Makerere University Journal of Agricultural and Environmental Sciences
Vol. 9 (1).   pp. 73 - 86, 2020
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ISSN 1563-3721

Nutritional and anti-nutritional physicochemical composition of cocoyam accessions grown under upland conditions

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Abstract

Cocoyam (*Colocasia esculenta* (L.) Schott) is commonly grown in wetlands, which are ecologically fragile ecosystems that should be conserved. The objective of this study, therefore, was to evaluate the effect of growing wetland adapted cocoyam in upland conditions on the nutritional and anti-nutritional properties of the edible parts of the crop. Four distinct accessions of *Colocasia esculenta* were collected from farmers in four agro ecological zones of southwestern Uganda. The accessions were planted under upland conditions as their counterparts in the wetland. The accessions were grown in a Randomized Complete Block Design (RCBD) with three replications at Mbarara Zonal Agricultural Research and Development Institute, Mbarara District, Uganda.Though there were no clear distinctions in nutritional composition of corms and leaves between upland and wetland habitats; there were highly significant differences in moisture, starch, total carbohydrate, sugars, proteins, and fibre in corms and leaves among the four accessions. On the other hand, there were significant differences in anti-nutritional (cyanide and oxalic acid) content of corms and leaves of *C. esculenta* accessions between upland and wetland conditions. The values for cyanide and oxalic acid obtained in *C esculenta* in this study were also significantly higher than WHO acceptable levels for human and other animals' consumption. As such, though upland areas offer opportunities for increased production of the crop without affecting the nutritional status of the crop, methods of preparation that emphasize reduction of the anti-nutritional contents of the crop need meticulous attention in order to expand the to production boundary to upland conditions.

Key words: *Colocasia esculenta*, cyanide, oxalic acid, Uganda, wetland

Introduction

Cocoyam (synonym Taro; *Colocasia esculenta* (L. Schott) belongs to the Aroid family (Aracaceae) and is a food security crop that plays a crucial role in human diets in sub-Saharan Africa (Temesgen and Retta, 2015). Its corm is an excellent source of energy, most of which is in form of starch of which 17-28% is amylose, and the remainder is amylopectin (Oke, 1990). It is especially useful to people allergic to cereals. Cocoyam flour has also been used in infant food formula and canned baby foods because of the good amounts of vitamin B-complex, which are comparable to whole milk (Lee, 1999). *Colocasia esculenta* is one of the few major staple foods in which both the leaf and corms are important in the human diet (Lee, 1999). Opara (2001) reported that *C. esculenta* leaf is an excellent source of carotene, potassium, calcium, phosphorus, iron, riboflavin, as well as thiamine, niacin, vitamin A, vitamin C and dietary fibre. However, both the leaves and corms have anti-nutritional elements, notably cyanogenic glycosides (cyanide) and oxalic acid that have to be eliminated before consumption.

Colocasia esculenta can grow under flooded (lowland) and un-flooded (upland) conditions. It has been alleged that *C. esculenta,* which is traditionally grown in wetlands, changes in its physiochemical compositions when grown under upland conditions. For instance, Huang *et al.* (2007) working in Taiwan found that upland-cultivated *C. esculenta* was richer in mineral content than when grown under paddy (wetland) conditions. However, there has not been a comparative analysis of the status of nutritional profiles of the edible plant parts when the crop is grown in in upland conditions in Uganda. The objective of this study, therefore, was to evaluate the effect of growing wetland adapted cocoyam in upland locations on levels of nutritional and anti-nutritional properties of the edible parts of the crop.

Methodology

Collection of Colocasia esculenta accessions

This study was preceded by a survey to assess production and distribution of the crop in south-western Uganda. Thereafter, accessions of *C. esculenta* were collected from farmers' fields in the districts of Kabale, Ibanda, Rubirizi and Fort Portal, which fall in four agroecological zones of southwestern highlands, southwestern grass farmlands, western mid altitude farmlands, and Semuliki flats, respectively, in southwestern Uganda.

