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Characterization of chemical composition and anti-nutritional factors in seven species within the Ghanaian yam *(Dioscorea)* germplasm

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Abstract: This study characterized the most cultivated and consumed yam (*Dioscorea*) cultivars within the Ghanaian yam germplasm based on their chemical composition and anti-nutritional factors. Matured yam cultivars grown under the same climatic and edaphic factors were harvested from the Roots and Tuber Conservatory Division of the Council for Scientific and Industrial Research-Plant Genetic Resources Research Institute, Bunso Ghana. Samples were analyzed for proximate composition, mineral content and levels of tannins, phytates and oxalates using standard analytical methods. Significant differences ($p<0.05$) existed between the means of the yam varieties based on their chemical characteristics. The moisture content of the fresh tubers ranged between 58.18 to 77.79%. The varieties had low fat (<1.0%), protein (4.0-6.5%) and fibre (1.25-3.47%) with high carbohydrate (77.5-87.3%) and energy (1451.2-1574.7 kJ/100g). The most predominant minerals were potassium (475-1475 mg/100g), phosphorus (158-294.5 mg/100g) and sodium (62.5-102.5 mg/100g). All the studied varieties had low levels of oxalates, tannins and phytates (<15 mg/100g) and could all be safely recommended for food processing applications. *D. rotundata, D. praehensalis, D. cayenensis* and *D. bulbifera* differed from the rest by having higher levels of carbohydrate and energy with appreciable levels of minerals that make them nutritious and can be used as reliable food and energy security crops. *D. rotundata* (Pona) variety distinguishes itself because of low moisture content (high dry matter) that makes it suitable for high yield flour production.

Key words: Anti-nutritional factors, chemical composition, *Dioscorea* species, oxalate, tannin, phytate

Introduction

Yams are the edible tubers of various species of the genus Dioscorea and are important staple foods of many tropical countries including Côte d'Ivoire, Ghana, Togo, Burkina Faso and Nigeria (Kouakou *et al*., 2010; Amanze *et al.*, 2011). It is a major contributor to food security in West Africa (Zannou 2006), but out of the over 600 known yam species, only seven are mostly consumed (Jayakody *et al.,* 2007). These include *Dioscorea rotundata Poir* (White yam), *Dioscorea cayenensis* (Yellow yam), *Dioscorea alata* (Water yam), *Dioscorea bulbifera* (Aerial yam), *Dioscorea esculenta, Dioscorea praehensalis* (Bush yam) and *Dioscorea dumetorum* (Bitter yam). D. rotundata is the most important species grown and consumed in Ghana, in terms of area planted and quantity produced (Otoo and Asiedu, 2008).

Yam is cultivated mainly in three areas of the world; West Africa and parts of East, Central and Southern Africa (FAO, 1999) are the primary cultivation areas, producing about 95% of the world yam production, followed by Southeast Asia including China, Japan and Oceania. The third area includes the Caribbean, Mexico, and parts of Central America (FAO, 1999). According to FAO statistics, 48.7 million tonnes of yams were produced on five million hectares in about 47 countries worldwide in 2005, and 97% of this was in sub-Saharan Africa (FAO, 2008). West and Central Africa account for ca. 94% of world production. Nigeria is the leading producer with 34 million tonnes followed by Côte d'Ivoire (5 million tonnes), Ghana (3.9 million), and Bénin (2.1 million tonnes). Average yam consumption per capita per day is highest in Bénin (364 kcal) followed by Côte d'Ivoire (342 kcal), Ghana (296 kcal), and Nigeria (258 kcal) (IITA, 2009).

Yam is composed mainly of starch, with some proteins, lipids, vitamins and minerals (Lasztity *et al.,* 1998). Afoakwa and Sefa-Dedeh (2001) reported that *D. dumetorum* is the most nutritious of the commonly consumed yam species, with fairly high protein content and a well balanced amino acid. Agbor-Egbe and Treche (1995) reported a starch content of 15-38% (fresh/wet weight) and 70-80% (dry weight basis) in yams from Cameroon.

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D. rotundata is reported to have about 85% on dry weight basis (Treche and Agbor-Egbe, 1996), *D. dumetorum* is reported to have about 75% (Bell and Favier 1981; Eka 1985; Afoakwa and Sefa-Dedeh 2001), *D. alata* has about 65-80% while D. bulbifera contain about 43-70% (Baah, 2009; Shanthakumari *et al.,* 2008). Their protein, fat and ash content is low with only 3-11%, 0.05-2.5% and 3–9% respectively on dry weight basis have been identified (Treche and Agbor-Egbe, 1996; Afoakwa and Sefa-Dedeh, 2001; Shanthakumari *et al.,* 2008). Yams generally have a considerably higher protein than the 1.2–1.8% on dry weight basis reported for cassava (Charles *et al*., 2005).

