GSC Biological and Pharmaceutical Sciences
eISSN: 2581-3250 CODEN (USA): GBPSC2
Cross Ref DOI: 10.30574/gscbps
Journal homepage: https://gsconlinepress.com/journals/gscbps/

(RESEARCH ARTICLE)

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Biochemical variation among local *Cocoyams morphotypes* (*Colocasia esculenta* and *Xanthosoma sagittifolium*) cultivated in Côte d'Ivoire

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GSC Biological and Pharmaceutical Sciences, 2025, 33(03), 407-420

Publication history: Received on 27 October 2025; revised on 24 December 2025; accepted on 27 December 2025

Article DOI: https://doi.org/10.30574/gscbps.2025.33.3.0485

Abstract

Cocoyams (*Colocasia esculenta and Xanthosoma sagittifolium*) is an underutilized local crop of the Araceae family, valued for its edible leaves and tubers. This study evaluated the biochemical variation among local leaf and tuber morphotypes cultivated in Côte d'Ivoire. Five leaf morphotypes (three *C. esculenta* (Taro), two *X. sagittifolium* (Tannia)) and three tuber morphotypes of *X. sagittifolium* were collected from an experimental field 116 km north of Abidjan. pH, macronutrients, minerals, phytonutrients, and antinutritional factors were determined using standard methods. Principal component analysis (PCA) was applied to assess variability among morphotypes. Results showed that *X. sagittifolium* leaves had higher concentrations of dry matter (18.7%), protein (6.6%), ash (1.7%), magnesium (5.6 mg/g DM), potassium (3.7 mg/g DM), flavonols (7.7 mg QE/g), total polyphenols (13 mg GAE/g), and tannins (24.4 mg TAE/g) compared to *C. esculenta* leaves, which contained higher sodium (0.4–0.9 mg/g DM) and oxalates (183–213 mg/100 g). Among tubers, beige-fleshed *X. sagittifolium* had the highest dry matter (44.2%), protein (6.5%), carbohydrates (34.2%), and energy (164.3 Kcal/100 g), whereas pink-fleshed tubers were richer in potassium (9.3 mg/g DM) and iron (0.35 mg/g DM), and white-fleshed tubers had the highest oxalate content (286 mg/100 g). PCA grouped leaf and tuber morphotypes based on their biochemical profiles. *These* findings demonstrate significant biochemical variability among local *cocoyams morphotypes* in Côte d'Ivoire, highlighting their potential nutritional value and contribution to food security.

Keywords: Cocoyams; *Colocasia esculenta; Xanthosoma sagittifolium*; Morphotypes; Nutritional value; Correlation

1. Introduction

The term "cocoyams" refers to a range of edible aroids cultivated in humid tropical regions, belonging to genera such as Colocasia, and Xanthosoma (1). Among these, Colocasia esculenta (L.) Schott and Xanthosoma sagittifolium Schott are perennial herbaceous aroids widely grown in the humid tropics of Asia, Africa, and Latin America (2).

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Physicochemical analyses of taro tubers in Ethiopia reported 67.6% moisture, 3.9% crude ash, 5.8% crude fiber, 6.6% crude protein, and 0.7% crude fat (3). Starch content ranges from 73 to 80%, with amylose content between 19 and 24% (4) and up to 30.6% (5). Potassium is the dominant mineral, representing 1–2% of dry matter (6).

Globally, Nigeria leads taro production, contributing around 25% of total output, followed by Cameroon, China, Ethiopia and Ghana (7). *C. esculenta* is an underutilized crop with high commercial potential in several countries, including Cuba, Ghana, El Salvador, Indonesia, Malaysia, Mexico, and Uganda (7). Taro and other tropical root and tuber crops are critical for food security, sustaining over one billion people worldwide, particularly in low-income regions (8).

Taro corms are commonly consumed boiled, baked, or fried; they can also be processed into flour for pastries. Young leaves are consumed as vegetables (9). All plant parts provide health benefits, with taro mucilage emerging as a potential alternative to conventional mucilage in food applications (10). Additionally, taro corms have a medium glycemic index, making them a suitable carbohydrate source for diabetic individuals (11).

In Côte d'Ivoire, tuber crops play a central role in local diets. While yam and cassava are the most widely consumed staples, other species such as taro are also valued (12). However, local taro varieties remain poorly characterized, limiting their utilization in breeding and nutritional improvement programs. To address this problem, studies have been underway in Côte d'Ivoire for several years to allow for the clear identification of taro genetic resources (13). These studies propose genetic characterization using molecular markers to identify clones and implement a taro breeding program, as well as an evaluation of nutritional potential (14). Local taro morphotypes exhibit distinct nutritional profiles, some being richer in essential nutrients than others.

This study aimed to investigate the biochemical composition of local taro morphotypes (*C. esculenta* and *X. sagittifolium*) cultivated in Côte d'Ivoire, with the goal of identifying and valorizing the most nutritionally promising morphotypes.

2. Materials and Methods

2.1. Sample Collection

Plant material comprised young leaves of *C. esculenta* (Taro) and *X. sagittifolium* (Tannia), as well as mature tubers of *X. sagittifolium*, collected from an experimental field in Nianda, a village located north of Abidjan in the Tiassalé Department, sub-prefecture of N'douci, Côte d'Ivoire (5°54′41.54″ N, 4°47′25.85″ W; 68.21 m a.s.l.).

A total of five leaf morphotypes (three *C. esculenta* and two *X sagittifolium*.) and three tuber morphotypes of *X. sagittifolium* were sampled. Leaf morphotypes were characterized as follows: Morphotype 1 of *X. sagittifolium* (XFsGr) exhibited dark green sagittate leaves with an erect apex and a petiole dark green in the upper two-thirds and purple in the lower third, with a subpeltate insertion and pink sheath. Morphotype 2 (*X. sagittifolium*, XFsGl) showed dark green sagittate leaves with a drooping apex, a petiole dark green in the upper two-thirds and purple in the lower third, a subpeltate insertion, and a white sheath. Morphotype 3 (*C. esculenta*, CFpGr) had dark green peltate leaves with a drooping apex, a petiole green in the upper two-thirds and purple in the lower third, a peltate insertion, and pink sheath. Morphotype 4 (*C. esculenta*, CFpGv) displayed light green peltate leaves with a drooping apex, a uniformly green petiole, a peltate insertion, and a sheath matching the petiole color. Morphotype 5 (*C. esculenta*, CFpGi) possessed light green peltate leaves with a drooping apex, a uniformly purple petiole, a peltate insertion, and a sheath of identical color.