Study design

Four distinct accessions of the crop were identified and planting material collected from the farmers' fields pinpointed in the preliminary survey. The accessions were then planted in upland conditions at Mbarara Zonal Agricultural Research Institute (MBAZARDI), located in the southwestern grass farmlands. The four accessions were planted in a Randomised Complete Block Design (RCBD), with three replications. Total plot size was a 25m by 16m. At 9 months, plants from the accessions in the upland garden at MBAZARDI and similar aged counterparts under wetland conditions in farmers' fields were collected, labelled and taken to the laboratory for analysis.

Plant and soil sampling and analysis

At maturity (9 months), fresh corms and leaves were collected from three randomly selected *C. esculenta* plants of each accession grown under upland and wetland sites as explained above. The corms were harvested using a hand hoe, washed with distilled water, placed in an ice-box and taken for analysis. The fresh leaf samples were cut from each accession, using a sterile stainless steel knife. The corms and leaves of individual accessions were cut into thin slices using a sterile stainless steel knife. Triplicates of 200g were weighed off each accession and batch and dried in an air-forced oven at 60^0C until no more change in weight point was reached. They were then milled into powder using a pestle mill. The Dry Matter Content (DMC) was expressed as a percentage of fresh leaf and corm weight as:

$$\text{DMC}(\%) = (\text{Dry weight})/(\text{Fresh weight}) \times 100$$

The dried plant samples were subjected to proximate analysis for nutritional components, namely moisture, starch, protein, reducing sugars and crude fiber. Dry matter content (DMC) and moisture were determined using the gravimetric method as described by Benesi (2005). The digestible starch content was determined using a Megazyme total starch assay kit (Megazyme International, Bray, Ireland) based on the AOAC (2005) method 996.11 by enzymatic hydrolysis of starch (0.1g), using amylase and amyloglucosidase enzymes in mixture and quantification of glucose using glucose oxidase/peroxidase reagent. The reducing sugar content of the extracted starch samples were determined by dissolving 0.5g of the starch powder in hot 95% ethanol for initial extraction. The reducing sugars extracted into the ethanol were then subsequently quantified by using the Dubois *et al.* (1956) method of reducing sugar quantification.

Total protein content was determined using Bradford method (Bradford, 1976). Dietary fiber was quantified using a Megazyme dietary fiber kit (Megazyme International, Bray, Ireland) by de fating, drying, hydrolysis and deproteinisation of 1.0 g of sample, according to Morrison *et al.* (1995).

The anti-nutritional contents analysed for included cyanide and oxalic acid. Cyanogenic potential was determined by extracting *C. esculenta* leaf and corm samples in a phosphate buffer and subsequent hydrolysis of linamarin with linamarase enzyme (Bradbury *et al*., 1994; Ezeigbo *et al*., 2015). The titrimetric method of Day and Underwood (1986) was used in the determination of oxalate in leaves and corms. In addition, Soil samples were collected at the depth of 0-20cm from both the upland and farmers' wetland gardens where the plant samples were collected to help determine the soil properties at each site. Six sub-samples were collected per farmer garden to constitute a composite sample per site. Soil chemical and physical properties were analysed using the methods adapted from Rhoades (1982).The soil parameters analysed included total C, total and plant available nitrogen (ammonium, nitrite, nitrate), available phosphorus and exchangeable potassium, calcium and magnesium were determined at the soil science laboratory of Makerere University.

Data analysis

Data were subjected to Analysis of Variance (ANOVA) using SPSS version 23.0 (IBM Corp., 2015) at 5% level of significance, to compare parameters means of nutritional and anti-nutritional component levels for different cocoyam accessions, plant parts, and growing habitats. The Least Square Differences Multiple Comparison test was used for mean comparisons.