Yam tubers are known to contain different toxic substances that affect both human and animals when they are consumed, despite their high nutritional values. Bhandari and Kawabata (2004) reported that most yam tubers are acrid and they are associated with irritation and inflammation of the buccal cavity and throat; consumption can result in gastrointestinal disturbances, vomiting and diarrhea especially when large amounts are ingested into the human body. Anti-nutritional factors, which consist of polyphenols, oligosaccharides (α-galactosides), lectins, proteases and amylase inhibitors, are widely distributed in most plants (Medoua *et al*., 2007). Yang and Lin (2008) reported that the age, the cultivar, the geographic locality of a plant or the storage condition after harvest could significantly affect its anti-nutritional content. The utilization of yams can be limited by the presence of toxic anti-nutrients. The presence of enzyme inhibitors in yams, for example could impair digestion of starch and protein thereby limiting their utilization as food.

In Ghana, yam is consumed by boiling (and eaten as boiled slices, "ampesi" or pounded yam, "fufu"), frying (as yam chips) and roasting. Traditionally, it is often served as yam balls when mashed during festivals (Afoakwa and Sefa-Dedeh 2001). Some yams are also used as medicines to prevent diarrhoea and diabetes (Chou *et al*., 2006; Mignouna, 2008). In China, some species are known to be used in medicines for intestinal colic (and indigestion), to soothe diverticulitis, relieve dysmenorrhoea, as well as allay uterine and ovarian pain (Dwech, 2002; Mignouna, 2008). Yams are however highly perishable commodities which require much attention due to pest infestation and physiological processes as a result of its high moisture content (50-80%) and high respiration rates (Noamesi, 2008). As a result, the tubers have not been processed to any significant extent commercially to establish their potential food and industrial applications. The objective of this study was to investigate the relative nutritional value and anti-nutritional factors within the most cultivated and consumed yam varieties within the Ghanaian yam germplasm.

Material and Methods

Materials and sample preparation

Thirteen matured accessions of the seven cultivated Dioscorea species grown under the same climatic and edaphic factors were harvested randomly from the Council for Scientific and Industrial Research-Plant Genetic Resources Research Institute, Bunso in the Eastern region of Ghana for laboratory studies. The samples include two cultivars each of white yam (*Dioscorea rotundata*), yellow yam (*D. cayenensis*), water yam (*D. alata*), Chinese yam (*D. esculenta*), aerial yam (*D. bulbifera*), trifoliate yam (*D. dumentorum*) and one cultivar of bush yam (*D. praehensalis*). The samples were cleaned by brushing off soil particles and transported at tropical ambient temperature (28-31°C) to the laboratory for analysis. In the laboratory, the samples were washed thoroughly with water, peeled, cut into slices of 1.0 by 1.0 cm using a hand slicer. The slices were then dried at 70°C using an air oven. The dried samples were grounded in a Hammer mill (Christy and Norris Ltd, Model 2A, Chelmsford, Surrey, England) into flour to pass through a 250µm mesh size. Flour samples were bagged in sealed transparent polythene (stomacher) bags which were properly labelled and stored in the cold room (4-10°C), RH of 85-90%.

Proximate analysis

The moisture content and total solid of the fresh tubers were analyzed using the Association of Official Analytical Chemists' (AOAC) approved method 925.09 within 24 hours after harvest. Crude protein, lipid (fat), ash and crude fibre contents of the flours were determined using the Association of Official Analytical Chemists' Approved methods 920.87, 920.39, 923.03 and 962.09E respectively (AOAC 1990). Carbohydrate content was determined by difference.

Mineral analysis

The concentrations of five major and four trace minerals in each yam cultivar were determined by digesting 2.0 g of the flour sample using the Atomic Absorption Spectrophotometric method as outlined in the Association of Official Analytical Chemists' Approved method 968.08 (AOAC, 1990).

Estimation of Ca, Mg, Zn, Mn, Cu and Fe

One (1) ml of the digested solution was used to determine the minerals Ca, Mg, Zn, Mn, Cu and Fe in the sample using Perkin Elmer Atomic Absorption Spectrophotometer (AAS) (Lambda-45, Shelton CT, USA) with acetylene flame. The AAS was filled with Zn, Cu and Fe EDL lamps while CHCL lamps were used for Mg and Ca at various wavelengths.

Estimation of Na and K

Two (2) ml of the digested solution was used to determine Na and K using a Flame Photometer (Jenway PFP7, Sheffield, UK) with methane gas.