Tuber morphotypes were distinguished based on flesh color: pink (XTCR), beige (XTCB), and white (XTCBl).

2.2. Methods

2.2.1. Sample Preparation

The collected leaves and tubers were transported to the laboratory and thoroughly washed. Fresh leaves were ground into a paste and stored in vials for subsequent analysis. The tubers were peeled, cut into small pieces, and oven-dried at 45°C for 48 hours. After drying, they were ground and stored in vials for further analysis.

2.2.2. Physicochemical Characterization

The pH of leaves and tubers was measured following AOAC (2000). Moisture, dry matter, and ash contents were determined using standard procedures (15). Crude protein content was assessed by the Kjeldahl method (AOAC 960.52), while total lipids in tubers were extracted using a Soxhlet apparatus (Gerhardt, Germany) with hexane as the

solvent (15). Dietary fiber was quantified according to AOAC method 978.10. Carbohydrate content was calculated by difference. The caloric value was estimated using the following formula:

$$\text{Energy (kcal/100 g)} = (9\times\text{lipids \%}) + (4\times\text{proteins \%}) + (4\times\text{carbohydrates \%})$$

2.2.3. Determination of Mineral Elements

Mineral content was determined using flame atomic absorption spectrophotometry (FAAS) with an air-acetylene flame.

2.2.4. Determination of Phytochemical Compounds

The total phenolic content in cocoyam's leaves and tubers was determined using the Folin–Ciocalteu spectroscopic method (16), with a calibration curve prepared from gallic acid (2 g/L). Tannins were quantified according to Bainbridge and al. (1996) using the Folin–Denis reagent, with absorbance measured at 500 nm and catechin (2 g/L) as the standard (17). Flavanols were measured spectroscopically following Yi et al. (2007), using quercetin (2 g/L) for calibration and absorbance recorded at 415 nm. Phytate content was assessed according to Latta and Eskin (1980), with absorbance read at 490 nm against a blank, using a sodium phytate calibration range of 10–50 mg/mL (18). Total oxalates were determined by titration as described by Day and Underwood (1986), using 0.05 N potassium permanganate until a persistent pink endpoint was achieved.

2.3. Statistical Analysis

The data were analyzed using ANOVA followed by 5% significance level with XLSTAT software. Values are presented as mean ± standard deviation. Principal component analysis (PCA) was performed using R software version 4.5.1 to identify the parameters most associated with the differentiation of leaf and tuber morphotypes.

3. Results

3.1. Physicochemical characteristics of the leaf morphotypes

The physicochemical characteristics of the leaf morphotypes of *X. sagittifolium* and *C. esculenta* are presented in Table 1. The results show pH values and contents of moisture, dry matter, ash, protein, and total fiber ranging respectively from 5.9 to 6.4, 81.3 to 87.1%, 12.9 to 18.7%, 1.2 to 1.7%, 2.0 to 6.6%, and 2.3 to 4.0%. The leaves of *X. sagittifolium* exhibit significantly higher levels of dry matter, protein, fiber, and ash compared to those of *C. esculenta*. Among the *X. sagittifolium* morphotypes, XFsGr shows the highest values for dry matter (18.7%), protein (6.6%), and ash (1.7%). In contrast, the leaves of *C. esculenta* are characterized by higher moisture content, particularly in the CFpGvi morphotype, which recorded 87.1% moisture.

Table 1 Physicochemical Characteristics of the leaf morphotypes (% Dry matter)

Parameters	***X. sagittifolium***		***C. esculenta***			**Pr (>F)**
	XFsGr	**XFsGl**	**CFpGr**	**CFpGv**	**CFpGvi**	
Moisture (%)	81.28 ± 0.00^{e}	82.05 ± 0.00^{d}	84.60 ± 0.09^{b}	83.09 ± 0.02^{c}	87.1 ± 0.00^{a}	***
pH	6.17 ± 0.00^{b}	6.37 ± 0.00^{a}	5.94 ± 0.01^{d}	5.98 ± 0.01^{cd}	6.08 ± 0.00^{bc}	***
Dry matter (%)	18.71 ± 0.00^{a}	17.94 ± 0.00^{b}	15.47 ± 0.09^{d}	16.93 ± 0.02^{c}	12.92 ± 0.00^{e}	***
Ash (%)	1.73 ± 0.01^{a}	1.61 ± 0.00^{b}	1.24 ± 0.01^{c}	1.24 ± 0.00^{c}	1.24 ± 0.01^{c}	***
Total Fiber (%)	3.82 ± 0.01^{b}	3.97 ± 0.00^{a}	2.44 ± 0.02^{c}	2.89 ± 0.06^{d}	2.43 ± 0.03^{c}	***
Crude Protein (%)	6.58 ± 0.01^{a}	1.98 ± 0.03^{e}	3.30 ± 0.01^{b}	2.89 ± 0.06^{c}	2.45 ± 0.00^{d}	***

Legend: XFsGr = Xanthosoma sagittate leaves with arrow-shaped leaves and pink sheaths; XFsGl = Xanthosoma sagittate leaves with white sheath; CFpGr = Colocasia with peltate leaves and pink sheath, CFpGv : Colocasia with peltate leaves and green sheath ; CFpGi : Colocasia with peltate leaves and purple sheath ; ***=p<0,001, The letters represent significant differences at p<0,05.

3.2. Physicochemical Characteristics of cocoyams Tuber Morphotypes

Table 2 shows that the pH values and the contents of moisture, dry matter, ash, crude protein, total lipids, total fiber, carbohydrates, and energy of the *X. sagittifolium* tuber morphotypes range, respectively, from 7.7 to 8.0, 55.8 to 65%, 35.0 to 44.2%, 1.1 to 1.4%, 6.0 to 6.5%, 0.1 to 0.2%, 2.0 to 2.2%, 25.8 to 34.2%, and 127.6 to 164.3 kcal/100 g.

The beige-fleshed tuber exhibits the highest levels of dry matter (44.2%), ash (1.4%), crude protein (6.5%), total lipids (0.2%), carbohydrates (34.2%), and energy (164.3 kcal/100 g). In contrast, the white-fleshed tuber displays the highest fiber content (2.2%).