Results

Description of accessions

The accessions were characterised using morphological/phenotypic descriptors of *C. esculenta* as described by IPGRI (1999). The pictorial characterization of the different *C. esculenta* accessions is presented in Plate 1. Accession 1- had broad leaves with purple veins, and vein junctions; green upper leaf surface, purple green lower leaf surface; and with a predominantly horizontal leaf position. The petioles were pink/purple and the leaf sheath ranged from light to deep green (Plate 1a). Accession 2- had broad leaves, with green veins and yellow vein junctions, deep green lower and upper leaf surface with a predominantly dropping leaf position. The leaf petioles were dark pink and the leaf sheath were light green with dark strips in the interior (Plate 1b). Accession 3- had smaller and smooth leaves, with green veins and faint purple vein junctions, had green yellowish patches on upper leaf surface, green lower leaf surface. The petioles are pink at the upper parts but the color fades down wards, the leaf sheath were green (Plate 1c). Accession 4- had leaves that are deep purple all over, the petiole and leaf sheaths were deep purple (Plate 1d).

Plate a: Accession 1 **Plate b: Accession 2**

Plate c: Accession 3 **Plate d: Accession 4**

Plate 1. Accessions analysed for nutritional and anti-nutritional biochemicals.

Nutritional components in corms and leaves of accessions from upland and wetland conditions

Generally, there were no significant differences in nutritional composition between upland and wetland counterparts (Table 1). However, nutritional biochemical components of *C. esculenta* were significantly different among the different accessions, and between leaves and corms (P<0.05). Among the cocoyam accessions grown under upland conditions, corms of accession 4 had the highest moisture content

Table 1. Nutritional biochemical composition of corms and leaves of *Colocasia esculenta* accessions grown under upland and wetland conditions

Content	Habitat	Mean								
		Accessions 1		Accessions 2		Accessions 3		Accessions 4		F-value
		Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	
Starch (%)	Upland	23.676	9.349	21.122	7.331	18.589	6.113	15.828	5.431	101.745***
	Wetland	27.692	11.219	25.347	8.797	22.308	7.336	18.995	6.517	105.266***
Protein (%)	Upland	8.727	5.548	6.275	3.936	9.863	6.860	7.088	4.624	16.692***
	Wetland	11.616	7.385	8.353	5.239	13.116	9.132	9.434	6.155	16.710***
T.Carbohydrate (%)	Upland	35.670	17.059	44.586	28.983	31.117	13.482	36.581	22.389	32.932***
	Wetland	46.371	18.765	57.963	28.983	40.453	14.83	47.557	24.627	69.535***
Reducing sugars (%)	Upland	15.741	4.140	19.463	7.394	26.145	9.373	24.228	8.074	68.373***
	Wetland	18.89	4.970	23.355	8.875	31.375	11.25	29.075	9.690	68.353***
Moisture (%)	Upland	66.565	31.500	81.345	35.600	79.153	31.000	92.005	30.4	251.147***
	Wetland	75.410	39.37	87.270	44.5	85.555	38.750	91.170	38.0	319.69***
Fibre (%)	Upland	8.250	5.484	7.625	3.157	14.425	6.275	11.350	3.253	26.021***
	Wetland	6.875	4.570	6.354	2.632	12.021	5.229	9.459	2.711	26.018***

F values are for across accessions; *** Significant at P<0.001

(92.01%) and Accession1 had the lowest (66.57%). Corms of Accession 1 had the highest starch content (23.68%) whereas accession 4 had the lowest (15.83%); proteins were highest in Accession 3 (9.86%) and lowest in Accession 2 (6.28%) corms; total carbohydrates were highest in Accession 2 (44.59%) and lowest in accession 3 (31.12%) corms; reducing sugars were highest in Accession 3 (26.15%) and lowest in Acession 1 (15.74%) corms; whereas fibre was highest in Accession 3 (14.43%) and lowest in Accession 2 (7.63%) (Table 1). The leaves showed similar trends in nutreints as corms except for the moisture content where leaves of accession 2 had the highest content (Table 1).