Estimation of Phosphorus

One (1) ml of the digested solution was reacted with 5.0 ml molybdic acid. (Molybdic acid was prepared by dissolving 25 ml of ammonium molybdate in 300 ml distilled water, with 75 ml conc. H2SO4 in 125 ml water to get 500 ml of molybdic acid). One (1) ml each of 1% Hydroquinone and 20% Sodium sulphite were added to the mixture in that order. The solution was made up to 100 ml and allowed to stand for 15 minutes. The absorbance was read at 680 nm. A standard calibration curve was produced using standard phosphorus at 5, 10, 15, 20 and 25 µg. All readings were corrected using a blank to eliminate the effect of any colour produced by the reagents.

Determination of anti-nutritional factors

Tannin determination

Total tannin content of yam flour was determined by the spectrophotometric procedure described by Bainbridge *et al*. (1996).

Phytate determination

The phytate is extracted with trichloroacetic acid (TCA) and precipitated as ferric salt using the procedure outlined by Wheeler and Ferrel (1979).

Oxalate determination

The oxalate content in the yam flour samples was analyzed using the calcium oxalate precipitation method as used in the Association of Official Analytical Chemists' (AOAC, 1990) approved method 974.24 with slight modifications. Five (5) g of the ground samples were weighed into a 250 ml Erlenmeyer flask, 100 ml of 2N HCl was added and mixed thoroughly on orbital shaker at 120 rev/min for 2 hours. The mixture was then centrifuged at 3000 rpm for 5 min.

The mixture is filtered and 5 ml of phosphoric tungstate reagent (prepared by adding 12 g of Sodium tungstate dissolved in water to 20 ml of phosphoric acid and the solution was made up to 500 ml with distilled water) was added to 25 ml aliquots of the filtrate. The solution was mixed thoroughly and kept in the cold room overnight. The next day, the solution was centrifuged, filtered and 2 drops of methyl red solution was added to 20 ml aliquots of the filtrate. The mixture was neutralized with drops of ammonia until pink colour changes to faint yellow. Five (5) ml of calcium chloride buffer was added; mixed thoroughly and allowed to stand undisturbed overnight. The solution was filtered again the next day, washed with chloride free distilled water (this was tested with silver nitrate, $Ag(NO_3)$) and the precipitate together with the filter paper were transferred to the same beaker in which it was kept overnight. This was followed by the addition of 50 ml distilled water and 5 ml of $2NH_2SO_4$. The mixture was heated to about 80°C on a water bath and titrated while hot carefully against N/100 $KMnO_4$.

Statistical analysis

Statgraphics (Centurion version) and Minitab (version 14) were used respectively for statistical analyses and graphical presentation. Analysis of variance (ANOVA) was used to test for significant differences between means. A multiple range test (Tukeys Least Significant Difference) was conducted at a level of significance of $p<0.05$. Cluster analysis (cluster observation) was carried out to determine yam varieties with similar characteristics. Principal component analysis was used to determine any patterns and explore the relationships between the various parameters and the yam varieties.

Results and Discussion

Proximate composition

Significant differences existed between the moisture content of the fresh tubers from the different yam species (Table 1). The moisture content of all accessions were observed not to differ significantly except the accessions of *D. rotundata* and *D. bulbifera* which were significantly different at $p<0.05$. *D. rotundata* (Pona) recorded the lowest moisture of 58.18% while *D. dumetorum* (Yellow) had the highest, 79.26%. The ranges in moisture were below those observed by Agbor-Egbe and Treche (1995). Similar values were observed for *D. dumetorum* (Afoakwa and Sefa-Dedeh, 2001) while higher range of values 71.06 - 92.48% was observed by Shanthakumari *et al*. (2008). Varieties with low moisture content would be suitable for prolonged tuber storage and more efficient for industrial processing. After processing the tubers into flour, the moisture content ranged between 4.02 - 8.17 with

Table 1. Proximate composition of yam varieties

Yam Variety	Moisture content [1] (%)	Moisture Content [2] (%)	Crude Protein [2] (%)[§]	Crude Ash [2] (%)
D. rotundata (Pona)	58.18±1.22[a]	6.66±0.13[a]	4.42±0.18[a,b]	1.29±0.11[a]
D. rotundata (Labrekor)	63.23±0.24[b]	7.38±0.08[b]	4.03±0.87[a]	2.57±0.27[a]
D. bulbifera (Light Grey)	68.60±1.72[c]	4.58±0.59[b]	5.38±0.43[a,b]	8.15±0.37[d]
D. bulbifera (Deep Grey)	64.13±1.44[b]	4.02±0.14[c]	5.30±0.43[a,b]	7.73±0.67[c,d]
D. cayenensis (Light Yellow)	68.58±0.84[c]	8.17±0.10[c]	5.78±0.12[b,c]	5.48±0.76[b]
D. cayenensis (Pure Yellow)	68.99±0.85[c]	8.15±0.08[c]	5.30±0.03[a,b]	5.22±0.14[b]
D. praehensalis	64.06±0.63[b]	6.71±0.01[b]	5.38±0.31[a,b]	4.90±0.28[b]
D. dumetorum (White)	75.68±0.22[d]	7.44±0.06[c]	6.21±0.25[c]	7.79±0.19[c,d]
D. dumetorum (Yellow)	79.26±1.80[d]	7.59±0.04[c]	6.52±0.56[c]	7.79±0.03[c,d]
D. alata (Matches)	64.88±0.42[b,c]	5.71±0.01[b,c]	6.08±0.56[c]	6.29±0.01[b,c]
D. alata (Akaba)	66.82±0.38[b,c]	6.60±0.02[b,c]	5.91±0.02[b,c]	6.19±0.84[b,c]
D. esculenta (Large)	77.15±1.86[d]	5.32±0.03[d]	5.60±0.37[b,c]	8.50±0.55[d]
D. esculenta (Small)	76.79±0.13[d]	6.03±0.15[c]	5.73±0.19[b,c]	7.57±0.62[c,d]

