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The production, uses, nutritional and anti-nutritional characteristics of cocoyam as a potential feed ingredient in the tropics: A review

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Target Audience: *Students, researchers and farmers.*

Abstract

Several cocoyam species such as Xanthosoma and Colocasia previously cultivated for their economic and socio-cultural benefits are no longer popularly cultivated by farmers. They grow luxuriantly in the wild at many locations in Southern Nigeria, indicating that they could be harnessed into feed ingredients for animals. Average yields of 9.60 – 37.00 tons/ha per annum is reported for cocoyam root, while cocoyam foliage yield could be as high as 128 – 370 tons/ha/year. Cocoyam tuber has superior nutritional value over other major roots and tuber crops like yam and cassava in terms of digestible starch, proteins, vitamins and mineral compositions. Crude protein range of 2.01 – 10.10%, and metabolizable energy (2588.44 – 3902.70 Kcal/kg) have been reported. The leaves are high in moisture content, and rich in proteins, vitamins and minerals. The major phytochemical and anti-nutrients in cocoyam roots in mg/kg were alkaloids (0.19 – 1.97), oxalates (0.01 – 30.28), phenols (0.012 – 270.49), tannins (0.20 – 1066.19), and trypsin inhibitor (1.37 – 632.02). The leaves contain significant levels of tannin (32.15mg/100g), flavonoids (62.62mg/100g), phenols (6.28mg/100g), trypsin inhibitor (1069.43mg/kg), and alkaloids (2.40mg/kg) among others. In spite of the anti-nutrient contents of cocoyam which limit its use in livestock feed, it is concluded that when properly processed, cocoyam root meal could be adopted as alternative energy source, while the processed leaf meal could serve as alternative protein source for livestock, and poultry feeding.

Keywords: *Cocoyam, Xanthosoma, Colocasia, feed ingredients, anti-nutrients.*

Description of Problem

Cocoyam is cultivated in the tropics, primarily for its edible corms or root and leaves. It is regarded as an important staple crop in the Pacific Islands, Asia, and Africa (1,2) because it stores better than other roots and tuber crops, has the capacity to tolerate unfavourable environments, and serves as an inexpensive source of energy in the diets of the resource poor rural communities (3). The two major cultivated species are the taro (*Colocasia* species), and tannia (*Xanthosoma* species). According to Roots, Tubers and Bananas Newsletter (4), Africa is the major global producer of cocoyam, with Nigeria producing about 5.49 million metric tons annually, amounting to 45.90% of the global output, and 72.20% of West-African output. FAO (5) estimated 3.46 million metric tons for Nigeria (37.00%), followed by China (1.64 million tons), Ghana (1.51 million tons), and Cameroons (1.31 million tons). Cocoyam occupies the 9^{th} position among world food crops with its cultivation spread across Africa (6). It ranks third in importance after yam, and cassava in extent of production among the root, and tuber crops of economic value in Nigeria (7).

Most of the productions in Nigeria however come from the small-scale farmers, especially women who operate at subsistence levels of cocoyam production in the southern states of the country (8). Resource allocation to cocoyam is also significantly low when compared to other root, and tuber crops such as yam, and cassava (9, 10, 11). Cocoyam particularly plays important socio-cultural roles in the lives of rural dwellers in southeastern Nigeria, especially women whose social status may be directly linked to the size of their cocoyam barn (12, 13). Ritualism, and festivities are also associated with cocoyam cultivation in these communities (14, 15). Generally, cocoyam is regarded as the women's crop in Igbo land, while the yams which are culturally superior to cocoyams are regarded as men's crop (16).

Nutritionally, cocoyam is superior to cassava, and yam in protein, mineral, and vitamin contents, in addition to having a more digestible starch (17, 18). The leaves have also much higher contents of protein than those of the other root and tuber crops and are rich in minerals such as calcium, phosphorus, and iron as well as vitamin C, thiamin, riboflavin and niacin (17, 2). Cocoyam has been recommended for diabetic patients, the aged, children with allergy, and for persons suffering from intestinal disorders (19, 6, 20). The high beta-carotene, iron, and folic acid content of cocoyam leaves have made them valuable in the protection against acidosis and kidney stone formation (21, 6).