Table 2 Physicochemical characteristics of cocoyams tuber morphotypes (% dry matter)

Parameters	***X. sagittifolium***	***X. sagittifolium***	***X. sagittifolium***	**Pr (>F)**
	XTCR	**XTCB**	**XTCBl**	
Moisture (%)	65.02 ± 0.00^{a}	55.77 ± 0.00^{b}	60.47 ± 0.00^{c}	***
pH	7.95 ± 0.00^{a}	7.74 ± 0.00^{b}	7.72 ± 0.00^{c}	***
Dry Matter (%)	34.97 ± 0.00^{c}	44.22 ± 0.00^{a}	39.52 ± 0.00^{b}	***
Ash (%)	1.05 ± 0.00^{c}	1.37 ± 0.00^{a}	1.08 ± 0.00^{b}	***
Total Fiber (%)	2.18 ± 0.00^{a}	1.99 ± 0.01^{c}	2.08 ± 0.02^{b}	***
Crude Protein (%)	5.83 ± 0.01^{b}	6.48 ± 0.00^{a}	5.85 ± 0.00^{b}	***
Total Lipids (%)	0.12 ± 0.00^{b}	0.18 ± 0.00^{a}	0.11 ± 0.00^{b}	***
Carbohydrates (%)	25.78 ± 0.00^{c}	34.20 ± 0.00^{a}	30.40 ± 0.00^{b}	***
Energy (Kcal/ 100g)	127.55 ± 0.00^{c}	164.32 ± 0.00^{a}	145.95 ± 0.00^{b}	***

Legend: XTCR =Xanthosoma tuber with pink flesh, XTCB = Xanthosoma tuber with beige flesh, XTCBl = Xanthosoma tuber with white flesh; ***=p<0,001; The letters represent significant differences at p<0,05

3.3. Mineral profile of cocoyams leaf morphotypes

The mineral composition of the cocoyams leaf morphotypes (Table 3) indicates that calcium contents ranged from 0.7 to 4.4 mg/g DM, iron from 0.15 to 0.23 mg/g DM, magnesium from 0.6 to 5.6 mg/g DM, potassium from 2.6 to 3.7 mg/g DM, and sodium from 0.01 to 0.9 mg/g DM. The XFsGr and XFsGl morphotypes showed the highest calcium levels (2.8 and 4.4 mg/g DM, respectively), as well as elevated magnesium (5.6 and 0.62 mg/g DM) and potassium contents (3.7 mg/g DM for XFsGr). Conversely, the CFpGv morphotype exhibited the highest iron (0.23 mg/g DM) and sodium (0.9 mg/g DM) concentrations.

Table 3 Mineral profile of cocoyams leaf morphotype

Mineral (mg/g DM)	***X. sagittifolium***		***C. esculenta***			**Pr (>F)**
	XFsGr	**XFsGl**	**CFpGr**	**CFpGv**	**CFpGvi**	
Calcium	2.79 ± 0.00^{b}	4.37 ± 0.02^{a}	0.73 ± 0.02^{c}	0.68 ± 0.01^{c}	0.74 ± 0.00^{c}	***
Iron	0.17 ± 0.02^{c}	0.18 ± 0.00^{b}	0.16 ± 0.00^{d}	0.23 ± 0.00^{a}	0.15 ± 0.00^{e}	***
Magnesium	5.62 ± 0.00^{a}	0.62 ± 0.00^{b}	0.61 ± 0.00^{c}	0.58 ± 0.00^{d}	0.38 ± 0.00^{e}	***
Potassium	3.74 ± 0.00^{a}	3.31 ± 0.00^{c}	2.56 ± 0.00^{e}	3.61 ± 0.00^{b}	2.75 ± 0.00^{d}	***
Sodium	0.56 ± 0.00^{b}	0.01 ± 0.00^{e}	0.50 ± 0.00^{c}	0.87 ± 0.00^{a}	0.44 ± 0.00^{d}	***

Legend: XFsGr = Xanthosoma sagittate leaves with arrow-shaped leaves and pink sheaths; XFsGl = Xanthosoma sagittate leaves with white sheath; CFpGr = Colocasia with peltate leaves and pink sheath, CFpGv : Colocasia with peltate leaves and green sheath ; CFpGi : Colocasia with peltate leaves and purple sheath ; ***=p<0,001, The letters represent significant differences at p<0,05

3.4. Mineral profile of cocoyams tuber morphotypes

Table 4 presents the concentrations of selected mineral elements in the tuber morphotypes of *X. sagittifolium*. The results show that potassium is the predominant mineral in the tubers, with values ranging from 8 to 9.3 mg/g DM, the XTCR morphotype exhibiting the highest content (9.3 mg/g DM). Calcium was detected in very low amounts across all morphotypes (0 to 0.01 mg/g DM), with slightly higher levels observed in morphotype XTCBl. Iron was present in more appreciable proportions, with similar concentrations in morphotypes XTCR and XTCB (0.35 mg/g DM). Regarding magnesium, morphotype XTCB recorded the highest value (0.94 mg/g DM). Finally, sodium levels remained relatively low (1 to 1.07 mg/g DM), with the highest concentration found in morphotype XTCBl (1.07 mg/g DM).

Table 4 Mineral profile of tuber morphotypes

Mineral (mg/g DM)	***X. sagittifolium*** **XTCR**	***X. sagittifolium*** **XTCB**	***X. sagittifolium*** **XTCBl**	**Pr (>F)**
Calcium	0.00 ± 0.02^{b}	0.00 ± 0.08^{b}	0.01 ± 0.06^{a}	***
Iron	0.35 ± 0.00^{a}	0.35 ± 0.00^{a}	0.3 ± 0.00^{b}	***
Magnesium	0.90 ± 0.00^{b}	0.94 ± 0.00^{a}	0.79 ± 0.00^{c}	***
Potassium	9.34 ± 0.00^{a}	9.01 ± 0.00^{b}	8.11 ± 0.00^{c}	***
Sodium	1.06 ± 0.00^{b}	1.02 ± 0.00^{c}	1.07 ± 0.00^{a}	***

Legend: XTCR =Xanthosoma tuber with pink flesh, XTCB = Xanthosoma tuber with beige flesh, XTCBl = Xanthosoma tuber with white flesh; ***=p<0,001; The letters represent significant differences at p<0,05

3.5. Phytochemical composition of cocoyams leaf morphotypes

The phytochemical characteristics of the leaf morphotypes are presented in Table 5. They show significant variations, ranging from 5.4 to 7.7 mg QE/g for flavonols, 5.97 to 13.07 mg GAE/g for total polyphenols, and 16.7 to 24.4 mg TAE/g for tannins. The morphotype XFsGr exhibited the highest contents of these phytochemicals, with values of 24.4 mg TAE/g, 13.07 mg GAE/g, and 7.7 mg QE/g, respectively.

