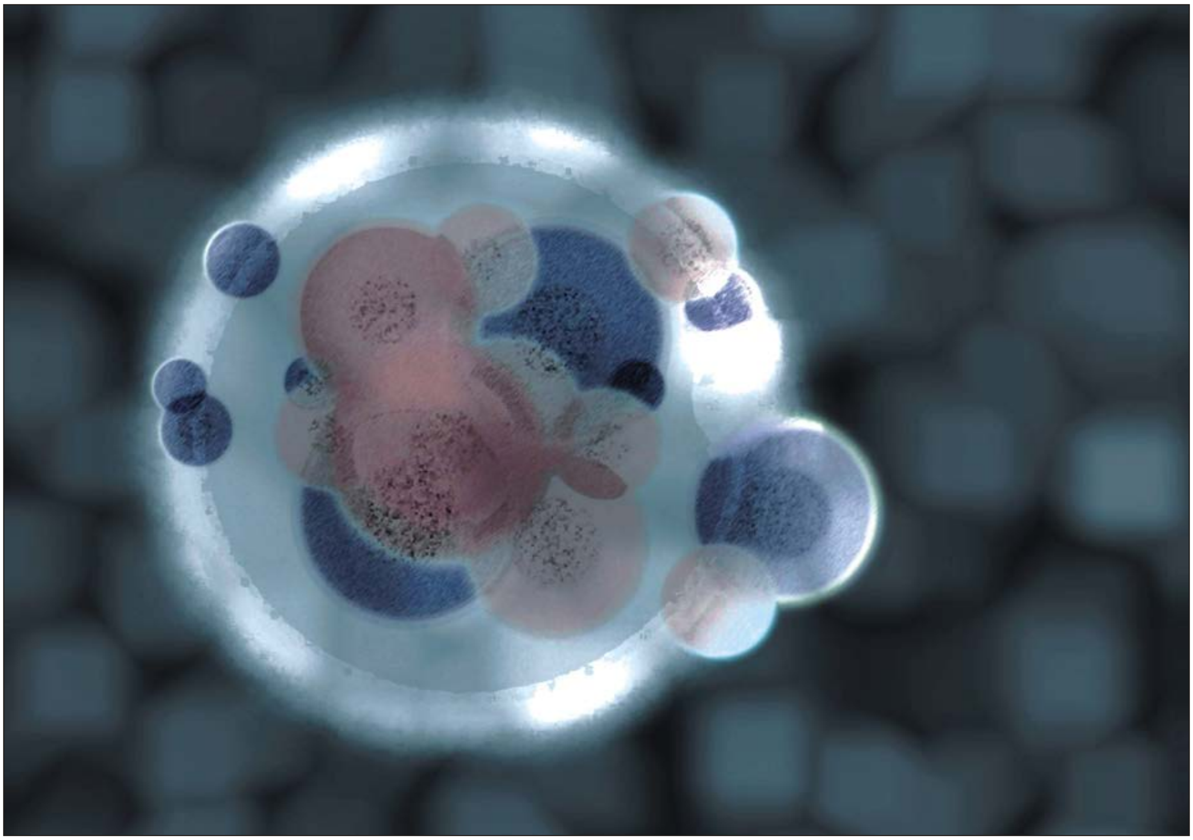

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Mineral Composition of Malawian Cocoyam (*Colocasia esculenta* and *Xanthosoma sagittifolium*) Genotypes

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Abstract: The starchy corms and cormels of cocoyam (*Colocasia esculenta* L. Schott and *Xanthosoma sagittifolium* L. Schott) are used as subsistence staple in the tropics, as they provide a cheap source of carbohydrates. They are also good sources of the essential mineral nutrients. The aim of this study was to determine the mineral content of cocoyam accessions grown by farmers in Malawi. Fifteen accessions from the genebank of Malawi which originated from different regions in the country, were planted in a replicated trial and analysed for mineral content. The accessions were shown to be high in K, P and Mg. They were also rich in essential minerals Ca, Fe and Zn. There was a wide variation in mineral composition among accessions. The *C. esculenta* accessions had significantly higher mean values than *X. sagittifolium* for Fe, Zn, Mn, Ca and Mg, indicating that *C. esculenta* rather than *X. sagittifolium* accessions should be used to address mineral deficiencies. A number of the accessions' K, P, Mg, Fe, Zn and Mn levels were well above the adult recommended dietary allowances and minimum requirements. This crop can be included in the diversification programme undertaken by the Malawi government to curb over reliance on predominantly cereal-based diets, especially in drought prone areas.

