

**VARIABILITY IN BIOCHEMICAL COMPOSITION AND CELL WALL
CONSTITUENTS AMONG SEVEN VARIETIES IN GHANAIAN YAM
(*DIOSCOREA SP.*) GERMPLASM**

Afoakwa EO^{1*}, Polycarp D¹, Budu AS¹, Mensah-Brown H² and E Otoo³



Emmanuel Afoakwa

*Corresponding Author: eofoakwa@gmail.com / eofoakwa@ug.edu.gh

¹Department of Nutrition & Food Science, University of Ghana. P. O. Box LG 134, Legon-Accra, Ghana

²Department of Food Process Engineering, University of Ghana. Legon – Accra, Ghana

³Crops Research Institute of Ghana, Fumesua-Kumasi, Ashanti Region, Ghana

ABSTRACT

This work characterized the most cultivated and consumed yam (*Dioscorea*) cultivars within the Ghanaian yam germplasm based on their biochemical and cell wall constituents to assess their potential alternative food and industrial processing applications. Samples were analyzed for their biochemical composition - starch, amylose, amylopectin, total sugars, reducing sugars and non-reducing sugars along the head, middle and tail regions of each tuber using standard analytical methods. Cell wall constituents - acid detergent fibre, neutral detergent fibre, acid detergent lignin, cellulose and hemicellulose of each tuber were also determined using standard analytical methods. The results showed no significant differences at $p < 0.05$ in biochemical compositions along the length of the studied cultivars. *D. cayenensis* (Pure-yellow), *D. rotundata* (Pona) and *D. alata* (Matches) were found to have high starch contents (63.16-65.69%, 63.54-65.30% and 63.24-65.17% respectively). Amylose content was observed to vary along the length of the tubers for the varieties studied. *D. alata* (Matches) was observed to contain the highest amylose content of 19.66-20.64%. No identifiable trend was however, observed for the amylopectin content along the length between the varieties investigated. *D. bulbifera* recorded the lowest amylopectin content of 41.29%, 43.59% and 44.63% while *D. esculenta* had the highest with 49.84%, 50.24% and 50.13% along the tail, middle and head sections respectively. Total sugar content varied significantly ($p < 0.05$) along the lengths of all the varieties investigated. It was higher at the tail portions for all the varieties studied than the head regions; the middle portions recorded the least. *D. bulbifera* recorded highest total sugar contents (4.74-4.84%) and total sucrose (3.58-3.64%). There were significant differences ($p < 0.05$) in the cell wall constituents of the yam varieties. Cellulose was found to be the most common cell wall component with *D. rotundata* having the highest level of 3.36% whilst *D. dumetorum* had the least (1.56%). Hemicellulose content ranged between 0.42 g/100g in *D. alata* to 4.58 g/100g in *D. esculenta* while lignin content ranged from 1.56 g/100g in *D. dumetorum* to 2.87 g/100g for *D. praehensalis*. There were significant differences ($p < 0.05$) in the neutral detergent fibre found in *Dioscorea esculenta* and the other yam species. It ranged from 1.18 g/100g in *D. alata* to 5.46 g/100g in *D. esculenta*. Less than 1% of acid detergent fibre was identified in the yam varieties, suggesting varied levels of biochemical composition and cell wall constituents in the different yam varieties.

Key words: Biochemical quality, cell wall composition, yams

INTRODUCTION

Yams are tropical-vine tuber crops of the genus *Dioscorea* which are popular in Africa, the West Indies, and parts of Asia, South and Central America [1]. They are high value crops, cultivated by virtue of their excellent palatability. Yams are produced on 5 million hectares in about 47 countries in tropical and subtropical regions of the world where they are reported to yield about 11 t/ha in the major producing countries of West Africa [2]. They rank second to cassava as the most important tuber crop in Africa [3]. Out of the over 600 known yam species, the major edible species 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) [1, 4].

Starch is one of the most important natural organic compounds, found in the roots or fruits of plants. The most common sources of food starch for the industries are corn, potato, wheat, tapioca (cassava) and rice [5, 6]. Developed countries (Canada, USA, Europe and Japan) contribute 77% of the global starch [5]. The food sector consumes 55% of world production while the remaining 45% are used in board industries, textile, adhesive, glue and pharmaceutical products [7]. In foods, starch is used to control such characteristics as aesthetics, moisture, consistency and shelf stability. It can be used to bind, expand, densify, clarify or opacify, attract or inhibit moisture. It is also used for different textures such as stringy texture, smooth texture or pulpy texture, soft or crisp coatings, and to stabilize emulsions [5]. Starch and its derivatives are important class of excipients in tablet and capsule formulation [6]. They have excellent properties of compressibility, good binding functionality, powder crystallinity, flowability, acceptable moisture content and desired particle size distribution for favourable mixing conditions with drug [8]. Starches may be used as disintegrants, fillers, glidants (or lubricants) in powder form or as binders in the paste form. The main carbohydrate in yam reserves is starch [9]. Starch in yam tubers account for about 85% of the dry weight matter, which exist as granules of linear amylose (10-30%) and highly branched amylopectin (70-90%) molecules [6].