Values are Means ± standard deviation from triplicate analyses. Those with the same superscripts in the same column are not significantly different at P < 0.05.
[§] (N x 6.25) [1] Values reported on Fresh weight basis [2] Values reported on Dry weight basis

Table 1 continued. Proximate composition of yam varieties

Yam Variety	Crude Fat (%)	Crude Fibre (%)	Carbohydrate (%)	Energy (kJ/100g)*
D. rotundata (Pona)	0.41±0.00[a]	1.25±0.32[a]	87.31±0.07[a]	1574.7±1.80[a]
D. rotundata (Labrekor)	0.46±0.07[a]	1.68±0.18[a]	85.51±1.21[a]	1539.1±3.27[d]
D. bulbifera (Light Grey)	0.55±0.17[a]	2.35±0.38[a,b]	81.76±0.23[c,d]	1501.8±9.77[b,c]
D. bulbifera (Deep Grey)	0.53±0.02[a]	2.03±0.34[a,b]	82.52±0.43[d]	1512.7±12.00[c,d]
D. cayenensis (Light Yellow)	0.50±0.07[a]	1.91±0.40[a]	80.01±0.57[b,c]	1476.8±14.30[a,b]
D. cayenensis (Pure Yellow)	0.53±0.07[a]	2.44±0.58[a,b]	80.75±0.24[c,d]	1482.5±0.99[b]
D. praehensalis	0.48±0.28[a]	1.41±0.10[a]	82.52±0.31[d]	1511.9±10.20[c,d]
D. dumetorum (White)	0.61±0.18[a]	3.47±0.92[b]	77.91±0.12[a,b]	1452.6±0.29[a]
D. dumetorum (Yellow)	0.61±0.06[a]	2.10±0.01[a,b]	77.53±0.59[a]	1451.2±1.63[a]
D. alata (Matches)	0.81±0.27[a]	1.75±0.31[a]	81.10±0.27[c,d]	1511.9±5.28[c,d]
D. alata (Akaba)	0.82±0.02[a]	1.59±0.06[a]	80.47±0.80[c,d]	1499.0±14.70[b,c]
D. esculenta (Large)	0.76±0.06[a]	2.19±0.11[a,b]	79.84±0.98[b]	1480.5±8.10[b]
D. esculenta (Small)	0.73±0.03[a]	2.34±0.03[a,b]	80.05±0.46[b,c]	1485.2±9.89[b]

Values are Means ± standard deviation from triplicate analyses expressed on dry weight basis. Those with the same superscripts in the same column are not significantly different at P < 0.05.
*Calculated Metabolisable energy (kJ/100 g sample) = (Protein x 17+ fat x 37 + carbohydrate x 17)

D. bulbifera and *D. cayenensis* respectively having the lowest and highest. These values were slightly different from the 5.26-7.57% reported by Udensi *et al*. (2008). The moisture levels were however within the acceptable limit of not more than 10% for long term storage of flour. Protein content recorded for the varieties were generally lower (4.03 – 6.52%) for *D. rotundata* (Labrekor) and *D. dumetorum* (Yellow) respectively than what has been previously reported by Agbor-Egbe and Treche (1995) on Cameroonian yams (3.7-13.2%) and Shanthakumari *et al.* (2008) (5.25-15.75%). The levels were similar to reported values for cocoyam (4.00 – 5.12) (Sefa-Dedeh and Agyir-Sackey 2004), but higher than reported range for cassava (0.2 – 1.5%) (Charles et al., 2005). The protein contents in the studied varieties were significantly different ($p<0.05$).