Key words: Accessions, essential minerals, cocoyam, genetic variation, subsistence staple

INTRODUCTION

Cocoyam contributes significantly to the human diet in parts of the Pacific region, Latin America, Africa and Asia (FAO, 2001). It is ranked as the fifth most consumed root and tuber crop in the world after potato, cassava, sweet potato and yam (FAOSTAT, 2005). Its starchy corms and cormels are used as a subsistence staple as they provide a cheap source of carbohydrates. Cocoyam serves as a source of income for many families in the tropics and subtropics (Sajeev *et al*., 2004). The main nutrient provided by cocoyam, as with many other root and tuber crops, is the dietary energy supplied by carbohydrates (O'Hair, 1990). The protein fraction of cocoyam tubers is low (1-3%) and like most root and tuber crop proteins, sulphur containing amino acids are limiting. Cocoyam corms and cormels are good sources of essential mineral nutrients that contribute to growth as well as health maintenance and general well being (SPC, 1993). The major mineral nutrient in cocoyam is K (Food and Agriculture Organisation of the United Nations, 1990) and it is also rich in Fe, Zn and Ca (Bradbury and Holloway, 1988; Englberger *et al*., 2008). Variable mineral nutrient levels between different cultivars of cocoyam were observed in Papua New Guinea (Wills *et al*., 1983). The corms contained K (250-480 mg/100 g), Mg (19-37 mg/100 g), Ca (11-45 mg/100 g), Zn (0.2-6.3 mg/100 g), Fe (0.6-1.8 mg/100 g) and Na (0-3 mg/100 g). In a different study (Agbor-Egbe and Rickard, 1990) variation in mineral composition of the two genera of cocoyam was observed, with *C. esculenta* corms showing higher mineral levels than *X. sagittifolium*. *X. sagittifolium* corms contained, on fresh weight basis, Ca (0.5-4.0 g kg^{-1}), P (2.2-4.7 g kg^{-1}), K (15.1-39.1 g kg^{-1}), Mg (1.0-2.1 g kg^{-1}), Fe (12.9-26.9 mg kg^{-1}), Na (38.2-147.7 mg kg^{-1}), Mn (7.2-11.3 mg kg^{-1}), Zn (13.4-16.2 mg kg^{-1}) and Cu (8.3-13.9). Cocoyam is a good source of Na , K, Mg and Ca whose salts regulate the acid-base balance of the body (Njoku and Ohia, 2007). Wide variations observed in the mineral composition values between sections of the corms as well as among different cultivars of cocoyam have been attributed to differences in genetic background as well as climate, soil, season and agronomic factors (Food and Agriculture Organisation of the United Nations, 1990).

Englberger *et al*. (2003, 2008) found that cocoyam tubers contained good levels of provitamin A carotenoids. A wide range of provitamin A carotenoid

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levels were found in cocoyam cultivars (especially in the giant swamp taro) and coloured cultivars showed high levels of α-and β-carotene and essential minerals like Zn and Ca.

In countries like Malawi, where most people's diets are low in animal proteins, i.e., with meat consumption per capita of 5.1 against 13.0 kg per person per year of sub-Saharan Africa (SSA) (FAOSTAT, 2004), the risk of micro-nutrient deficiency is high. Cocoyam nutritional composition studies suggested that it contains a range of important macro-and micro-nutrients (Agbor-Egbe and Rickard, 1990; Njoku and Ohia, 2007; Englberger *et al*., 2003; Sen *et al*., 2006). Recent research has provided data to confirm the micro-nutrient superiority of some lesser known crops like cocoyam and their wild varieties over other more extensively utilised crops (Burlingame *et al*., 2009). However, the existence of many cocoyam genotypes and/or cultivars with distinct botanical characteristics suggests the presence of variation in nutritional composition due to differences in habitat, growth conditions and genetic background. Therefore, in order to develop criteria to improve these cultivars through selection or breeding, nutritional composition of corms need to be determined and compared together with yield traits (Sen *et al*., 2006). Data on nutritional composition would help to re-assess the value of neglected varieties and encourage their sustainable use as well as coming up with a detailed database of micro-nutrient rich plant species that would help in planning nutritional intervention programmes as well as save the loss of micronutrient rich plant species (Hesse, 1971).

This study assessed Malawi cocoyam germplasm with respect to micro-nutrient content in order to identify germplasm that could be used to develop lines that would help combat micro-nutrient deficiencies in the country. Specifically the study assessed the mineral levels (K, P, Ca, Mg, Mn, Na, Fe and Zn) and their variation among the different cocoyam accessions.

