due to the concentration of insoluble cell-wall material and where blanching was applied, it could be because enzyme inactivation likely helped maintain wall integrity during drying. After storage for 42 days, the fiber values now ranged between approximately 15–19%, consistent with some moisture regain and limited solubilization of wall polymers during storage. The significant interaction effects observed (e.g., pretreatment  $\times$  storage days,  $F = 117.57$ ; drying  $\times$  pretreatment  $\times$  storage days,  $F = 845.11$ ) could be explained with the cell-wall processes mentioned above. Similar results are reported for other leafy vegetables such as fluted pumpkin leaves where crude fiber was much higher after drying than in the fresh control (fresh  $\approx 2.9\%$  vs. oven-dried 11.2%, air-dried 10.7%, sun-dried 9.2%), and storage further controlled proximate values, thereby highlighting the

important role that the drying method and storage conditions interaction plays in the nutritional content of leafy vegetables (Obembe et al., 2021). Studies comparing drying routes also show method-dependent differences in macronutrients (including fiber) for leafy matrices such as stinging nettle, where oven and freeze-drying produced distinct proximate profiles, consistent with our finding that fiber outcomes depend on the processing path and what happens during storage (Shonte et al., 2020).

#### 4.1.5 Fat

The fat content in the samples studied were the lowest of all the proximate content ranging from about 1.2–4.4%. These values change very slightly across treatments. The lower values seen in some stored, solar-dried samples and the slight increases in a few freeze-dried, steam-blanching samples are consistent with two well-known mechanisms: (i) lipid oxidation promoted by oxygen exposure and warmer storage, and (ii) matrix-controlled diffusion/retention set by the drying route (Fellows, 2009).

Statistical analysis on the results shows a similar pattern. The largest interaction which was between drying method and storage days ( $F = 39.16$ ), indicates a time- and matrix-dependent behavior. Smaller but significant interactions, drying  $\times$  pretreatment ( $F = 7.22$ ) and pretreatment  $\times$  storage days ( $F = 8.95$ ), are consistent with the role of blanching in deactivating lipase/lipoxygenase (enzymes that otherwise accelerate fat degradation) and in reducing surface exudate that can carry lipids. Empirical work has repeatedly shown blanching's enzyme-inactivation effect in vegetables, which supports our observation that pretreatment modulates subsequent fat stability (Fellows, 2009). In stinging nettle, macronutrients, including crude fat, differed by drying method (oven vs. freeze-drying), indicating that the drying method produces the matrix that determine later changes that occur (Shonte et al., 2020).

#### 4.1.6 Carbohydrate

The carbohydrate content which was calculated by difference ranged from approximately 6.5 to 47.9%. Because "by difference" subtracts the measured fractions (moisture, protein, ash, fat, fiber) from 100, the carbohydrate value typically moves opposite to moisture and also reflects any changes in the other proximate values. The very large drying method  $\times$  storage days interaction effect ( $F = 7,326.37$ ), therefore most likely reflects moisture absorption and the redistribution of solids set by the drying method and the storage environment, rather than large absolute gains or losses in the real carbohydrate value. This interpretation is consistent with dehydration or rehydration and sorption principles described by Fellows (2009) and by Ramaswamy and Marcotte (2006), where the matrix formed during drying determines subsequent water uptake and diffusion in storage. Obembe et al. reported that proximate composition (including carbohydrate by difference) in fluted pumpkin leaves, varied with drying method and then shifted further during storage, similar to the observation in this study that the interaction between drying and storage determine the direction and magnitude of change.

In practice, preserving the composition of dried cocoyam leaves will mean keeping the final moisture low. This can be achieved by using high-barrier packaging followed by cool storage. Most importantly, it is necessary to plan pretreatment, drying, and storage treatments together as one integrated process rather than optimizing any single step in isolation.

## 4.2 Antioxidant activity and total phenolic content

This study investigated the influence of drying methods, pretreatment, storage temperature, and storage duration on the antioxidant activity and total phenolic content of cocoyam leaves (*Xanthosoma sagittifolium*). The findings highlight the significant impact of interactive effects of processing and storage parameters on the phytochemical quality of a dried leafy vegetable, echoing earlier works on the susceptibility of bioactive compounds to postharvest conditions (Doymaz and İsmail, 2011; Bala and Mondal, 2001).