For antinutritional compounds, values ranged from 150 to 212.67 mg/100 g for total oxalates and 64.9 to 87.3 mg/100 g for phytates. The lowest contents of oxalates and phytates were observed in morphotypes XFsGr (150 mg/100 g) and XFsGBl (64.9 mg/100 g), respectively.

Table 5 Phytochemical composition of cocoyams leaf morphotypes

Parameters	***X. sagittifolium***		***C. esculenta***			**Pr (>F)**
	XFsGr	**XFsGl**	**CFpGr**	**CFpGv**	**CFpGvi**	
Flavonols (mg QE/g)	7.68 ± 0.00^{a}	7.44 ± 0.00^{b}	5.44 ± 0.00^{e}	5.80 ± 0.00^{d}	6.46 ± 0.00^{c}	***
Total Polyphenols mg GAE/g)	13.07 ± 0.00^{a}	12.27 ± 0.00^{b}	5.97 ± 0.00^{e}	11.40 ± 0.00^{c}	11.30 ± 0.00^{d}	***
Tannins (mg TAE/g)	24.36 ± 0.01^{a}	22.77 ± 0.02^{b}	16.69 ± 0.00^{e}	20.42 ± 0.01^{c}	19.50 ± 0.01^{d}	***
Total Oxalates (mg/100 g)	150.33 ± 0.01^{c}	179.67 ± 0.06^{b}	183.33 ± 0.06^{b}	212.67 ± 0.06^{a}	196.17 ± 0.17^{ab}	***
Phytates (mg/100g)	78.59 ± 0.46^{b}	87.28 ± 0.60^{a}	64.04 ± 0.46^{d}	67.81 ± 0.40^{c}	65.86 ± 2.14^{cd}	***

Legend: XFsGr = Xanthosoma sagittate leaves with arrow-shaped leaves and pink sheaths; XFsGl = Xanthosoma sagittate leaves with white sheath; CFpGr = Colocasia with peltate leaves and pink sheath, CFpGv : Colocasia with peltate leaves and green sheath ; CFpGi : Colocasia with peltate leaves and purple sheath ; ***=p<0,001, The letters represent significant differences at p<0,05

3.6. Phytochemical composition of cocoyams tuber morphotypes

Table 6 summarizes the phytonutrient and antinutritional composition of cocoyams tuber morphotypes. Regarding phytonutrient, Flavonol content ranged from 0.8 to 1.2 mg QE/g, total polyphenols from 3.1 to 4.1 mg GAE/g, and

tannins from 10.5 to 13.7 mg TAE/g. The XTCB morphotype exhibited the highest levels of flavonols (1.2 mg QE/g), total polyphenols (4.1 mg GAE/g), and tannins (13.7 mg TAE/g).

Regarding antinutrient, total oxalates content varied between 169 and 286 mg/100 g, while phytates ranged from 72.4 to 99.8 mg/100 g. The lowest oxalate and phytate contents were observed in XTCR (169 mg/100 g) and XTCBl (72.4–99.8 mg/100 g), respectively.

Table 6 Phytochemical composition of cocoyams tuber morphotypes

Parameters	***X. sagittifolium***	***X. sagittifolium***	***X. sagittifolium***	**Pr (>F)**
	XTCR	**XTCB**	**XTCBl**	
Flavonols (mg QE/g)	0.769 ± 0.00^{c}	1.17 ± 0.00^{a}	0.86 ± 0.01^{b}	***
Total Polyphenols (mg GAE/g)	3.11 ± 0.00^{c}	4.08 ± 0.00^{a}	3.59 ± 0.00^{b}	***
Tannins (mg TAE/g)	10.51 ± 0.00^{c}	13.68 ± 0.00^{a}	12.20 ± 0.00^{b}	***
Total Oxalates (mg/100 g)	168.67 ± 0.05^{c}	242.00 ± 0.09^{b}	286.00 ± 0.09^{a}	***
Phytates (mg/100g)	75.5 ± 0.4^{b}	99.8 ± 0.1^{a}	72.4 ± 0.6^{c}	***

Legend: XTCR =Xanthosoma tuber with pink flesh, XTCB = Xanthosoma tuber with beige flesh, XTCBl = Xanthosoma tuber with white flesh; ***=p<0,001; The letters represent significant differences at p<0,05.

3.7. Principal component analysis of cocoyams leaf morphotypes

3.7.1. Correlation matrix of variables within cocoyams leaf morphotypes

The correlation matrix of nutrients, phytonutrients, and antinutritional compounds (Table 7) showed strong, significant positive correlations (r > 0.70) among five physicochemical variable pairs (ASH–T.FIB, ASH–DM, DM–T.FIB, pH–ASH, pH–T.FIB) and three phytochemical pairs (FLA–TPP, FLA–TAN, TPP–TAN), while no positive correlations were observed among minerals. Significant negative correlations were detected between three physicochemical pairs (MO–ASH, MO–T.FIB, MO–DM), one mineral pair (Na–Ca), and one antinutritional pair (PHYT–OXAL), with no negative correlations among phytonutrients.

To reduce redundancy, variables explaining the highest variance were retained. For principal component analysis, three physicochemical variables (ASH, CP, T.FIB), three minerals (Ca, Fe, K), one phytochemical (TAN), and one antinutritional compound (PHYT) were selected.