MATERIALS AND METHODS

The trial was planted at Chitedze Research Station in July 2008. Soil samples were collected from the trial site and analysed for pH, organic matter, organic carbon and available minerals at the Agricultural Research and Extension Trust Soil Laboratory (Table 1).

Cocoyam samples used were collected from the germplasm bank (collected for genetic diversity studies) at Chitedze Research Station, Lilongwe. Fifteen accessions were used that originated from different districts in the north and south of the country (Table 2). They were classified as *Colocasia esculenta* or *Xanthosoma sagittifolium* according to their leaf type where *C. esculenta* has a peltate and *X. sagittifolium* a sagittate leaf form. Each entry was replicated three times in a randomised complete block design. The planting distance was 0.9 m between rows and 0.9 m between plants. Sampling was done based on maturity of the accessions (corms). The corms were thoroughly washed with water and the outer skins peeled off using a kitchen knife. The fleshy part of the corms was grated, air-dried for 72 h and ground manually into a fine powder using a laboratory metallic motor. The powder of each sample was stored in transparent air-tight plastic bottles as stock samples until required for analyses.

Table 1: Pre-planting soil chemical properties at trial site

Depth	pH $CaCl_2$	OC	OM	N	Total N	P (ppm)	Na	K	Ca	Mg
		------------(%)------------					---------(Meq %)---------			
Top	4.57	1.45	2.94	0.15	0.13	21.70	0.35	0.27	3.12	0.83
Sub	4.60	1.45	2.94	0.15	0.10	20.74	0.31	0.27	3.60	0.80
Top	4.59	1.60	3.25	0.15	0.14	17.20	0.30	0.34	3.76	0.90
Sub	4.85	1.14	2.31	0.12	0.10	18.30	0.23	0.26	4.28	1.00

Top-soil: 0-20 cm, Sub: Soil: 20-40 cm, OC: Organic carbon, OM: Organic matter, ppm: Parts per million, Meq: Milliequivalent

Table 2: Passport data, area of origin in Malawi and species of the entries

Accession name*	Region	District	Species
MHG/SI/07/Coy10	South	Machinga	*X. sagittifolium*
MH/MDU/2007/Coy5	South	Mangochi	*X. sagittifolium*
ZA/CHI/07/Coy27	South	Zomba	*X. sagittifolium*
CK/MKHU/2007/Coy42	South	Chikwawa	*X. sagittifolium*
MJ/NA/07/Coy34B	South	Mulanje	*C. esculenta*
ZA/DU/07/Coy24	South	Zomba	*X. sagittifolium*
TO/NJO/07/Coy39	South	Thyolo	*X. sagittifolium*
MJ/NA/07/Coy34B	South	Mulanje	*X. sagittifolium*
NB/KA/07/Coy53	North	Nkhata-bay	*C. esculenta*
MJ/CHI/07/Coy33	South	Mulanje	*X. sagittifolium*
ZA/MDO/07/Coy14	South	Zomba	*C. esculenta*
MHG/MTE/07/Coy23	South	Machinga	*C. esculenta*
MHG/MPHO/07/Coy12	South	Machinga	*X. sagittifolium*
ZA/KAZE/07/Coy45	South	Zomba	*C. esculenta*
DZ/MBE/07/Coy75	Centre	Dedza	*X. sagittifolium*

*Accession name of the genotypes includes the district, traditional leader of the area and year of collection

Fe, Zn, Mn, Na, K, Ca and Mg was determined according to the method of Hesse (1971) and was read on an atomic absorption spectrophotometer. Phosphate was determined by adding the ammonium vanadate (NH_4VO_3) colour reagent and read on a thermo-spectromic meter.

Statistical analyses: Mineral composition data were subjected to analysis of variance and correlation coefficients were calculated between the minerals (Agrobase, 2005). The least significant difference at $p \leq 0.05$ was used to compare the different entries.

Principle Component Analysis (PCA), a data reduction technique, was performed using the Number Cruncher Statistical System (Hintze, 1998). The goal of this analysis was to construct linear combinations of the original variables that accounted for as much of the total variation as possible. In order to reduce the influence of outliers and scale differences during PCA, data were standardised as follows: The mean observation for each genotype was standardised by subtracting the mean value of the variable and subsequently dividing with its respective standard deviation (FAOSTAT, 2004). This results in standardised values for each variable with an average of zero and standard deviation of one or less.