The study demonstrates that the stability of bioactive quality in dried cocoyam leaves is influenced by processing – storage interactions rather than by any single factor applied in isolation. Interaction terms involving drying method (D), pretreatment (P), storage temperature (T), and storage duration (S) consistently explained the observed variability in antioxidant capacity and total phenolics in cocoyam leaves and these interactions determine how the nutrient in the cocoyam leaves changes during storage (Fellows, 2009; Ramaswamy and Marcotte, 2006).

For both indices, D  $\times$  P was significant, indicating that the impact of a given drying method depends on whether and how leaves were pretreated. Blanching can inactivate oxidative enzymes and alter membrane permeability before dehydration, while drying fixes microstructure and water activity that later modulate diffusion and reaction rates (Abano and Sam-Amoah, 2011; Managa et al., 2020; Shonte et al., 2020; Fellows, 2009). Where pretreatment is too severe, leaching of soluble phenolics may limit the gains obtained through the inactivation of enzyme, whereas if pretreatment too mild, residual polyphenol oxidases and peroxidases accelerate losses after drying resulting in lower values (Assouhoun-Djeni et al., 2021; Owusu-Kwarteng et al., 2017; Ramaswamy and Marcotte, 2006).

The significant interaction effect between drying method and storage temperature for both antioxidant activity and phenolic content indicate that storage temperature is critical for maintaining these quality indices in the dried leaves during storage. According to Adepoju and Osunde (2017), drying methods that produce minimal damage, tend to produce matrices with lower residual reactivity and reduced moisture sorption. However, this quality is better observed when the samples are stored under cooler temperatures which further suppresses oxidation and hydrolysis (Obembe et al., 2021). For antioxidant activity, the significant interaction observed between pretreatment and storage temperature suggest that, pretreatment only positively affect antioxidants only when it is stored under cooler temperatures. When products are stored under higher temperatures, that benefit is reduced since heat speeds non-enzymatic oxidation and polymerization (Fellows, 2009; Mensah et al., 2008; Dada et al., 2021).

The significant interaction effects between drying method and storage days for both antioxidant activity and phenolic content shows the compounded effect of processing and storage on nutrient retention. Similar interaction trends have been observed in leafy vegetables like *Telfairia occidentalis* and *Amaranthus* spp., where drying and storage combinations influenced bioactive stability (Adetuyi et al., 2008; Maseko et al., 2019a; Maseko et al., 2019b; Negi and Roy, 2001; Managa et al., 2020). These findings imply that even optimal drying methods may not guarantee retention of antioxidant activity or phenolic content unless post-processing conditions are equally controlled.

The extremely high  $R^2$  values (0.9997 for antioxidant activity and 0.9998 for phenolic content) and low coefficients of variation confirm the model's explanatory strength and experimental reliability. These metrics reflect the precision with which treatment combinations captured variance in phytochemical retention, validating the robustness of the factorial design used in the study.

Total phenolics ranged from  $80.69 \pm 2.54$  to  $221.74 \pm 2.33$  mg/g (Table 4). Immediately after drying (day 0), blanched and unblanched freeze-dried and solar-dried leaves had phenolic content between 200 and 205 mg/g, suggesting that blanching which slows down enzyme activity and effect of drying did not affect the phenolic content much in the leaves (Fellows, 2009; Ramaswamy and Marcotte, 2006). After 42 days of storage, the level of phenolics in all dried samples reduced to between about 81–104 mg/g, which is consistent with slow chemical changes during storage, processes that are promoted by oxygen getting in and residual moisture in the samples, even when products are kept cool (Shahidi and Naczek, 2004).