Table 7 Correlation matrix of variables within cocoyams leaf morphotypes

	Ca	**ASH**	**IRON**	**T. FIB**	**FLA**	**K**	**Mg**	**DM**	**Na**	**OXAL**	**CP**	**pH**	**PHYT**	**TPP**	**TAN**	**MO**
Ca	1															
ASH	**0.87**	1														
IRON	-0.05	-0.09	1													
T. FIB	**0.95**	**0.96**	-0.15	1												
FLA	**0.84**	**0.93**	-0.19	**0.91**	1											
K	0.44	0.64	0.63	0.50	0.56	1										
Mg	0.32	**0.75**	-0.12	0.57	0.63	0.59	1									
DM	0.68	**0.77**	0.44	**0.72**	0.55	**0.80**	0.59	1								
Na	**-0.75**	-0.44	0.50	-0.64	-0.53	0.23	0.14	-0.07	1							
OXAL	-0.57	-0.81	0.50	**-0.76**	-0.69	-0.24	**-0.83**	-0.51	0.34	1						
CP	0.09	0.56	-0.10	0.35	0.40	0.48	**0.96**	0.49	0.34	-0.75	1					
Ph	**0.94**	**0.77**	-0.03	**0.87**	**0.86**	0.43	0.20	0.50	**-0.75**	-0.39	-0.06	1				

PHYT	**0.78**	**0.98**	-0.00	**0.90**	**0.91**	**0.73**	**0.83**	**0.79**	-0.28	**-0.79**	0.65	0.69	1			
TPP	0.53	0.64	0.25	0.56	**0.79**	**0.77**	0.43	0.42	-0.12	-0.20	0.23	0.69	0.69	1		
TAN	**0.74**	**0.90**	0.17	**0.82**	**0.92**	**0.84**	0.68	**0.72**	-0.23	-0.54	0.47	**0.77**	**0.93**	**0.90**	1	
MO	-0.68	**-0.77**	-0.44	**-0.72**	-0.55	**-0.80**	-0.59	-1.00	0.07	0.51	-0.49	-0.50	**-0.79**	-0.42	**-0.72**	1

Legend : Ca= Calcium, T.FIB = Total Fiber, FLA = Flavonols, K= Potassium, Mg= Magnesium, DM = dry Matter, Na= Sodium, OXAL = Oxalates, CP = crude Protein, pH= Hydrogen Potential , PHYT = Phytates, TPP = Total polyphenols, TAN = tannins, MO = Moisture

3.7.2. Eigenvalue matrix of correlations among variables in cocoyams leaf morphotypes

Principal Component Analysis (PCA) was conducted on physicochemical traits, mineral content, phytonutrients, and antinutritional compounds of cocoyams leaf morphotypes to identify major sources of variation. The first two principal components (PC1 and PC2) accounted for 85.85% of the total variance (Table 8), with seven of eight variables showing high loadings (>0.70).

PC1 (eigenvalue = 5.32) explained 66.54% of the variance and was strongly associated with ash (0.99), total fiber (0.93), calcium (0.84), potassium (0.76), tannins (0.95), and phytates (0.99), reflecting mineral density and phenolic/antinutritional composition. PC2 (eigenvalue = 1.54) accounted for 19.31% of the variance, dominated by iron (0.94), representing the axis of iron richness.

Table 8 Eigenvalue matrix of correlation among variables in cocoyams morphotypes

Parameters	**Axe F1**	**Axe F2**
Eigenvalue	5.32	1.54
% of variance	66.54	19.31
% of cumul variance	66.54	85.85
Ash	0.99	-0.16
Total Fiber	0.93	-0.31
Crude Protein	0.56	0.13
Calcium	0.84	-0.30
Iron	0.04	0.94
Potassium	0.76	0.64
Tanins	0.95	0.14
Phytates	0.99	-0.03

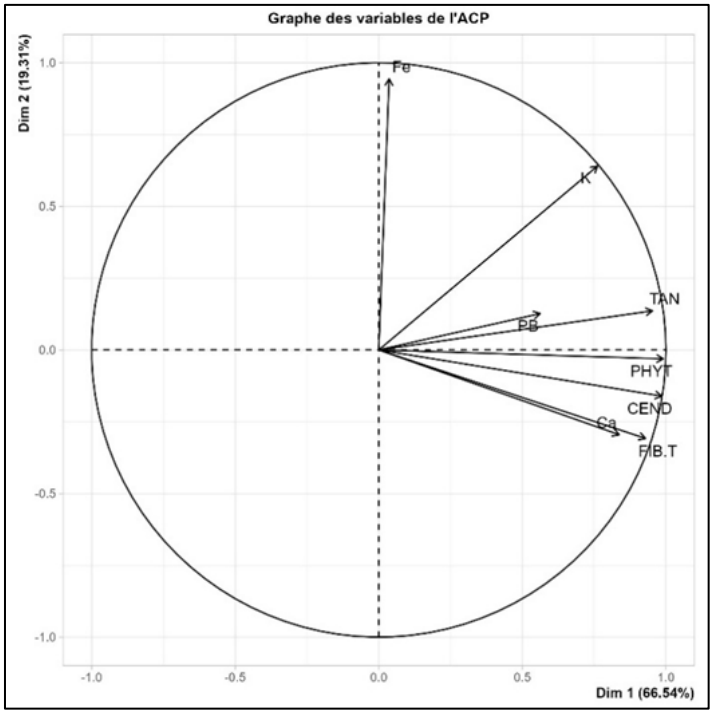
Legend : The underlined values indicate the variables that contribute most to the formation of the axes.

3.7.3. Variable distribution and structural differentiation of cocoyams leaf morphotypes

The distribution of variables (Figure 1) and leaf morphotypes (Figure 2) are represented on the F1–F2 principal component plane. The PCA projection of the morphotypes (Figure 2) revealed four distinct groups.