The cocoyam corm is highly prone to spoilage due to its inherent high moisture content which favours the activities of pests and pathogens. In Nigeria, the major problems faced by cocoyam farmers in general include low crop yield due to the activities of field, and storage pests, diseases such as leaf blight, other fungi infections, and sometimes scarcity of planting materials (22, 23, 18). Cocoyam corms, peels and leaves are traditionally offered to domestic animals, especially in Asian countries where they are used extensively in feeding pigs (26, 18). They have also been fed to ducks, fish, chicken, and ruminants in experimental trials with promising results (27, 28, 29). The use of cocoyam roots and leaves as food and feed have however been limited by factors such as storage, and presence of anti-nutrients such as oxalates, phytates, tannins, and saponins (30, 31, 18, 32). Several approaches such as heat treatments, drying, fermentation, mixing with other feedstuffs, and additive inclusion have been used to reduce the levels and effects of these anti-nutrients, and therefore improve their feeding values for various animal species (33, 34, 35, 36).

Many cocoyam varieties are no longer priority crops in countries like Nigeria and central Africa, where they have been abandoned for other crops such as cassava, yam, potatoes, and bananas (23, 38). FAOSTAT (39) reported the declining taro yields, and trade from 2000 – 2019 in Africa, and Nigeria. Most of the other cocoyam species, especially *X. maffafa* which was cultivated for economic, and socio-cultural purposes in Southern Nigeria during the pre-colonial, colonial, and well into the mid years of the last century (44) are no longer cultivated. The crop has therefore assumed the status of an abandoned crop in most communities in Southeastern Nigeria where they grow luxuriantly in the wild or waste dumps (45). The growing research interest in the use of cocoyam roots, and leaves in feeding livestock, and poultry is founded on its nutritional qualities which compares favourably with cassava root, and leaf meals, therefore making them potential substitutes for the expensive conventional grains in animal feeds (37). Cocoyam root meal could serve as cheap energy source in the diets of most livestock, while the leaf meal could partially replace the costly protein grains in pig diets, especially in the low-input small-scale production system practiced in the rain forest zones of Nigeria, West and Central Africa. Most efforts to rekindle interest in cocoyam production among African farmers have focused on the *Colocasia esculenta* and *Xanthosoma sagittifolium* (37, 40, 41, 2). They are mostly used for human food and, industrial applications (42, 41, 43).

This paper reviews the existing literature on the production, nutrient, and anti-nutrients, compositions of cocoyam roots and leaf meals as potential ingredients in animal feeding in the tropics.

Classification of Cocoyam

Cocoyams are aroids classified as tropical herbaceous perennial plants, belonging to the family *Araceae* (46), and are primarily grown for their edible corms (roots), and leaves which serve as energy foods and vegetables in some tropical countries (47, 24). The family is large, comprising about 100 genera, and more than 1500 species, including terrestrial plants, vines, creepers, and epiphytes (18).

About 25 species are known for the genus *Colocasia*, and 50 species for the genus *Xanthosoma* (49). There are two general types of cultivated *Colocasia;* those with large edible main corm with many cormels which grow under variable conditions, and have twenty eight chromosomes (i.e. *C. esculenta* var. *esculenta*), and those that produce small to medium sized inedible corm with variable number of cormels, and have forty-two chromosomes, and are often found growing close to water or on irrigated lands (49, 6). Ten distinct cultivars, of which three are *Xanthosoma* species and seven *Colocasia* species, have been identified from germplasm collections, and are recommended for cultivation (50, 51, 6). The two major *Xanthosoma* specie, *X. sagittifolium* and *X. maffafa* are cultivated in Nigeria (22, 52, 53), although the latter is currently abandoned and grows mostly in the wild in Southern Nigeria.

The *Colocasia* species may also be referred to as taro, and are known locally as Ede ofe, ngbowa, akikara, akanoke, coco-india, nkpongnambing, ede-alakochuo and okoroko among the Igbos of southeastern Nigeria (54, 18). The *Xanthosoma* species are referred to as tannia, and are locally known as ede oku, edebuji or akoahuri among the Igbos (54, 18). *Colocasia spp.* originated from Southeast, and central Asia, and may have gotten to Nigeria from Southeast Asia, while *Xanthosoma spp.* may have been introduced from Central, and South America by early Portuguese visitors (14, 24). The *Colocasia spp.* is one of the world's oldest food crops, and among the first to be domesticated in Southeast Asia (55).

The *X. maffafa* species are glabrous erect plants that can grow up to 2 meters tall. The mature plant has thick erect fleshy stem of about 1 meter long with numerous leaf scars, and sometimes with an aerial root (56, 57, 24, 25). Similar to the more popular *X. sagittiffolium*, the tubers have protective leaves modified into skins or tunics, formed from dead petiole sheaths, and remnants of leaves produced during the growth periods, and which act as protection against, insects, digging pests, flooding, and water losses (57, 58). Internally, the corms consist mostly of parenchyma cells rich in starch, and above the parenchyma is a circular basal node from which roots grow (56, 57). Corms are generally used in propagation of the crop, which is usually done by cutting the corms into smaller sections before planting to grow new corms (22, 53).