From the results, it is observed that phenolics were affected primarily by how the leaves were dried and how long they were stored – the drying method  $\times$  storage duration ( $F = 5,298.45$ ;  $p < 0.05$ ). The drying method  $\times$  pretreatment interaction was also significant ( $F = 4.42$ ;  $p < 0.05$ ), which indicates that blanching altered the extent to which each dryer preserved extractable phenolics in freshly dried samples. Significant interaction effects was observed for drying method and temperature ( $F = 5.88$ ;  $p < 0.05$ ) which can indicate temperature-sensitive degradation during storage. By contrast, pretreatment  $\times$  temperature and the three-factor interaction effects (pretreatment  $\times$  drying method  $\times$  temperature) were not significant. This can imply that time and the choice of drying method explained most longer-term variation. The increase in antioxidant activity observed in some solar-dried samples and the reduction in phenolic content across all dried samples emphasizes that common antioxidant assays capture multiple contributors (phenolics plus Maillard-derived and other non-phenolic antioxidants) and that extractability and reaction products can shift assay responses independently of total phenolic content (Nicoli et al., 1999; Morales and Jiménez-Pérez, 2001; Dewanto et al., 2002).

#### 4.2.1 Implications for value addition and nutrition security

These results demonstrate that to maintain the bio-functional quality of cocoyam leaves, processors must optimize drying and storage conditions. Adoption of low-temperature drying, mild pretreatments, and moisture-tight, cool storage conditions can substantially preserve antioxidant and phenolic characteristics, which are critical to the health benefits of traditional leafy vegetables. This is particularly relevant for small- and medium-scale processors in Ghana and across sub-Saharan Africa, where indigenous vegetables are vital to household nutrition and livelihoods but face rapid spoilage and market undervaluation due to poor postharvest handling (FAO, 2019).

### 4.3 Mineral composition

This study shows that the mineral content in cocoyam leaves is determined mainly by how processing and storage steps work together, rather than by any single factor. Considering drying method

(D), pretreatment or blanching (P), storage temperature (T), and storage duration (S), it was observed that the interaction effects determine both the initial level of minerals and how those levels change over time. This pattern is consistent with process-systems perspectives on stabilizing plant foods, where product structure set during processing interacts with the storage environment to drive composition over shelf life (Fellows, 2009; Ramaswamy and Marcotte, 2006). The results show that postharvest handling significantly influences micronutrient retention and nutritional quality of cocoyam leaves.

#### 4.3.1 Calcium (ca)

Calcium content in the leaf samples that were studied depended on how processing and storage worked together rather than on any single step. It was observed that the best drying methods in terms of calcium content is affected by when the samples were blanched or unblanched as well as on the storage time and temperature. A likely explanation is that blanch severity can increase membrane permeability and disrupt pectin–calcium crosslinks, which promotes leaching if the blanch is too harsh. In contrast, a brief, enzyme-inactivating blanch paired with a gentle drying method helps conserve calcium bound in the cell-wall matrix (Fellows, 2009). After drying, the microstructure produced from using a particular drying method determines moisture sorption and the mobility of soluble ions with warmer storage speeding up re-equilibration and diffusion. In a study by Korus in 2021, blanching kale before drying reduced several minerals but not calcium (and not zinc or manganese). In fluted pumpkin leaves (*Telfairia occidentalis*), both the drying method and subsequent storage altered mineral composition, including calcium, which supports the view that processing and storage time and temperature interaction effects pairings, rather than main effects alone, shape mineral stability (Obembe et al., 2021).

#### 4.3.2 Zinc (Zn)

Zinc outcomes depended on how pretreatment was paired with the drying method and on storage temperature. The significance of the three-way interaction effects (drying method  $\times$  pretreatment and drying method  $\times$  temperature) indicate that blanching can change how each drying method retains Zn. Although the two-way interactions between drying method and time as well as the effect between pretreatment and time were not significant, the significant drying method  $\times$  pretreatment  $\times$  time term shows that specific pretreatment and drying combinations allow for distinct Zn trends during storage. The explanation for this observation could be that Zn in leafy tissues is associated with proteins, cell-wall ligands, and phytate complexes. Thus, any processing methods that limit leaching and avoid excessive structural damage such as controlled blanching followed by a gentle drying method would reduce the amount of Zn that is lost during processing.