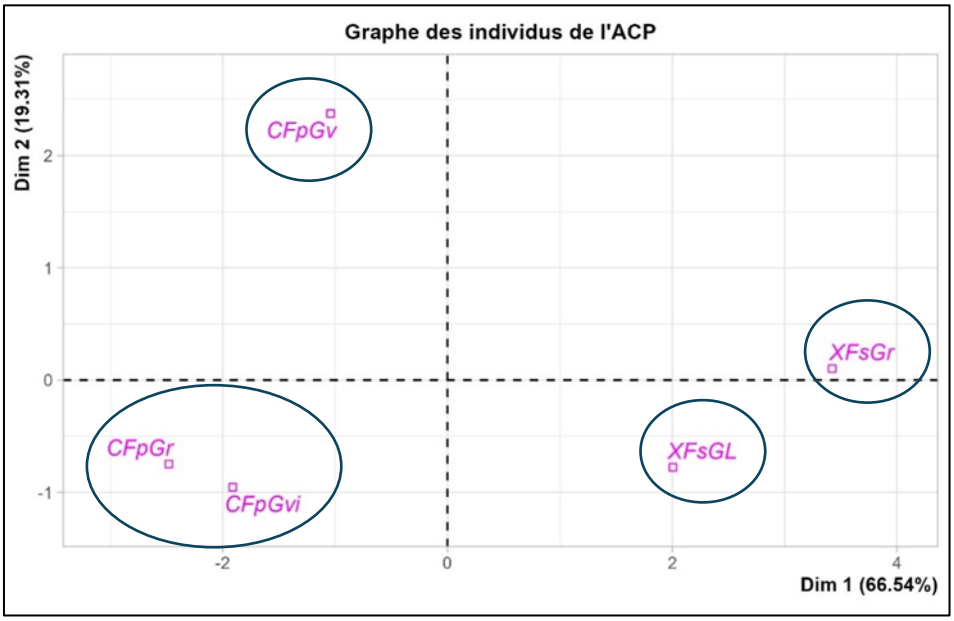
- Group I, located in the positive region of axis 2, consisted primarily of the *C. esculenta* morphotype CFpGv, characterized by high iron content, low potassium, and relatively low levels of calcium, ash, fiber, tannins, and phytates.
- Group II, in the negative region of axis 2, comprised the *C. esculenta* morphotypes CFpGr and CFpGvi, which exhibited low nutrient (ash, fiber), mineral (K, Ca, Fe), phytonutrient (tannins), and antinutritional compound (phytates) contents.
- Group III, located in the negative region to the right of axis 2, included the *X. sagittifolium* morphotype XFsGL, distinguished by high ash, calcium, potassium, fiber, tannins, and phytate levels, but low iron content.
- Group IV, in the positive region to the right of axis 2, was represented by the *X. sagittifolium* morphotype XFsGr, characterized by high tannins, ash, calcium, fiber, and phytates, moderate potassium, and low iron content.

Overall, *X. sagittifolium* and *C. esculenta* leaf morphotypes differed markedly in nutrient composition. The highest nutritional values were observed in XFsGr and XFsGL, with descending overall nutritional quality as follows: XFsGr > XFsGL > CFpGv > CFpGr > CFpGvi.



Legend: CEND = Ash, Fe=Iron, FIB T = Total Fiber, Potassium, Mg= Magnésium, PHYT = Phytates, PPT = Total Polyphénols, TAN = tanins.

Figure 1 Distribution of variables in the 1-2 plane revealed from PCA in cocoyams leaf morphotypes



Legend: XFsGr = Xanthosoma sagittate leaves with arrow-shaped leaves and pink sheaths; XFsGl = Xanthosoma sagittate leaves with white sheath; CFpGr = Colocasia with peltate leaves and pink sheath, CFpGv : Colocasia with peltate leaves and green sheath ; CFpGi : Colocasia with peltate leaves and purple sheath ; ***=p<0,001, The letters represent significant differences at p<0,05

Figure 2 Identification of cocoyams leaf morphotypes by PCA

3.8. Principal component analysis of cocoyams tuber morphotypes

3.8.1. Correlation matrix of variables within cocoyams tuber morphotypes

The correlation matrix (Table 9) revealed strong positive correlations among nutrients, phytochemicals, and antinutritional compounds (r > 0.70). Among physicochemical variables, seventeen pairs showed positive correlations: ASH–ENE, ASH–GLU, ASH–T.LIP, ASH–DM, ASH–CP, ASH–MO, ENE–CH, ENE–T.LIP, ENE–DM, ENE–CP, T.FIB–pH, T.FIB–MO, CH–DM, CH–CP, T.LIP–DM, DM–CP, and pH–MO. Similarly, three mineral pairs (Iron–K, Iron–Mg, K–Mg) and three phytochemical pairs (FLA–PPT, FLA–TAN, PPT–TAN) were strongly correlated.

Significant negative correlations were observed for thirteen physicochemical pairs: CEND–FIB, ENE–T.FIB, ENE–pH, ENE–MO, T.FIB–CH, T.FIB–DM, T.FIB–CP, CH–pH, CH–MO, T.LIP–MO, DM–pH, DM–MO, and CP–MO, as well as three mineral pairs (Ca–Iron, Ca–K, Ca–Mg). No significant correlations were detected among antinutritional compounds.

To minimize redundancy, variables contributing most to the overall variance were retained. For the principal component analysis, two physicochemical variables (ASH, DM), three minerals (Fe, K, Ca), one phytochemical compound (TPP), and two antinutritional compounds (PHYT, OXAL) were selected.

Table 9 Correlation matrix of variables within cocoyam tuber morphotypes

	Ca	ASH	ENE	IRON	T.FIB	FLA	CH	K	T.LIP	Mg	DM	Na	OXAL	CP	pH	PHYT	TPP	TAN	MO
Ca	1																		
ASH	-0.42	1																	
ENE	0.00	0.90	1																
IRON	-1.00	0.42	-0.00	1															
T.FIB	-0.030	-0.89	-0.99	0.03	1														
FLA	-0.30	0.99	0.95	0.30	-0.94	1													
CH	0.05	0.87	0.99	-0.05	-0.99	0.93	1												
K	-0.96	0.16	-0.26	0.96	0.29	0.03	-0.32	1											
TLIP	-0.69	0.94	0.72	0.69	-0.69	0.89	0.67	0.47	1										
Mg	-0.98	0.59	0.18	0.98	-0.15	0.47	0.13	0.89	0.81	1									
DM	-0.00	0.90	0.99	0.00	-0.99	0.95	0.99	-0.25	0.72	0.19	1								
Na	0.50	-0.99	-0.86	-0.50	0.85	-0.97	-0.83	-0.24	-0.97	-0.65	-0.87	1							
OXAL	0.78	0.22	0.61	-0.78	-0.64	0.35	0.66	-0.92	-0.10	-0.65	0.60	-0.14	1						
CP	-0.47	0.99	0.87	0.47	-0.86	0.98	0.85	0.22	0.96	0.63	0.88	-0.99	0.16	1					
pH	-0.60	-0.46	-0.80	0.60	0.81	-0.58	-0.83	0.79	-0.16	0.43	-0.79	0.39	-0.96	-0.41	1				
PHYT	-0.58	0.98	0.80	0.58	-0.79	0.94	0.77	0.34	0.99	0.73	0.81	-0.99	0.03	0.99	-0.29	1			
TPP	-0.01	0.91	0.99	0.01	-0.99	0.95	0.99	-0.25	0.73	0.20	0.99	-0.87	0.60	0.88	-0.78	0.81	1		
TAN	0.03	0.88	0.99	-0.03	-0.99	0.94	0.99	-0.30	0.69	0.15	0.99	-0.84	0.64	0.86	-0.82	0.78	0.99	1	
MO	0.00	-0.90	-0.99	-0.00	0.99	-0.95	-0.99	0.25	-0.72	-0.19	-1.00	0.87	-0.60	-0.88	0.79	-0.81	-0.99	-0.99	1