RESULTS AND DISCUSSION

Mineral content: There were highly significant differences among the accessions with regard to mineral composition (Table 3). Results suggested that K is the major mineral present in the cocoyam accessions studied followed by P, Mg and Ca.

Accessions Coy45, Coy34B and Coy27 showed high levels of K, while Coy12, Coy75 and Coy27 showed high levels of P. Mg was high in accessions Coy23, Coy53 and Coy34A. Accessions that showed high levels of trace elements i.e., Fe and Zn were Coy34A, Coy42, Coy23 and Coy53. On the otherhand cultivars Coy10, Coy5 and Coy33 showed low mineral levels.

The results of this study suggested higher levels of the trace elements (Fe, Zn and Mn) in the cocoyam accessions than reported by Wills *et al.* (1983) and Njoku and Ohia (2007). The high levels of especially K and also P, Mg and Ca support data reported by Njoku and Ohia (2007). The mean values of the essential minerals Fe, Ca and Zn indicated that the mineral levels present in these accessions were above that of other major root and tuber crops (Ravindran *et al.*, 1995). This mineral variation among accessions suggested a wide range of diversity in terms of mineral levels and offers potential genetic material to improve the micro-nutrient levels in accessions through breeding (Sen *et al.*, 2006). The *C. esculenta* accessions had significantly higher mean values than *X. sagittifolium* for Fe, Zn, Mn, Ca and Mg (Table 3) which supported earlier findings (Agbor-Egbe and Rickard, 1990). Therefore *C. esculenta* rather than *X. sagittifolium* accessions should be recommended for planting by small scale farmers.

Variation in mineral composition among the accessions is probably due to differences in the genetic potential of each accession to obtain nutrients from the soil (Guchhait *et al.*, 2008) since different cocoyam genotypes have different nutrient-use efficiencies (Goenaga and Chardon, 1995). As was found in the present study, regarding mineral content, high levels of variability in South East Asia and Oceania taro germplasm were also found with regard to chemical composition for minerals but also for lipids, proteins, amylose, glucose, fructose and saccharose (Lebot *et al.*, 2004). Clearly, the species also played a very large role, with *C. esculenta* accessions generally having significantly higher levels of minerals.

Availability of N, P, K and S fertilisers increase yield as well as nutritional quality of root and tuber crops (Wang *et al.*, 2008). The high mineral levels obtained in

Table 3: Mineral composition (mg kg^{-1}) of cocoyam accessions from Malawi

Accession	Fe	Zn	Mn	Na	Ca	K	Mg	P
Coy10	43.72	16.17	5.67	170.20	81.00	11900.00	662.00	1206.00
Coy5	50.28	17.33	6.17	272.50	76.70	14241.00	650.00	1156.30
Coy27	42.67	17.50	6.00	330.00	70.90	21877.00	715.00	1358.70
Coy42	68.88	19.17	6.33	343.90	85.50	8523.00	605.00	1146.20
Coy34A	153.57	39.33	31.00	30.50	206.80	7633.00	760.00	1234.20
Coy24	45.95	17.17	6.33	230.00	136.10	14917.00	553.00	1129.20
Coy39	35.77	16.83	7.00	322.00	128.30	10717.00	595.00	1144.70
Coy34B	53.11	18.00	11.33	59.50	143.40	22506.00	635.00	1169.00
Coy53	45.94	28.67	42.50	22.80	588.30	8367.00	1283.00	868.50
Coy33	40.82	20.83	7.59	113.60	358.00	18517.00	730.00	1240.50
Coy14	30.79	12.17	5.17	275.70	131.50	15106.00	626.00	1117.50
Coy23	41.87	37.51	42.55	29.00	638.10	13293.00	1316.00	1256.00
Coy12	39.33	22.84	8.25	260.30	133.90	16223.00	553.00	1401.30
Coy45	37.16	25.46	6.25	150.30	198.80	27389.00	659.00	1297.20
Coy75	34.06	17.47	10.25	270.30	133.90	14973.00	534.00	1348.70
Mean	50.90	21.80	13.50	192.00	207.40	15078.60	725.00	1204.90
Mean X^1	45.46	18.33	7.49	237.23	134.77	15439.40	623.20	1230.10
Mean C^2	61.87	28.63	25.49	101.66	352.70	14357.60	928.80	1154.70
CV%	12.33	11.57	3.63	18.73	4.62	9.84	10.28	6.12
SE (±)	5.13	2.06	1.77	29.37	7.82	1210.94	60.87	60.23
$LSD_{0.05}$	10.51	4.21	16.07	60.17	13.30	2480.51	124.69	123.38