#### 4.3.3 Sodium (Na)

In this study, only the drying method  $\times$  pretreatment interaction was significant for sodium. This indicates that pretreatment before drying (e.g., blanching) changes how each drying method retains sodium. This pattern fits sodium's high water-solubility and therefore, long or intense blanches can leach sodium into the blanch water. Alternatively, brief enzyme-inactivating blanches coupled with gentle

drying is able to better conserve soluble salts. However, after the product was dried, storage temperature and duration did not significantly affect the sodium content. These results indicate that most differences between treatments were established during the dehydration stage. In kale, blanching prior to drying significantly reduced several minerals (3–38%) which can be explained with solute leaching during pretreatment (Oboh and Madojemu, 2016). In controlled study on selective mineral losses during blanching, Kawashima and Valente Soares (2005) found that losses in sodium content increased with the time used for blanching, directly supporting the sensitivity of Na to pretreatment severity.

#### 4.3.4 Phosphorus (P)

Phosphorus was affected by different interactions. Significant interactions were observed between drying method with pretreatment and storage temperature, as well as their three-way interaction. Every time-related term was also significant (drying method  $\times$  storage days, pretreatment  $\times$  storage days, and the three-way term). The results thus shows that in practical terms, pre-treatment, drying method, and storage conditions interact to determine how much P is retained during storage.

In leafy tissues, P occurs in phytate complexes, phospholipids, and soluble phosphate pools (Marschner, 2012). A harsh blanching process can promote leaching, while drying will fix the product's microstructure that later controls moisture uptake and ion mobility. According to Fadupin et al. (2017), phosphorus is retained more effectively in dried leafy vegetables if the leaves are exposed to brief enzyme-inactivating blanching and is paired with a gentle, quality-preserving drying method. Thereafter, storage under cool conditions maintains the P content.

#### 4.3.5 Iron

In contrast to the other minerals studied, iron content did not vary significantly with any of the main effects or their interactions. This suggests that iron levels in cocoyam leaves were largely not influenced by the treatment factors used in this study. Iron showed no meaningful process or storage interactions in this study (all  $F \leq 1.91$ ), and the overall fit was also poor (low  $R^2$  and very high CV). Given this imprecision, it is not possible to make any interaction-based deductions for iron.

#### 4.3.6 Storage temperature and interaction effects

Storage temperature significantly affected calcium and phosphorus content in the dried and stored cocoyam leaves, although it had minimal effects on zinc and sodium. Elevated temperatures are known to accelerate chemical degradation and facilitate mineral redistribution, particularly in loosely bound or reactive mineral forms (Damodaran et al., 2017). The significant interaction between drying method and storage temperature especially for zinc and phosphorus shows the importance of linking initial drying techniques with appropriate storage protocols to preserve nutrient quality.

The interaction between drying method and pretreatment had notable effects on all minerals except iron, with the highest significance observed for phosphorus. This indicates that certain combinations of pretreatment and drying may either stabilize or exacerbate nutrient loss, depending on the synergy between the techniques. Similarly, the three-way interaction between drying method, pretreatment and storage duration significantly affected phosphorus and zinc,

underscoring the complex interplay of processing and storage variables over time.

#### 4.3.7 Implications for nutritional quality and value chain development

Overall, the study confirmed that processing and storage conditions significantly influence the mineral profile of dried cocoyam leaves, with phosphorus and calcium being particularly sensitive. These findings are consistent with observations from other African leafy vegetables, such as *Amaranthus* spp. where mineral retention is highly influenced by postharvest practices (Akubugwo et al., 2008; Apolot et al., 2020).

To maintain the nutritional quality of cocoyam leaf products, processors should prioritize low-temperature drying, employ gentle pretreatments that minimize mineral loss, and implement short-duration storage under cool, dry conditions.

### 4.4 Sensory evaluation

This study assessed the sensory characteristics such as color, aroma, texture, and overall acceptability of cocoyam leaf-based samples. The ANOVA results revealed no statistically significant differences ( $p > 0.05$ ) across all sensory attributes, suggesting that the applied processing treatments did not lead to perceptible differences in consumer sensory perception.