Ash contents of the varieties were significantly different ($p<0.05$) and ranged from 1.29 to 8.50% for *D. rotundata* (Pona) and *D. esculenta* (Large) respectively. These values were comparable to literature values as reported by Afoakwa and Sefa-Dedeh (2001); Bhandari *et al*. (2003) and Shanthakumari *et al*. (2008). All the yam varieties had low fat contents below 1.0% (Table 1) similar to values found by Agbor-Egbe and Treche (1995) on Cameroonian yams (0.10 – 0.92). *D. alata* (Akaba) was observed in this study to have the highest fat level of 0.82% while *D. rotundata* (Pona) had 0.41%. There were no significant differences ($p<0.05$) amongst the studied varieties. Crude fibre content noted were slightly higher than the 0.6 - 2.44 reported by earlier researchers (Afoakwa and Sefa-Dedeh, 2001; Bhandari *et al*., 2003; Alinnor and Akalezi, 2010). *D. rotundata* (Pona) had the lowest value of 1.25% while 3.47% was detected in *D. dumetorum* (White). Carbohydrate values ranged from 77.53% for *D. dumetorum* (Yellow) to 87.31% for *D. rotundata* (Pona). These values are comparable to literature values 76.80 – 78.3% (Eka, 1985; Bell and Favier, 1981) and 81.31 – 87.64% (Udensi *et al*., 2008). The estimated metabolized energy registered the range of 1451 kJ 100 g-1 for *D. dumetorum* (Yellow) and 1574.7 kJ 100 g-1 for *D. rotundata* (Pona). The high carbohydrate and energy values of the yams recorded in this study make them reliable food security crops.

Mineral composition

Significant differences ($p<0.05$) were observed in the mineral content of the yam varieties investigated. The samples generally had high levels of potassium, phosphorus, calcium and sodium (Table 2). Potassium was the most abundant, recording high levels (1475.0 mg/100g) in *D. bulbifera* (Light) and lowest (475.0 mg/100g) in *D. rotundata* (Pona). The contents of sodium, potassium, phosphorus and magnesium were higher than those reported for Cameroonian yam species (Agbor-Egbe and Treche, 1995), but are lower than the values reported for yam species from Sri Lanka (Wanasundera and Ravindran, 1994). The contents of micro-nutrients, such as copper, iron, zinc

Table 2. Mineral composition of yam varieties (mg/100g)

Yam Variety	Potassium (K)	Sodium (Na)	Calcium (Ca)	Magnesium (Mg)	Phosphorus (P)
D. rotundata (Pona)	475.0±3.54^{a}	70.0±1.41^{a,b}	103.25±4.60^{d,e}	35.5±4.95^{a}	158.0±17.0^{a}
D. rotundata (Labrekor)	900.0±1.42^{b,c}	87.5±1.77^{a,b}	91.50±17.7^{c,d}	53.0±1.41^{b}	211.5±54.4^{a,b}
D. bulbifera (Light Grey)	1475.0±10.61^{g}	102.5±3.54^{b}	103.00±1.41^{d,e}	83.5±0.71^{e}	223.5±2.12^{b}
D. bulbifera (Deep Grey)	1250.0±14.1^{e,g}	92.5±3.54^{a,b}	116.50±2.12^{e}	76.5±13.44^{e}	224.5±10.61^{b}
D. cayenensis (Light Yellow)	825.0±17.7^{a,b}	70.0±7.07^{a,b}	74.50±3.54^{c}	57.5±2.12^{b}	164.5±10.61^{a}
D. cayenensis (Pure Yellow)	700.0±7.07^{a,b}	62.5±3.54^{a}	82.00±1.41^{c,d}	38.0±1.41^{a}	190.5±53.0^{a,b}
D. praehensalis	1000.0±21.2^{b,c}	80.0±7.07^{a,b}	79.50±3.54^{c}	43.5±0.71^{a}	200.5±0.71^{a,b}
D. dumetorum (White)	670.0±0.00^{a,b}	72.5±3.54^{a,b}	27.50±3.54^{a,b}	61.5±0.71^{b,c}	269.0±2.83^{b,c}
D. dumetorum (Yellow)	772.5±3.54^{a,b}	77.5±3.54^{a,b}	29.50±2.12^{b}	61.5±0.71^{b,c}	286.0±4.95^{c}
D. alata (Matches)	742.5±3.54^{a,b}	95.0±1.41^{a,b}	16.50±0.71^{a,b}	41.5±0.71^{a}	239.0±29.7^{b}
D. alata (Akaba)	622.5±4.60^{a,b}	62.5±3.54^{a}	6.50±0.71^{a}	40.0±4.24^{a}	219.0±4.24^{b}
D. esculenta (Large)	795.0±1.41^{a,b}	87.5±10.61^{a,b}	20.50±0.71^{a,b}	67.5±3.54^{c,d}	273.5±3.54^{b,c}
D. esculenta (Small)	765.0±1.41^{a,b}	92.5±10.61^{a,b}	27.00±2.83^{a,b}	73.0±1.41^{c}	294.5±4.95^{c}

Values are Means ± standard deviation from duplicate analyses. Those with the same superscripts in the same column are not significantly different at P < 0.05.