Anti-nutritional components (cyanide and oxalic acid) in corms and leaves of accessions from upland and wetland conditions

Corms and leaves of accessions grown under upland conditions contained more cyanide and oxalic acid content than the same accessions when grown under wetland conditions (Figs. 1 and 2; Table 2). Generally, the cyanide and oxalic acid contents in

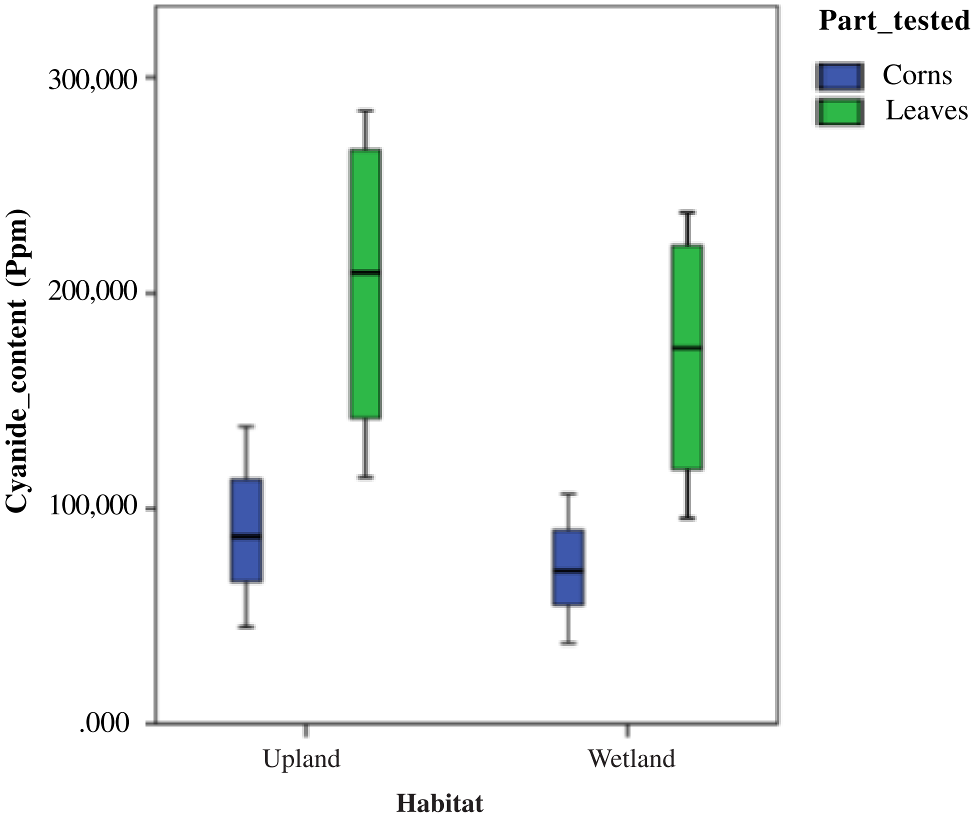

Figure 1. Mean cyanide content in corms and leaves of *Colocasia esculenta* accessions grown under both upland and wetland conditions.