Legend : Ca= Calcium, ENE = Energy, T.FIB = Total Fiber, FLA = Flavonols, CH = Carbohydrates, K=Potassium, T.LIP = Total Lipid, Mg=Magnesium, DM = Dry Matter, Na= sodium, OXAL= Oxalates, CP = Crude Protein, pH= Hydrogen Potential, PHYT = Phytates, TPP = Total polyphenols, TAN= Tannins, MO = Moisture

3.8.2. Eigenvalue matrix of correlations among variables in cocoyams tuber morphotypes

PCA of physicochemical, mineral, phytonutrient, and antinutritional traits of cocoyams tuber morphotypes revealed two principal components explaining 100% of the total variance (Table 10). The formation of these two axes involved the eight variables selected (factorial weight > 0.70). F1 (eigenvalue = 4.21) accounted for 52.64% of the variance and was

associated with high ash, iron, and total phytate contents, and negatively with calcium, representing the ash–mineral–phytate dimension. F2 (eigenvalue = 3.79) explained 47.36% of the variance and was characterized by high dry matter, polyphenol, and oxalate contents, and negatively by iron, reflecting the dry matter–polyphenol–oxalate axis.

Table 10 Eigenvalue matrix of correlations among variables in cocoyams tuber morphotypes

Parameters	Axe 1	Axe 2
Eigenvalue	4,21	3,79
% of variance	52,64	47,36
% of cumul variance	52,64	100
Dry matter	0,58	0,81
Ash	0,87	0,50
Calcium	-0,82	0,57
Iron	0,85	-0,53
Potassium	0,64	-0,77
Total Polyphénols	0,58	0,81
Phytates	0,95	0,33
Total Oxalates	-0,29	0,96

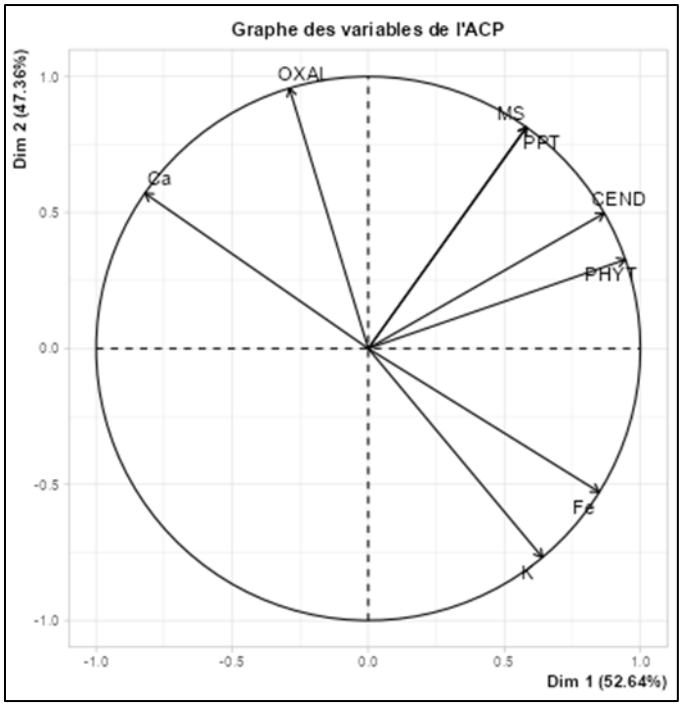
Legend: The underlined values indicate the variables that contribute most to the formation of the axes

3.8.3. Variable distribution and structural differentiation of cocoyams tuber morphotypes

The distribution of variables (Figure 3) and the analyzed tuber morphotypes (Figure 4) are represented on the plane defined by axes 1 and 2. The projection of tuber morphotypes on the F1–F2 factorial plane (Figure 4) highlights the separation achieved by PCA, revealing three homogeneous groups.

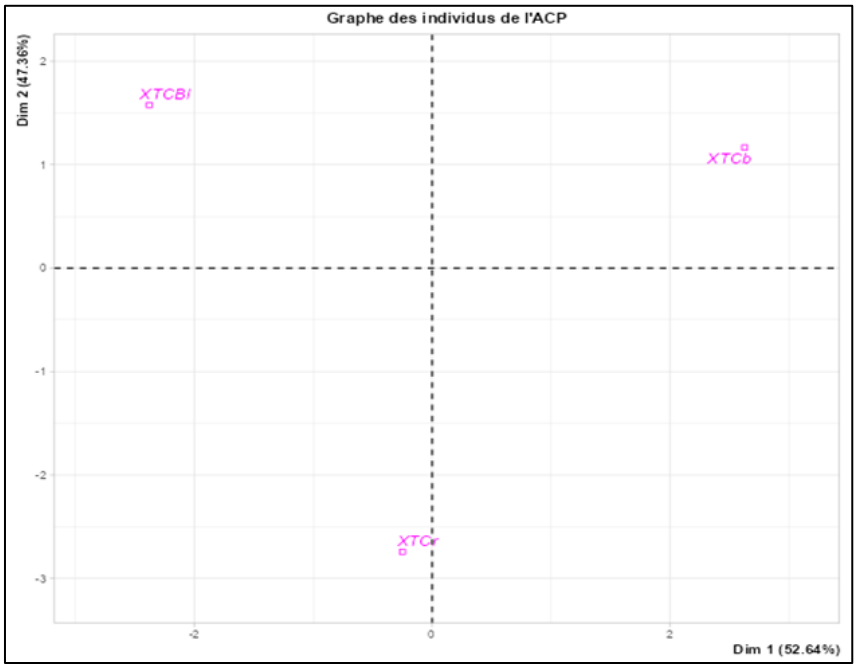
- Group I, located on the left of axis 2 in the positive plane, comprises the *X. sagittifolium* morphotype XTCBl, characterized by high levels of dry matter, polyphenols, calcium, and oxalates, but low ash, iron, potassium, and phytate contents.
- Group II, on the left of axis 2 in the negative plane, includes the morphotype XTCR, distinguished by high potassium, moderate calcium, and low levels of dry matter, ash, iron, polyphenols, oxalates, and phytates.
- Group III, situated on the right of axis 2 in the positive plane, consists of the morphotype XTCB, which exhibits high contents of phytates, iron, ash, potassium, dry matter, polyphenols, and oxalates, while showing lower calcium and potassium levels.