The corms are surrounded by smaller edible cormels which are smaller than the corms, and are rich in starch. The cormels provide reproductive functions, and are important surviving strategy of the plant (22). The *X. maffafa* can form mature plants from corms within 14 to 20 weeks, and once established, the mature plants can produce large amount of foliage in the first 6 to 9 months, and may also produce up to 10 or more corms within 10 months (59, 57). *Xanthosoma* species may tolerate water logging, and shades, and grow best in deep, well-draining loams having pH values of 5.5, to 6.5 in partial shade (56). Other species of interest are the *Caladium* species which also grow in the wild, in Southern Nigeria, and have been reported to serve as potential energy source in poultry, and fish feeds (60, 61). These and several other species could therefore serve as cheap, and readily available alternative feed stuffs for animal production in tropical environments where they are found.

Production of Cocoyam Tubers and Leaves

Cocoyam as a food crop is very important in the lives of rural farmers, especially at the subsistence level. In addition to serving as staple food for them, it also serves as a source of income for meeting other economic needs (54, 62). During critical times such as famine, conflicts, flooding, and other natural disasters, farmers especially in the rain forest zones of Africa have been known to depend heavily on cocoyam for their survival (7, 63, 3). Despite being planted for economic purposes, cocoyams are also planted for its roles in cultural ceremonies. According to Gelleh *et al*. (64), cocoyam grows best in fertile lands, well-draining, sandy loam soil, with a pH range of 4.2 to 7.5. It can also grow in wide variety of conditions including wetlands. The *Xanthosoma* species does not however tolerate water logging, and requires temperatures above 21^{o}C, well drained loam soil of 5.5 – 6.5 pH in partial shed. FAOSTAT (39) estimates for 2019 show that for the taro, Asian region has the highest average yield of 37 tons/ha from Palestine, while the highest average-yield in Africa was the 9.60 tons/ha harvested in Madagascar. The highest yield from America was 25 tons/ha, while for the Oceania it was 17.57 tons/ha, indicating that yields are relatively low in Africa, although the continent remains the highest producer of cocoyams in the world. Iwuagwu *et al*. (65) reported that the application of cow dung or rice husk at the rate of 20 tons/ha resulted in taro cocoyam yield of 22 tons/ha in Southeast Nigeria. The leaf area, number, and yield were also improved significantly, indicating that with adequate management, productivity could be improved in Africa to levels similar to that of America and Oceania. Iroegbu *et al*. (66) also reported that application of saw dust and poultry manure at the rate of 20 tons/ha, yielded 9.08 – 10.00 tons/ha and 11.25 – 16.25 tons/ha of *Xanthosoma maffafa* corms and cormels respectively in the same Southeastern Nigeria.

The taro cocoyam has been reported to yield up to 370 tons/ha/year of foliage, made up of leaves, and petioles. Hang *et al*. (26) however, reported yearly *Colocasia esculenta* foliage yield estimate of approximately 200 tons/ha, in Vietnam, with the leaves representing 50 percent of the foliage dry matter. Rodriguez (67) reported a fresh biomass (leaves and petioles) yield of 128 tons/ha/year,14.5 tons dry matter, and 1.9 tons crude protein/ha/year for *X. sagittifolium* in Colombia, South America. These report show that the yields from both the corms are comparable to those of the other root and tuber crops in Nigeria like cassava and yam with the average yield of

14.1 and 13.1 tons/ha respectively (68, 69). Cocoyam corms, and leaves could therefore be produced for processing into feedstuffs.

Traditional and Current Uses of Cocoyam

Cocoyam is traditionally grown for its edible corms, and leaves. Locally in Nigeria, the *Colocasia* and *Xanthomona* species are usually prepared, and eaten boiled, as dry chips, or boiled, and pounded with cassava, yam or alone, to produce fufu (54, 70). Cocoyams are important carbohydrate staple food particularly in the rain forest zone of West, and Central Africa. (71, 72, 70). According to Ene (73), boiled cocoyam corms, and cormels are peeled, cut up, dried and stored or milled into flours. Cocoyam tubers have been used to prepare Kokobele, which is a flour derived from the fermentation and milling of the cocoyam tuber in Southwest Nigeria (74). The cocoyam flour has also been used as soups, thickener for making biscuits, and bread, and puddings for beverages, while the peels have been utilized as feed for ruminants (73). Added to its traditional uses, cocoyam tubers have been processed into several food forms in many countries. It has been processed into a fresh paste called poi, flour, beverage powders, chips, sundried slices, and drum-dried flakes (70). These processes are aimed at adding value to the tuber, by converting it into stable shelf foods, usually by boiling, roasting, baking, frying in oil, pasting, milling and pounding (75, 76, 77, 41, 70).