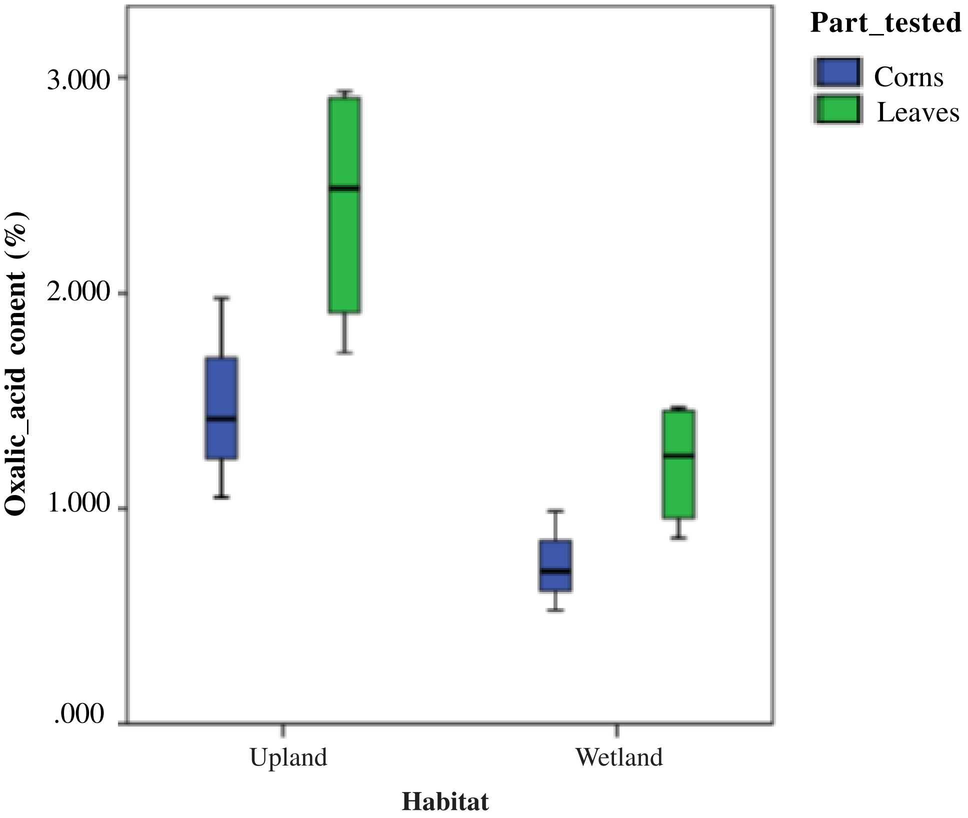

Figure 2. Mean oxalic content in corms and leaves of *Colocasia esculenta* accessions grown under both upland and wetland conditions.

C. esculenta were higher in leaves than corms in accessions grown under both upland and wetland conditions (Figs. 1 and 2). The comparison of cyanide content in the accessions grown under upland condition indicated that corms of accession 3 had the highest cyanide (132.65ppm); while corms of accession 1 had the lowest (46.21ppm). Leaves of accession 2 had the highest cyanide (282.61ppm); while leaves of accession 4 had the lowest cyanide (115.37ppm). Oxalic acid content in corms grown under upland conditions indicated accession 3 to contain the highest level (1.98%). The same accession 3 had the highest oxalic acid (2.94%) in the leaves while leaves of accession 2 had the lowest (1.723) (Table 2). Under wetland conditions, the corms of accession 3 had the highest cyanide (106.42ppm) and oxalic acid (0.988%) content, which was the same trend as for the same accessions grown under upland conditions. The analysis of the contents in leaves also indicated the same trend with accession 3 having the highest cyanide content (235.5ppm) and oxalic acid (1.470%) content. As such, though Accession 3 was rich in nutritional content, it also had the highest anti-nutritional content in both corms and leaves.

Table 2. Anti-nutritional biochemical composition of corms and leaves of *Colocasia esculenta* accessions grown under upland and wetland conditions

Content	Habitat	Mean								
		Accessions 1		Accessions 2		Accessions 3		Accessions 4		F-value
		Corms	Leaves	Corms	Leaves	Corms	Leaves	Corms	Leaves	
Cyanide (Ppm)	Upland	46.210	167.560	86.924	282.609	132.652	251.694	92.005	115.365	17.197***
	Wetland	38.50	96.137	72.43	209.745	106.420	235.5	70.512	139.634	18.572***
Oxalic acid (%)	Upland	1.421	2.096	1.052	1.723	1.976	2.935	1.409	2.876	16.597***
	Wetland	0.711	1.048	0.526	0.862	.988	1.468	0.705	1.438	16.604***

F values are for across accessions; *** Significant at $P<0.001$

Discussion

Nutritional content in corms and leaves of C. esculenta

The results showed that the nutrional components composition of *C. esculenta* was not much different between upland and wetland conditions. However, accessions showed significant differences in nutritional profiles that are noteworthy as far as utility of the crop is concerned. There was a significant effect of accession on moisture content. This meant that the accessions of cocoyam influenced moisture content irrespective of where they were grown. Remarkably, corms of *C. esculenta* had high moisture contents (67-91%), which may predispose them to significant decremental effects during storage in the form loss of weight and marketability due respiration and transpiration (Osunde *et al.*, 2009). As such, processing into flour can prolong the shelf life and add versatility to the product as exemplified by Njintang and Mbofung (2003).