LSD: Least significant difference, CV: Coefficient of variation, SE: Standard error. ^{1}*X. sagittifolium*, ^{2}*C. esculenta* the current study may be as a result of the available and exchangeable minerals from both the top- and sub-soils, especially P and K that are important for root development (Li *et al*., 2005). The variation in mineral composition could also be attributed to genetic differences between the accessions in absorbing the soil ions and anions in an acidic soil. The soils at Chitedze Research Stations are sandy clay loam (MoAFS, 2008). The soils were acidic and values of soil organic C, total N, available P, exchangeable Ca, K and Mg were high for both top- and sub-soils. This could be attributed to residual fertilisers from previous cropping seasons (Table 1).

Correlations: The correlation matrix revealed positive and highly significant ($p \leq 0.01$) correlation between Mg and Mn, Mg and Ca as well as Ca and Mn and negative significant correlation between Mg and Na, Ca and Na and Mn and Na (Table 4). The presence of significant negative correlations among different minerals suggest a major challenge to breeders to enhance specific minerals in these genotypes without causing associated negative effects on other minerals (Sen *et al*., 2006).

Principle component analysis: The PCA grouped the eight mineral nutrients into eight components which accounted for 100% of the variability existing among the cocoyam accessions. The first six principal components explained 98.66% of the total variation (Table 5). The first three eigenvectors (the only ones with eigenvalues greater than one) accounted for a cumulative value of 83.34% of the entire variability among the tested cocoyam accessions.

Table 4: Pearson's correlation matrix for the eight minerals of the tested cocoyam accessions

	Zn	Mn	Na	Ca	K	Mg	P
Fe	0.194	0.349	-0.336	-0.031	-0.425	0.045	-0.027
Zn		0.297	-0.343	0.325	0.361	0.274	0.167
Mn			-0.630*	0.861**	-0.428	0.904**	-0.362
Na				-0.580*	0.054	-0.589*	0.312
Ca					-0.193	0.927**	-0.354
K						-0.269	0.481
Mg							-0.416

*$p \leq 0.05$, **$p \leq 0.01$

Table 5: Eigenvectors, eigenvalues, individual and cumulative percentage of variation explained by the first three Principal components (PC) for the eight mineral nutrients of the cocoyam accessions studied

	Eigenvectors		
Variables	PC1	PC2	PC3
Fe	-0.16	-0.17	-0.82
Zn	-0.17	0.59	-0.28
Mn	-0.49	0.00	-0.05
Na	0.38	-0.17	0.17
Ca	-0.46	0.15	0.27
K	0.21	0.63	0.17
Mg	-0.48	0.07	0.23
P	0.27	0.41	-0.26
Eigenvalues	3.77	1.67	1.24
Individual percentage variation explained	47.09	20.81	15.43
Cumulative percent variation explained	47.09	67.91	83.34

The first PC, that explained 47.09% of the total variation among the accessions, was mainly attributed to variation in Mn, Mg, Ca, Na, P and K. Likewise, 20.81% of the total variability among the genotypes accounted for the second PC originated from variation in K, Zn and P. The third PC that explained 15.43% of the total variation was due to variation in Fe only. K and P contributed significantly to variation in two of the three significant PCs, making them relatively more important. This agrees with earlier studies where K was portrayed as the major mineral nutrient component and confirms cocoyam as a good source of Na, Mg, Ca and P (Njoku and Ohia, 2007) as well as having significant levels of Fe, Cu and Zn, especially in purple and yellow or pink-fleshed cultivars (Englberger *et al*., 2003, 2008).

CONCLUSIONS

The results in this study revealed that cocoyam accessions from Malawi are high in K, P and Mg and the crop is capable of absorbing a wide range of minerals with relevance to human health. Accessions were also rich in essential minerals Ca, Fe and Zn. There was a wide variation in mineral composition among accessions. *C. esculenta* had significantly higher levels of the most important minerals (Fe, Zn, Mn, Ca and Mg) than *X. sagittifolium* accessions. Accessions Coy45, Coy27, Coy12 and Coy34B had K, P, Mg, Fe, Zn and Mn levels well above the adult recommended dietary allowances and minimum requirements. Cocoyam can serve as a cheap dietary source of essential minerals required by humans. A complete information package on the nutritional composition of the local cocoyam germplasm would help to guide policy makers, nutritionists and research in incorporating the crop into the diversification programme undertaken by the Malawi government in order to curb drought famine recurrence due to over reliance on predominantly cereal-based diets.

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