These results indicate that tuber morphotypes of *X. sagittifolium* differ significantly in nutrient composition, with the highest overall nutritional values observed in XTCB, followed by XTCBl and XTCR.



Ca = Calcium, CEND = Ash, Fe= Iron K=Potassium, MS = Dry Matter, OXAL= Oxalates, PHYT = Phytates, PPT = Total Polyphénols.

Figure 3 Distribution of variables in the 1-2 plane revealed from PCA in cocoyams tuber morphotypes



Legend: XTCR =Xanthosoma tuber with pink flesh, XTCB = Xanthosoma tuber with beige flesh, XTCBl = Xanthosoma tuber with white flesh

Figure 4 Identification of cocoyam tuber morphotypes by PCA

4. Discussion

The biochemical analysis of taro (*C. esculenta*) and tannia (*X. sagittifolium*) leaf and tuber morphotypes revealed significant interspecific differences, reflecting species-specific physiological and nutritional strategies. *X. sagittifolium*

leaves exhibited higher dry matter, protein, and ash contents than *C. esculenta*, indicating superior nutritional density. These results align with previous reports from Togo (19).

The mineral content of *X. sagittifolium* leaves, particularly magnesium (5.6 mg/g), exceeded values reported in Colombia (20), though cassava leaves remain richer in iron, calcium, and potassium (21). The *C. esculenta* morphotype CFpGv contained the highest sodium (0.9 mg/g DM), consistent with observations in Kenya (22).

Phytochemical assessment showed that *X. sagittifolium* leaves had the highest tannin levels (24.4 mg EAT/g), indicating greater phytonutrient density than amaranth leaves (Amaranthus graecizans) (23). *C. esculenta* leaves contained higher oxalates (212.67 mg/100 g), while *X. sagittifolium* had elevated phytic acid. Both remained below established safety thresholds (24), confirming the morphotypes as safe leafy vegetables. Phytate and oxalate levels below 300 mg/100 g DM and 500 mg/100 g DM, respectively, are low and nutritionally safe. Diets low in calcium and high in oxalate are not recommended for humans (25).

Correlations among ash, fiber, dry matter, pH, phytonutrients, and antinutritional factors allowed differentiation of morphotypes based on ash, fiber, calcium, iron, tannin, and phytate content. PCA grouped leaves into four clusters: Group I (*C. esculenta* CFpGv) with high iron but low structural and antinutritional compounds; Group II (*C. esculenta* CFpGr and CFpGi) with low nutrient density; and Groups III and IV (*X. sagittifolium*) with high ash, calcium, fiber, tannins, and phytates, but low iron, reflecting species-specific mineral selectivity.

Among tubers, the beige-fleshed morphotype had high dry matter (44.2%) and crude protein (6.5%), confirming cocoyams as a valuable plant protein source, exceeding values for potato (26) and comparable to sweet potato (27). Potassium was the most abundant mineral (9.35 mg/g), supporting dietary needs and cardiovascular health (19,22), whereas calcium content was very low (0–0.01 mg/g), similar to *X. sagittifolium* in Colombia (20). Tannins (13.7 mg EAT/g) and oxalates (286 mg/100 g) were high, potentially limiting protein digestibility and iron bioavailability (28), but cooking can reduce these by over 50%, improving nutritional quality. Magnesium and potassium may also mitigate oxalate-related kidney risks (29).

PCA of tubers identified three groups: Group I (XTCBl) with high dry matter, polyphenols, calcium, and oxalates; Group II (XTCr) with high potassium but low nutrient density; and Group III (XTCb) combining high levels of phytates, iron, ash, potassium, dry matter, polyphenols, and oxalates, reflecting intense metabolic activity and dual accumulation of nutrients and antinutrients.

Overall, both leaves and tubers exhibit significant biochemical variability, demonstrating distinct physiological strategies that can be exploited for varietal selection and nutritional enhancement, supporting targeted use in food security and human nutrition programs.

5. Conclusion

This study highlighted significant biochemical variation among local cocoyams (*C. esculenta* and *X. sagittifolium*) morphotypes cultivated in Côte d'Ivoire, identifying groups based on their nutrient, phytonutrient, and antinutrient profiles. For leaves, four morphotype groups were distinguished, with XFsGr and XFsGl exhibiting superior nutritional traits. Among tubers, three groups were identified, with the beige-fleshed XTCB showing the most favorable composition. Overall, both leaves and tubers of the studied morphotypes demonstrate considerable nutritional potential and could contribute to mitigating food and nutritional insecurity. Further studies are needed to explore mineral content, phytochemicals, and post-harvest processing, while promoting taro cultivation within national programs could enhance food security.

Compliance with ethical standards

Acknowledgments

The authors sincerely thank the ORPHAN mobility program for funding this study (Project No. 101144314/NDICI-2023-MOBAF). They also express their gratitude to the authorities of Nangui ABROGOUA University (UNA). Special thanks are extended to Mr. Ismaël Touré for providing the site for the experiments, and to the technicians of the UNA Central Analysis Laboratory for their valuable guidance.

Disclosure of conflict of interest

We, Freddy BAKAKA BOLUKOLA, Léticia AHOU LOUKOU, KONAN Brou Roger, Victor-Heritier VAWAZOLA NSIMAKENTO, Eric KIMBEMUKEN THASUR, Riwan Uriel Jaurès KOUKE, Ange Kamari FEZA, Chance Bahati BUKOMARHE and Kevin Kouamé KOFFI, co-authors of this manuscript, declare on our honor that there is no conflict of interest, direct or indirect, that could influence or compromise the publication of this manuscript.

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