The leaves are also edible, and are usually consumed as vegetable after cooking in dishes such as stews, and soups (78, 79). Cocoyam leaf is however produced on subsistence basis. In Ghana, pickers who are not farmers dominate its harvesting, and marketing (80, 81). Thus most Ghanaian farmers actually cultivate cocoyam both for the cormel, and leafs (63). *Xanthosoma sagittifolium* leaves are harvested, and dried for use as vegetable, especially during dry season when vegetables are scarce. The cocoyam leaves are nutritious vegetables, that contain several minerals, and vitamins, and their consumption is not for carbohydrate utilization or bioavailability but majorly for protein, minerals, and vitamins supplies (82, 83, 78, 41).

Some cocoyam species such as taro (*Colocasia*) and tannia (*Xanthosoma*) also produce edible inflorescence, which is usually surrounded by stem leaves of the corm (84, 85). In these species, the emergence of inflorescence, usually mark the maturity of the cocoyam, and are readily harvested as vegetable. In South America, and some parts of Asia, the inflorescence is used in dressing salad, while it is consumed as a delicacy in Ghana, and southern parts of Nigeria (84, 86, 85). Traditionally, fresh cocoyam inflorescence is used as a vegetable in soup, and yam porridge or may be dried, milled, and used as spices in soup preparations to impact desirable color, and flavor (86, 32).

Nutritional compositions of cocoyam tuber

Cocoyam tuber has generally been profiled to have superior nutritional values over other major roots and tubers, especially in terms of digestible starch, proteins, vitamins, and mineral compositions among others. Boakye *et al*. (41) reported appreciable levels of dietary energy, proteins, vitamins, and minerals in *Xanthosoma sagittifolium* root meals. Wada *et al*. (89) reported a range of 8.48 – 10.10% crude protein, 2.14 – 2.66% crude fiber, 0.85 – 0.22% fat, 2.27 – 3.25% ash, and 84.70 – 85.36% NFE contents in *X. Sagittifolium* root meal. Abdulrashid and Agwunobi (90) reported the proximate values of *X. sagittifolium* tuber meal on dry matter basis as dry matter, 28.80%, crude protein, 5.68%, crude fiber, 4.50%, ether extract, 1.50%, ash, 5.50%, nitrogen free extract, 82.82%, and energy ME(kcal/kg) 3272.97.

According to Osuji and Nwala (91), *Xanthosoma* species tuber meal is rich in starch, and total dietary tuber starch of about 20-28%, and moisture content of about 67.1-69.1%. The starch granules under light microscope appear oval to kidney shaped, with smaller granules appearing spherical (72). The smaller starch granules of *X. maffafa* have been associated with increased digestibility over other crops. The specie according to the results of a Nigerian study by Amadi *et al*. (88) has a mean root meal crude protein of 6.75 % crude fat, 6.64 % crude fiber, 3.66 % total ash, and 62.04 % carbohydrate content. Leucine, lysine, tryptophan, and methionine are the major essential amino acids found in cocoyam root meal, with lysine being the first limiting amino acid (92), while the dominant fatty acid is oleic acid. The macro-mineral values were calcium (2345.00 mg/kg), magnesium (2361.33 mg/kg), potassium (11815.00 mg/kg), phosphorus (783.67 mg/kg), and sodium (1246.00 mg/kg) for the root meal. Osuji and Nwala (91) characterized two major globulins from *X. maffafa* and observed the presence of two unrelated globulin families during tuber development which are G2 protein with both storage, and trypsin inhibition activity, and a G1 protein also with storage, defensive, and protein inhibition activity, which accounts for about 80% of total soluble tuber proteins present in the tuber meal.

Azene and Molla (93) reported a moisture content of 67.64%, crude protein (6.62%), crude fiber (5.80%), ash (3.92%) and fat (0.67%) in *C. esculenta* tuber meal from Southern Ethiopia. The meal also recorded 60.83mg/100g phosphorus, 37.61mg/100g sodium, 710 mg/100g potassium and 186.74mg/100g calcium, indicating high contents of potassium and calcium. Adeyanju *et al.* (70) reported nutrient contents for *C. esculenta* species tuber meal as protein 1.8 g, fat 0.1 g, carbohydrate, 23 g, fiber 1.0 g, calcium 51 mg, phosphorus, 88 mg, and iron 1.2 mg in 100g of edible part. Vitamin values are, thiamine 0.10 mg, riboflavin 0.03 mg niacin 0.8 mg, and vitamin C 8 mg in 100g of edible part (70). Onu and Madubuike (60) in their own study reported 7.21% crude protein, 1.48 % crude fiber, 4.69 % ether extract, 5.13 % ash, 81.58 % nitrogen free extract, and 5.21% gross energy in the wild cocoyam specie, *Caladium bicolar* root meal.