Table 2 continued. Mineral composition of yam varieties (mg/100g)

Yam Variety	Iron (Fe)	Copper (Cu)	Manganese (Mn)	Zinc (Zn)
D. rotundata (Pona)	6.75±1.06^{c,d}	0.25±0.07^{a,b}	1.80±0.00^{b,c}	6.80±1.70^{a}
D. rotundata (Labrekor)	5.00±1.41^{b,c}	0.20±0.00^{a}	1.15±0.07^{a}	6.30±0.57^{a}
D. bulbifera (Light Grey)	6.00±0.00^{c}	0.20±0.00^{a}	1.30±0.00^{a,b}	6.10±0.14^{a}
D. bulbifera (Deep Grey)	6.50±0.71^{c,d}	0.20±0.00^{a}	1.35±0.07^{a,b}	6.35±0.50^{a}
D. cayenensis (Light Yellow)	5.00±1.41^{b,c}	0.20±0.00^{a}	1.20±0.42^{a}	5.45±0.35^{a}
D. cayenensis (Pure Yellow)	5.50±0.71^{c}	0.20±0.00^{a}	1.25±0.07^{a,b}	5.85±0.64^{a}
D. praehensalis	9.00±0.00^{d}	0.40±0.14^{b}	0.95±0.07^{a}	5.40±0.57^{a}
D. dumetorum (White)	2.50±0.71^{a,b}	0.10±0.00^{a}	2.65±0.07^{d,e}	5.80±0.57^{a}
D. dumetorum (Yellow)	2.00±0.00^{a}	0.10±0.00^{a}	2.50±0.14^{d,e}	5.80±0.85^{a}
D. alata (Matches)	2.00±0.00^{a}	0.15±0.07^{a}	2.15±0.07^{c,d}	6.80±0.42^{a}
D. alata (Akaba)	1.50±0.71^{a}	0.10±0.00^{a}	2.20±0.14^{c,d}	6.65±1.20^{a}
D. esculenta (Large)	2.00±0.00^{a}	0.10±0.00^{a}	2.70±0.00^{d,e}	7.80±0.00^{a}
D. esculenta (Small)	2.00±0.00^{a}	0.10±0.00^{a}	2.95±0.07^{e}	6.20±0.42^{a}

Values are Means ± standard deviation from duplicate analyses. Those with the same superscripts in the same column are not significantly at p < 0.05.

and manganese in the analyzed yam species (Table 2) compare well with reported values by Agbor-Egbe and Treche (1995). Comparison of mean values per species for each mineral estimated showed that significant differences ($p<0.05$) exist between the yam species studied. However, marked intra-species variability was not observed for most minerals. Varieties studied had higher mineral contents than minerals reported in cocoyam (*Colocasia esculenta (L.)*) (Alinnor and Akalezi, 2010; Lewu *et al*., 2010).The variations observed in this study may be considered to largely reflect the differences in genotype, since all samples were obtained from the same cropping area subjected to similar agronomic practices.

Anti-nutritional levels in yam varieties

The levels of tannins, phytates and oxalates in the yam varieties are given in Table 3. In general the tannins, phytates and oxalates content of the studied yam samples were comparatively lower than reported

Table 3. Antinutritional composition of yam varieties (mg/100g)

Yam Variety	Tannins	Phytates	Oxalates
D. rotundata (Pona)	4.56±0.01^{a}	2.60±0.15^{d,e}	0.58±0.01^{d,e}
D. rotundata (Labrekor)	6.94±0.29^{c}	2.54±0.11^{c,d}	0.59±0.03^{e,f}
D. bulbifera (Light Grey)	10.27±0.35^{f}	1.20±0.22^{a}	0.63±0.02^{f}
D. bulbifera (Deep Grey)	10.98±0.03^{g}	2.24±0.23^{c}	0.58±0.02^{d,e}
D. cayenensis (Light Yellow)	5.76±0.02^{b}	3.24±0.03^{f}	0.50±0.05^{c,d}
D. cayenensis (Pure Yellow)	4.40±0.14^{a}	4.16±0.21^{g}	0.51±0.03^{c,d}
D. praehensalis	8.08±0.04^{d}	2.19±0.17^{c}	0.52±0.05^{c,d}
D. dumetorum (White)	9.17±0.03^{e}	2.50±0.26^{c,d}	0.46±0.04^{b,c}
D. dumetorum (Yellow)	7.19±0.02^{c}	2.10±0.08^{b,c}	0.43±0.04^{b,c}
D. alata (Matches)	13.20±0.04^{h}	3.01±0.24^{e,f}	0.45±0.03^{b,c}
D. alata (Akaba)	10.75±0.05^{f,g}	0.89±0.20^{a}	0.50±0.03^{c,d}
D. esculenta (Large)	6.82±0.39^{c}	1.89±0.11^{b}	0.34±0.04^{b}
D. esculenta (Small)	7.03±0.03^{c}	1.02±0.14^{a}	0.20±0.03^{a}