These findings align with those of Ahmed et al. (2023), who reported that traditional African vegetables processed through various thermal methods often exhibit similar consumer acceptability profiles, particularly when the inherent flavors and textures of the vegetables are maintained. Similarly, Zulu et al. (2022) highlighted that the familiarity of local consumers with traditional leafy vegetables such as cocoyam leaves may contribute to a high baseline acceptability, minimizing detectable differences across preparation methods.

The relatively low  $R^2$  values for color (0.131), aroma (0.142), texture (0.135), and overall acceptability (0.168) suggest that treatment variables explained only a limited portion of the variation in sensory scores. This trend is not uncommon in consumer sensory studies, particularly those using untrained or semi-trained panelists, where individual taste preferences, cultural familiarity, and subjective perception play substantial roles in response variability (Lawless and Heymann, 2010). Furthermore, the high coefficients of variation (CVs), ranging from 52.38 to 56.36%, underscore this subjectivity and point to a potential need for larger or more homogenous panelist groups.

The absence of significant sensory differences should not be interpreted as a lack of product differentiation but rather as an opportunity for processors. The consistent acceptability across treatments provides flexibility in selecting processing techniques that optimize nutritional quality, reduce microbial risks, or extend shelf life without sacrificing consumer appeal. As noted by Sablani (2006), such flexibility is critical in developing value-added products from indigenous vegetables in resource-limited settings, where processing decisions must balance efficiency with consumer preferences.

Moreover, the general acceptability observed in this study supports the commercial potential of dried cocoyam leaf products. Given their nutritional value and cultural relevance, these products could be positioned as both traditional and functional foods.

## 5 Conclusion

This study provides a comprehensive evaluation of how drying method, pretreatment, storage temperature, and storage duration influence the nutritional, bio-functional, mineral, and sensory qualities of cocoyam leaves (*Xanthosoma sagittifolium*). The findings clearly demonstrate that freeze drying, particularly when combined with gentle blanching, offers superior retention of protein, antioxidant activity, and total phenolic content compared to solar drying. Storage duration emerged as a critical factor, that significantly affects phytochemical and mineral stability especially calcium, phosphorus, and zinc. This highlights the importance of controlled storage environments for maintaining product quality over time.

Sensory evaluation showed no statistically significant differences in consumer acceptability of dried cocoyam leaves. This suggests that value-added products made from dried cocoyam leaves retain acceptable organoleptic properties regardless of processing combinations, thereby offering processors flexibility in choosing methods based on available infrastructure and cost-effectiveness.

The study emphasizes the potential of integrating optimized drying and storage practices into postharvest handling systems for indigenous leafy vegetables in Ghana. Such strategies can minimize postharvest losses, extend shelf life, and preserve nutritional quality and this can contribute meaningfully to improved food and nutrition security, diet diversity, and the valorization of underutilized crops. While freeze drying consistently preserved superior nutritional quality, its high capital and operating costs may limit direct adoption in rural communities and small-scale enterprises. In such contexts, the main value of freeze drying may lie in its use for high value products. By contrast, improved solar and other low cost drying technologies remain more accessible options for small-scale processing. Future interventions should therefore pair technical optimization with economic and business models that enhance affordability. Examples can be through shared facilities, cooperatives, or public-private partnerships. Future work should also explore packaging innovations and shelf-life modeling to further enhance the scalability and commercial viability of cocoyam leaf-based products in both local and export markets.

## Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author/s.

## Ethics statement

The studies involving humans were approved by University of Ghana's College of Basic and Applied Sciences Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

GE: Writing – review & editing, Formal analysis, Project administration, Writing – original draft, Supervision, Methodology, Conceptualization, Validation, Funding acquisition. MA: Writing – review & editing, Data curation, Investigation, Formal Analysis. RB: Formal Analysis, Writing – review & editing, Data curation. RK-A: Writing – review & editing, Investigation, Data curation.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

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## Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2025.1657192/full#supplementary-material>

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