Table 1 shows the proximate composition of different varieties of cocoyam tuber reported by various authors.

Oladeji *et al*., (104) compared some minerals, and physico-chemical properties of taro cocoyam flour, with yam, bread fruit, and plantain flours, and reported the values shown in tables 2 and 3. The results showed that the cocoyam contains higher Ca and Zn levels than yam flour. It also recorded higher bulk density, water holding, and swelling capacities than yam flour. These studies suggest that the *Xanthosoma* cocoyam varieties contain higher crude protein than the *Colocasia* varieties, similar to the levels found in grains. The *Colocasia* variety however seem to contain more minerals than the *Xanthosoma* varieties (93, 88).

Table1: The nutritional compositions (%) of cocoyam tubers

Cocoyam spp	DM	CP	CF	EE	Ash	NFE	ME(Kcal/kg)	References
X. sagittifolium	91.95	2.01	3.80	1.60	10.08	74.46	3158.92	(94)
X. sagittifolium	28.80	5.56	4.50	1.50	5.50	82.82	3272.97	(95)
X. sagittifolium	90.74	3.70	7.80	0.11	3.60	75.58	-	(96)
X. sagittifolium	87.20	19.14	9.45	7.08	4.30	47.23	-	(97)
X. sagittifolium	36.47	8.42	2.14	0.22	2.27	84.76	3784.7	(89)
	38.09	10.10	2.66	0.85	3.25	85.36	3902.7	
C. esculenta	85.51	8.51	3.37	4.95	4.23	78.57	2588.44	(98)
C. esculenta	89.44	4.82	6.76	0.73	3.10	74.03	-	(99)
C. esculenta	31.00	7.87	4.75	0.75	6.00	80.63	3214.95	(31)
C. esculenta	88.42	7.07	3.90	1.10	2.93	73.43	2958.34	(100)
C. esculenta	80.48	8.61	1.71	0.56	2.25	86.58	3858.80	(101)
X. maffafa	89.46	10.38	6.75	6.64	3.66	62.04	-	(88)
X. maffafa	90.60	5.30	1.70	0.45-	1.50	80.56	-	(102)
	93.50	6.80	2.40	1.40	2.40	81.35		
C. bicolor	89.25	8.28	2.12	0.67	1.67	76.52	2830.00	(103)
C. bicolor	92.69	7.21	1.48	4.69	5.13	81.58	-	(60)

X = Xanthosoma
C = Colocasia

Table 2: Comparison of mineral content of yam, cocoyam, bread fruit and plantain flours (mg/100g)

Samples	Calcium	Iron	Magnesium	Zinc
Yam flour	0.015±0.00	2.37±0.39	0.174±0.05	0.035±0.01
Cocoyam flour	0.044±0.01	0.24±0.11	0.167±0.04	0.057±0.01
Breadfruit flour	0.011±0.00	0.36±0.02	0.332±0.02	0.072±0.02
Plantain flour	0.055±0.03	0.21±0.04	0.225±0.01	0.081±0.01

Values are means of triplicate sample ±SD
Source: Oladeji *et al*. (104)

Table 3: Comparison of mineral content of yam, cocoyam, bread fruit and plantain flours

Samples	Bulk density (g/ml)	Water binding capacity (%)	Swelling capacity (%)	pH
Yam flour	0.65±0.12	160.2±0.28	2.72±0.04	5.88±0.03
Cocoyam flour	0.71±0.03	163.1±0.14	3.89±0.1	5.23±0.01
Breadfruit flour	0.56±0.14	268.4±0.57	3.99±0.15	5.84±0.07
Plantain Flour	0.71±0.14	236.4±0.57	3.22±0.06	5.74±0.03

Values are means of triplicate sample ±SD
Source: Oladeji *et al*. (104)