Values are Means ± standard deviation from duplicate analyses. Those with the same superscripts in the same column are not significantlydifferent at P < 0.05

values in cocoyam, (*Colocasia esculenta (L)*) (Lewu *et al*., 2010). Tannins have been reported to form complexes with proteins and reduce their digestibility and palatability (Eka, 1985). However, their contents in foods are known to reduce through cooking (Lewu *et al*., 2010). Tannins concentration in the yam samples studied ranged from 4.40 mg/100g for *D. cayenensis* (Pure yellow flesh) to 13.20 mg/100g for *D. alata* (Matches). These values are relatively lower than those of 20-255 mg/100g reported on various under-utilized Dioscorea tubers (Arinathan *et al*., 2009). Phytates and oxalates are known to adversely affect mineral bioavailability (Bhandari and Kawabata, 2006). The phytate contents of the yams were low, with values ranging from 0.89 mg/100g in *D. alata* (Akaba) to 4.16 mg/100g dry matter in D. cayenensis (Pure yellow flesh), compared to the 58.6 – 198 mg/100g on cultivars of *D. alata* reported by Wanasundera and Ravindran (1994). These values in yams are much lower than those of 400-2060 mg/100 g reported for cereals and grain legumes (Reddy *et al*., 1982). Oxalates levels were also very low (0.20 – 0.63 mg/100g) for *D. esculenta* (Small) and *D. bulbifera* (Light) respectively relative to the 483 – 781 mg/100g noted by Wanasundera and Ravindran (1994).

Cluster and principal component analysis for chemical characteristics of yam varieties

The yam varieties were statistically analyzed for similarities in their proximate, mineral and antinutritional characteristics using cluster observation analysis. Principal component analysis was further used to display patterns and interrelationships between

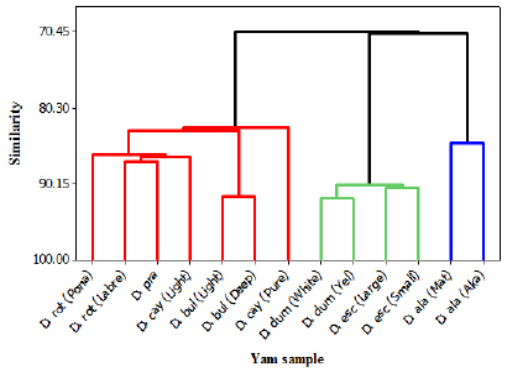

Figure 1. Cluster observation dendogram for chemical compositions of yam varieties
Key: D. rot (Pona) = *D. rotundata* (Pona), **D. rot (Labre)** = *D. rotundata* (Labrekor), **D. pra** = *D. praehensalis* (Kokoase), **D. cay (Light)** = *D. cayenensis* (Light yellow), **D. cay (Pure)** = D. *cayenensis* (Pure yellow), **D. esc (Small)** = *D. esculenta* (Small tubers), **D. esc (Large)** = *D. esculenta* (Larger tubers), **D. dum (White)** = *D. dumetorum* (White), **D. dum (Yel)** = *D. dumetorum* (Yellow), **D. ala (Mat)** = *D. alata* (Matches), **D. ala (Aka)** = *D. alata* (Akaba).

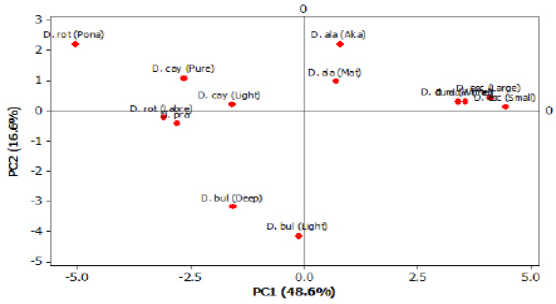

Figure 2. Sample score plot for the principal component analysis of the chemical characteristics of the yam varieties
Key: D. rot (Pona) = D. rotundata (Pona), D. rot (Labre) = D. rotundata (Labrekor), D. pra = D. praehensalis (Kokoase), D. cay (Light) = D. cayenensis (Light yellow), D. cay (Pure) = D. cayenensis (Pure yellow), D. esc (Small) = D. esculenta (Small tubers), D. esc (Large) = D. esculenta (Larger tubers), D. dum (White) = D. dumetorum (White), D. dum (Yel) = D. dumetorum (Yellow), D. ala (Mat) = D. alata (Matches), D. ala (Aka) = D. alata (Akaba).