The results on nutritional composition also show *C. esculenta* corms to have high levels of protein (6.3-13.1%) and fibre (6.4-14.4%) but relatively less starch (15.8-27.7%) compared to cassava (Protein 2.7%; Fibre 3.1; starch 76.5%) and sweet potato tubers (Protein 2.5%; Fibre 1.5; Starch 72.4%), findings that are in line with other reports (Abdulrashid and Agwunobi, 2009; Apata and Babalola, 2012; Rodriguez *et al.*, 2016; Olatunde *et al.*, 2018). This shows *C. esculenta* as more balanced in nutritional content and a prospective protein and crude fibre source, and with capacity to contribute to the caloric needs for adults and children.

Anti-nutrient content in corms and leaves C. esculenta

Unfortunately, like cassava, cocoyams have anti-nutrients; cyanogenic glycosides that hydrolyse to form hydrogen cyanide, and oxalic acid. Oxalic acid is another anti-nutrient found in cocoyam. Oxalic acid forms strong bonds with such elements as calcium, magnesium, sodium and potassium in the body (Fink, 1991; Noonan and Savage, 1999). These chemical combination results in the formation of oxalate salts, the insoluble oxalate salts such as calcium oxalate has the tendency to precipitate (or solidify) in the kidneys or in the urinary tract, forming sharp-edged calcium oxalate crystals (kidney stones) when the levels are high enough.

There was a significant increase in cyanide and oxalic acid levels of the different accessions when transferred to the upland habitat. This could be explained by the differences in environmental aspects of the different sites used. Burns *et al.* (2012) showed that differences in cyanide content in cassava was influenced by the genotype environment interaction; and Huang (2007b) showed differences between upland and paddy Taro. Earlier, Tan (1995) and Santisopasri (2000) indicated that water stress (drought) tended to increase cyanide levels in cassava. This may explain why upland conditions produced corms/leaves with high cyanide content than the counterparts grown in wetlands.

Corms and leaves of all accessions under both upland and wetland habitats had significantly higher cyanide levels than the World Health Organization acceptable levels of 10 Ppm/10mg/Kg for human consumption,10-15ppm for Rats, and 5.3ppm for Dogs (WHO, 1990). High levels of the compound can inhibit several enzyme systems, depress growth through interference with certain essential amino acids and utilization of associated nutrients (Olajide *et al*., 2011). The leaves were especially more potent in cyanide and oxalic acid.

As such, efficient methods of preparation/processing like fermentation, sun/oven drying, boiling, blanching, steaming, stewing, ensiling, and garification with palm oil are a prerequisite before consumption by humans or value addition for other animals to reduce cyanide and other anti-nutrient like oxalic acid to below the set limits (Njintang and Mbofung, 2003; Ismaila *et al.,* 2018).

Conclusion

Colocasia esculenta corms and leaves from the accessions used in this study had higher levels of cyanide and oxalis acid than the WHO set standards for safety for human and livestock consumption. This may hinder their utilisation as notable protein, fibre and caloric sources for humans and/or livestock if due consideration is not given to prior processing to reduce them to safe levels. Growing the crop in upland areas increased the levels of the two antinutritional components. As such, though upland areas offer opportunities for increased production of the crop without affecting the nutritional status of the crop, methods of preparation that emphasize reduction of the anti-nutritional contents of the crop need meticulous attention in order to expand the production boundary to upland conditions.

Acknowledgement

We acknowledge the fraternity of Mbarara University of Science and Technology for the academic and material support given. We are indebted to the farmers who availed us with the study materials; and to Mr. John Bosco Muhumuza and Mr. Luke Ninsiima, agronomists at Mbarara Zonal Agricultural Research Development Institute (MBAZARDI). We do extend our heartfelt gratitude to Dr. Ephraim Nuwamanya and Mr. Arnold Katungisa for their technical guidance in plant analysis.

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