Nutritional compositions of cocoyam leaf

Cocoyam leaves are generally, very high in moisture content, rich in proteins, vitamins, and minerals. The fresh leaf, and petiole of *X. sagittifolium* together have been reported to weight 450 to 650 g, with the leaf component accounting for 40%, and the petiole 60% (32). The average dry matter value of the fresh leaf is 11 - 31%, indicating its high moisture content. Saenphoom *et al*. (33) showed that analysis of taro (*C. esculenta*) leaves yielded, 9.2, 29.7, 4.3, and 15.2% ash, crude protein, ether extract, and hemicellulose contents respectively. Okafor *et al*. (105) reported that *X. maffafa* leaf meal contains 28.5, 15.2, 3.5, 7.8, and 35.3% crude protein, ether extract, crude fiber, total ash, and nitrogen-free extract values respectively, indicating relatively high crude protein, and ether extract values. Studies by Rodriguez (67) revealed 12.4 % crude fiber, and a range of 16.0 – 26.0 % crude protein as influenced by the rate of cutting or age or maturity of the plant, while the calorific value was 20.3-kilocalories per 100 grams of *X. sagittifolium* leaf meal. It has also been reported that cocoyam leaves contain higher levels of starch, and total soluble sugar than most tropical forages, but similar in organic matter, and fiber contents (32). The value of minerals such as Ca, P, K, and Mg have also been reported to average 1.8, 0.2, 3.2, and 0.2% respectively, indicating the need for P supplementation in cocoyam leaf meal-based diets for monogastrics animals (32). Rodriguez, (67) reported that the protein in *X. sagittifolium* leaf meal is rich in lysine (46g/kg crude protein), methionine (27.2g/kg crude protein), cysteine (12.2g/kg crude protein), threonine (49.5g/kg crude protein), and methionine+cysteine (26.9g/kg crude protein). These results show the high level of threonine, and significant levels of the sulphur amino acids in the leaf meal. Temesgen *et al*. (92) also report the major essential amino acids in taro leaf meal to include leucine (9.51g/100g), phenylalanine (6.32g/100g), lysine (6.09g/kg), threonine (4.9g/100g), and methionine+cysteine (4.08g/100g). The proteins are however generally low in digestibility (32). Odedeji *et al*. (78) reported that *Colocasia spp* leaves contain 16.00 and 15.00% B-carotene and vitamin C respectively. Okafor *et al*. (105) also reported that the *X. maffafa* leaf is exceptionally rich in calcium, and moderate in magnesium, potassium, phosphorous, and sodium concentrations, with the values of 17255.00, 2263.00, 13090.00, 2460.00 and 1252.50 mg/kg respectively. The nutrient profiles indicate that cocoyam leaf meals could be used to substitute the costly protein ingredients in animal diets. Leterme *et al*. (106) also reported total and reducing sugar values of 19.7 – 22.9% and 13.7 – 14.0% in the leaves of *X. sagittifolium.* The summary of the nutrient profiles of cocoyam leaves including the fiber fractions are presented in table 4.

The tuber meal therefore has higher energy value than the leaf meals, which contains much higher crude protein, and essential amino acids. The tuber meal could therefore be utilized as a good energy source in monogastric animal nutrition with appropriate protein, and additive supplementations (107). The high protein content of the leaf meal could be exploited in raising the protein, and nutrient values of most chaffy or fibrous cereal by-products such as rice chaff, grain offals, straw or even saw dust for pigs, and ruminants feeding.

Anti-nutritional compositions of cocoyam tuber meals

The usage of cocoyam as food or feed is constrained by its contents of anti-nutritional compounds. These compounds lower palatability because of the acrid nature of the corms, and leaves, which cause irritation in the mouth, throat and skin, and is capable of causing inflammation of these tissues, especially when the corm is taken without treatment (2, 18, 32). The scratchiness, and off-taste problems of cocoyams have been linked to the presence of needle like raphids of calcium oxalate crystals (117), and other anti-nutritional compounds like tannins, and phytates (89). Among the toxicants commonly found in cocoyam corm are phytate, oxalate, tannin, saponin, hydrogen cyanide, trypsin, and alpha-amylase inhibitors (88, 89). Acheampon *et al*. (118), and Amadi *et al*.

(88) confirmed the presence of significant levels of alkaloids, glycosides, flavonoids, and other phenolics compounds in *X. sagittifolium and X. maffafa* tuber meals respectively. Abdurashid and Agwunobi (90) reported the levels of anti-nutritional compounds in raw cocoyam as 1.29, 33.32, 1.52, 6.40 and 1.07 mg/kg for phytate, oxalate, tannin, saponin and cyanide respectively, indicating that oxalates are the major anti-nutrients. Other notable anti-nutrients in cocoyams include trypsin inhibitor, and alpha amylase inhibitors (119, 120). Amadi *et al*. (88) reported that the phytochemical contents of *X. mafafa* root meal in mg/kg were 1066.19 for tannin, 270.49 for phenol, 21.28 for hydrogen cyanide, 632.02 trypsin inhibitor, 1.97 for alkaloids and 24.47for phytate.