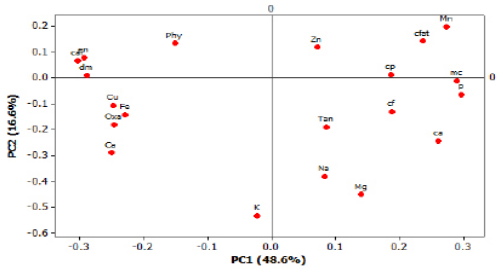

Figure 3. Variable weights plot for the principal component analysis of the chemical characteristics of the yam varieties
Key: mc =Moisture content, dm = Dry matter, cp = Crude protein, ca = Crude ash, cf = Crude fibre, cfat = Crude fat, car = Carbohydrate, en = Energy, K = Potassium, Na = Sodium, Ca = Calcium, Mg = Magnesium, P = Phosphorus, Fe = Iron, Cu = Copper, Mn = Manganese, Zn = Zinc, Tan = Tannins, Phy = Phytates, Oxa = Oxalate

samples and their chemical characteristics. Figure 1 shows the cluster observations dendogram for the chemical characteristics of the yam varieties. The samples were partitioned into three clusters based on similarity of chemical characteristics. Accessions of *D. rotundata, D. praehensalis, D. cayenensis* and *D. bulbifera* form the first cluster; *D. dumetorum* and *D. esculenta* accessions form the second cluster while *D. alata* accessions constituted the third cluster.

Principal component (PC) analysis applied to the chemical characteristics of the yam varieties showed two components explaining a total of 65.2% of the variability in the sample score plot (Figure 2). PC1 accounted for 48.6% of the total variation in the chemical characteristics while PC2 related to 16.6%. PC1 is dominant with moisture content, carbohydrate, energy, phosphorus, iron, copper, manganese and oxalate which contributed significantly to the percentage variations described by this component. Major minerals such as potassium, sodium and magnesium were the determinants of PC2. The loadings of the samples on the score plot (Figure 2) supported the clusters observed in the dendogram (Figure 1). The accessions of *D. rotundata, D. praehensalis, D. cayenensis* and *D. bulbifera* that form the first cluster were loaded to negative side of PC1; *D. dumetorum* and *D. esculenta* accessions which are in the second cluster were loaded to the rear positive end of PC1 while *D. alata* accessions in the third cluster were loaded close to the positive reference (zero) axis of PC1. The sample score plot corresponds to the variable weights plot (Figure 3). Dry matter, carbohydrates, energy, copper, iron, calcium, potassium, oxalates and phytates contents loaded on PC1 relates to *D. rotundata, D. praehensalis, D. cayenensis* and *D. bulbifera*; whilst moisture, protein, fat, fibre, ash, phosphorus and manganese concentrations associated with *D. dumetorum* and *D. esculenta*. The minerals magnesium, sodium, zinc and tannins levels related with *D. alata* (Figures 2 and 3).

Conclusion

The chemical composition and anti-nutrient constitution of the seven different yam (*Dioscorea*) species grown and consumed in Ghana varied significantly. The moisture content of the fresh tubers was identified to range between 58.18 to 77.79%, and showed that the varieties could be grouped into three categories according to their dry matter content. These groupings included: high dry matter (with low moisture content of 58.18% for *D. rotundata*), intermediate dry matter (with moisture content of 63-66.8% for *D. alata, D. praehensalis* and *D. bulbifera*) and low dry matter (with high moisture content of 67-78.3% for *D. cayenensis, D. esculenta* and *D. dumetorum*). Among all the varieties, *D. rotundata* (Pona) variety distinguishes itself because of low moisture content (high dry matter) that makes it suitable for high yield flour production. The varieties had low fat (<1.0%) and fibre (1.25-3.47%) with high carbohydrate (77.5-87.3%) and energy (1451.2-

1574.7 kJ/100g). *D. rotundata, D. praehensalis, D. cayenensis* and *D. bulbifera* differ from the rest by having higher levels of carbohydrate and energy with appreciable levels of minerals that make them nutritious and can be used as reliable food and energy security crop. The low levels of protein (4.0-6.5%)) in these yam varieties means that food products from such crops should be eaten with high-protein sauce for good nutritive value. The most predominant minerals identified were potassium (475-1475 mg/100g), phosphorus (158-294.5 mg/100g) and sodium (62.5-102.5 mg/100g). All the studied varieties had low levels of oxalates, tannins and phytates (<15 mg/100g) and could all be safely recommended for food processing applications. No clear differences were observed between accessions of the same species in both nutritional and anti-nutritional compositions.

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