Table 4: The nutrient compositions (%) of cocoyam leaves

Cocoyam Spp.	CP	CF	Ash	EE	NFE	NDF	ADF	ADL	Hemi-cellulose	Cellulose	References
X. sagittifolium	24.8	14.2	13.3	-	-	25.5	19.8	-	-	-	(111)
X. sagittifolium	23.1-24.0	12.4-13.0	11.5-13.9	8.0-9.7	-	24.6-29.8	14.6-17.7	3.2-4.6	-	-	(106)
C. esculenta leaves	17.9-26.20	16.9-20.60	11.0-14.5	-	-	53.2-64.8	19.1-41.6	-	-	-	(109)
C. esculenta petiole	3.90-8.20	19.5-22.9	15.3-17.1	-	-	35.3-45.1	25.4-31.4	-	-	-	(109)
C. esculenta	29.71	-	9.23	4.31	-	48.49	33.52	11.90	15.18	21.73	(33)
C. esculenta	15.53-16.41	17.17-17.41	11.60	6.99-9.60	37.71-40.43	-	-	-	-	-	(112)
C. esculenta	25.71-28.20	17.48-26.24	11.58-12.78	9.82-10.93	23.55-31.78	-	-	-	-	-	(113)
C. esculenta	47.10	16.41	12.61	8.82	35.22	-	-	-	-	-	(114)
C. esculenta	16.83	8.88	15.34	6.68	50.04	-	-	-	-	-	(115)
C. esculenta (leaves + petiole)	13.52	23.64	25.76	2.27	34.81	-	-	-	-	-	(167)
X. maffafa	28.5	15.2	7.8	3.5	35.3	-	-	-	-	-	(105)

McEwan *et al*. (119) also reported high levels of trypsin inhibitor (16.5 – 19.7 mg.g-1), amylase inhibitor (21 – 25 mg.g-1), total phenol (11.5 - 13 mg.g-1), alkaloids (0.18 – 0.19 mg.g-1), oxalate (0.10 - 0.13 mg.g-1), phytate (2.8 – 3.1 mg.g-1), saponin 0.14 – 0.15 mg.g-1), and traces of cyanogens in raw *C. esculenta*. Mergedus *et al*. (121) listed mucus, Oxalic acid tannins, cyanides, alpha lectins, amylase inhibitors, protease and chymotrypsin inhibitors in the taro variety. Onu and Madubuike (60) reported similar high levels of tannin, and trypsin inhibitor in the wild cocoyam, *C. bicolor*, indicating that their liberal use in animal feeding would be encumbered by the presence of these anti-nutrients, which would adversely affect protein, and energy utilization, especially in monogastric animals (18). Yahaya *et al*. (122) also reported a seasonal influence on the anti-nutrients content of *X. sagittifulium* root peels in the guinea savannah zone of Nigeria. They showed that the dry season values of phytate, hydrogen cyanide, soluble oxalate, and tannin were lower than the rainy season values.

The major limiting factor in the utilization of cocoyams is its oxalate content which is responsible for the acrid taste or irritation in its raw corm (123). The oxalic acid can occur as soluble or insoluble (Ca^{2+}, Fe^{2+} and Mg^{2+}) salts (124), rendering the minerals unavailable in the later group. The concentrations of anti-nutrients in different varieties of cocoyam meal (table 5) shows varied concentrations of the anti-nutrients across cocoyam species and within species probably because of soil and genetic variations. Holloway *et al*. (125) reported specifically that wild taro cocoyam from Fiji contains 10 times more calcium oxalate than the edible ones, indicating the need for analysis of the anti-nutrients in the cocoyam of different species or from different locations before their use in animal feeding.

Table 5: Concentrations of anti-nutrients (mg/kg) in the corms of different varieties of cocoyam

Cocoyam Spp	Alkaloids	Oxalates	Phenol	Saponin	Tannin	Trypsin	Flavonoid	Phytate	Cyanide	References
X. saggit (mg/kg)	-	33.32	-	6.40	1.52	-	-	1.29	1.07	(90)
X. saggit (g/100g)	-	0.41	-	0.21	0.20	-	-	0.28	7.55	(94)
X. saggit (mg/100g)	-	-	-	-	156.11	-	-	187.52	-	(89)
X. saggit (%)	-	1.69	-	-	8.24	-	-	1.43	3.20	(122)
C. bicolor (%)	-	0.01	0.012	0.128	0.0	1.37	0.004	0.01	0.62	(102)
X. maffafa (mg/100g)	-	0.65	0.78	0.67	0.32	-	0.4	3.27	1.39	(126)
X. maffafa (mg/kg)	1.97	-	270.49	-	1066.19	632.02	-	24.47	21.28	(88)
C. esculenta (%)	-	0.75	-	-	0.35	-	-	1.25	4.18	(99)
C. esculenta (g/100g)	-	0.53	-	0.31	0.25	-	-	1.01	1.71	(100)
C. esculenta (%)	-	30.28	-	-	22.20	-	-	1.78	10.21	(101)
C. esculenta (mg/g^{-7})	0.19	0.13	13.0	0.15	-	19.71	-	3.10	0.025	(119)

Anti-nutritional composition of cocoyam leaf meal

The cocoyam leaves like the roots or corms also contain anti-nutritional compounds. Similar to the situation in the roots, the presence of calcium oxalate crystals in cocoyam foliage, is chiefly responsible for its acridity (123, 26). The total, and insoluble oxalate content of the leaves of nine different cultivars of taro grown in Fiji were reported to range from 278 to 574 mg/100 g wet matter, with the edible leaves generally containing lower levels of total oxalates than the inedible ones (32). The values of tannins, phytates, and oxalates in raw cocoyam leaves have been reported as 34.5, 27.0, and 55.2 mg/kg respectively (78). In addition to this, *X. maffafa* leaves have been reported to contain significant levels of tannins, and phytates. They also contains phenols, cyanide, trypsin inhibitor, alkaloids, and flavonoid at the levels of 1409.12, 4.35, 1069.43, 2.40 and 5890.62 mg/kg respectively (105). In their study of *esculenta* cultivated in Nigeria, (127) reported 62.62, 6.28, 32.15, 35.14, and 3.17 mg/100g for flavonoids, phenols, tannin, saponins, and glycosides respect-tively.

Again, the authors, (84) who worked on *X. sagittifolium* and *C. esculenta* inflorescence showed that fresh cocoyam inflorescence is also associated with irritating sensation in the mouth, and throat due to the presence of oxalate salts, and is the limiting factor to their consumption. Other phytochemicals found in the inflorescence were alkaloids, flavonoids, glycosides, phenols, saponins, steroids, and tannins, with *C. esculenta* containing more alkaloids than *X. sagittifolium* (9.80 and 6.22% respectively), while it was the opposite for saponins (6.61 and 5.50% respectively). Analysis of petiole sap from *X. sagittifolium* revealed that the saponin content was 4.71%, flavonoids 0.51%, alkaloid 4.31%, tannin 1.25%, and glycoside 527.5 ppm, while *C. esculenta* petiole contains 4.20% saponins, 1.80% flavonoids, 5.50%, 1.16% tannins, and 865.8 ppm glycosides (84).

The effects of these anti-nutrients usually include reduced feed intake, digestibility, nutrient utilization, and weight gain. Indeed, a significant amount of the total calcium in cocoyam foliage may be locked up as insoluble calcium oxalate, leaving very insignificant amounts of free calcium in the leaf tissue (26). The chief limitation of the use of cocoyam leaves or inflorescence as a vegetable for humans or feedstuff for livestock, is therefore the presence of oxalates, which can form non-absorbable salts with Ca, Fe, and Mg, rendering these minerals unavailable (124, 32). The presence of numerous anti-nutrients that affect both the intake, and digestibility of cocoyam-based diets however remain serious constraints to their use in commercial livestock, and poultry production (18, 35) and needs to be addressed.

Conclusion and Applications

1. Cocoyam is an abundant tuber crop of the tropical, and sub-tropical regions of the world, including Africa that has remained the major producer of the different edible varieties.
2. Many cocoyam species such as *Xanthosoma maffafa* which were previously part of the food culture of peoples of southern Nigeria are no longer consumed.
3. Since these cocoyam species have been shown to have high calorific value, they could be adopted as alternative energy sources for livestock, and poultry feeding. Other wild species such as *Caladium bicolor* having similar attributes should also be adopted.
4. Cocoyam characterized by high biomass yield in the form of leaves, and petioles, which shown to be moderate in calorific value, and high in crude protein, especially the leaves. The leaf meal could therefore be used as alternative protein source in both ruminants, and non-ruminant diets.
5. The cocoyam tuber and leaf were shown to contain high levels of anti-nutrients such as calcium oxalates which impacts on their palatability, and digestibility.
6. The tuber is low in crude protein, while the protein in the leaves are poorly digested indicating the need for proper processing (heat and chemical treatments among others) and adoption of appropriate feed formulation approaches to maximize their use in animal nutrition.

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