Sugars are present in minute quantities in yam tubers. Ketiku and Oyenuga [10] observed that the highest total sugar concentration in yam tubers was only 2%, which was attained 4 months after planting. At final harvesting, they recorded less than 1 %. Sucrose was observed as the main sugar, most of which were concentrated at the tail (bottom) end of the tuber. Freshly harvested yam tubers have been reported to have lower free sugar levels than stored yams [11-13], these are suspected to be brought about by the breakdown and subsequent hydrolysis of starches into sugars after harvesting. The increase in sugar levels of stored yam gives a more desirable eating quality.

The non-starchy (dietary fibre) components of plants comprise cellulose, lignin, hemicellulose and pectin. They are generally present in the cell wall and have been

found to have numerous benefits for health and in food product and process development [14]. The cell wall is known to provide rigidity, strength and shape to the plant cell and the non-starchy component of it is partly responsible for the textural properties of the plant-based food. Cellulose has been used as a bulking agent in food due to its water-absorbing ability and low solubility. Both soluble and insoluble hemicelluloses play important roles in food products as soluble and insoluble fibre [15]. Any variations in sugars, starches and the cell wall constituents might have significant influences in their use in both food and industrial processing applications. Thus, the objective of this study was to characterize the relative biochemical compositions and cell wall constituents the different yam species within the Ghanaian yam germplasm, and to assess their potential alternative food and industrial processing applications.

MATERIAL AND METHODS

Materials and Sample Preparation

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 were white yam (*Dioscorea rotundata*), yellow yam (*D. cayenensis*), water yam (*D. alata*), Chinese yam (*D. esculenta*), aerial yam (*D. bulbifera*), trifoliolate yam (*D. dumetorum*) and 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 250 µm 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), and RH of 85-90%.

Determination of biochemical compositions

Starch Determination

The starch content was determined by the acid hydrolysis method described by Association of Official Analytical Chemists' Approved method 14.023 [16], as modified by Bainbridge *et al.* [17].

Determination of Amylose content

The iodo-colorimetric assay method of Sowbhagya and Bhattacharya [18] with some modifications as outlined below was used in the amylose determination: One (1) ml of absolute ethanol (95%) was added to 100 mg of the powdered sample in a 100 ml volumetric flask, followed by the addition of 10 ml of 1N NaOH. The mixture was kept undisturbed at room temperature overnight. The volume of the mixture was made to 100 ml. To 2.5 ml of the extract were added 20 ml of distilled water and three drops

of phenolphthalein in a 50 ml volumetric flask. This was followed by drops of 0.1N HCl until the pink colour just disappeared. One (1) ml of iodine reagent (prepared by dissolving 1 g iodine crystals and 10 g Potassium iodide in distilled water made up to 500 ml) was added and made to 50 ml. The absorbance was read at 590 nm. A standard was prepared with 100mg of pure potato amylose dissolved in 10 ml 1N NaOH and made to 100 ml with distilled water. Series of 0.1, 0.5, 1.0, 1.5 and 2.0 ml were pipetted into separate 50 ml volumetric flask and the colour was developed as in the case of the sample. A blank was prepared with 1 ml iodine reagent diluted to 50 ml.

Determination of Amylopectin content

The amount of amylopectin was obtained by subtracting the amylose content from that of starch.

Determination Total Sugars

Total sugars were determined by the method described by Lane and Eynon [19]. Ten (10) grams of the fine flour sample dissolved in 100 ml of distilled water was mixed with 10 ml concentrated HCl and the mixture was heated in a water bath for 10 minutes. The solution was then neutralized with 10 ml NaOH, made up to 200 ml with distilled water and filtered. 10 ml mixed Fehling's solution was placed in a conical flask followed by 15 ml of the prepared solution. The solution was heated and on boiling, three drops of methylene blue was added. Further quantities of the solution were added from the burette (1 ml at a time) at 10-15 seconds interval to the boiling liquid until the indicator was completely decolourized. The titre values obtained correspond to mg of invert sugar per 100 ml.

Determination of Reducing and Non-reducing Sugars

Reducing sugars were determined by the procedure outlined by Lane and Eynon [19]. About 20-25 g of the flour sample was dissolved in 150 ml of distilled water. The solution was made up to 200 ml and filtered. Ten (10) ml mixed Fehling's solution was placed in a conical flask followed by 15 ml of the prepared solution. The solution was heated and on boiling, three drops of methylene blue was added. Further quantities of the solution were added from the burette (1 ml at a time) at 10-15 seconds interval to the boiling liquid until the indicator was completely decolourized. The titre values obtained correspond to mg of invert sugar per 100 ml. The content of non-reducing sugars was estimated as the difference between the total sugars and reducing sugars while sucrose content was estimated by multiplying the content of non-reducing sugars by the factor 0.95.

Determination of Cell Wall Constituents

The cell wall constituents were determined according to the Van Soest fibre analysis principle [14]. The concept behind the detergent fibre analysis is that plant cells can be divided into less digestible cell walls (containing hemicellulose, cellulose and lignin) and mostly digestible cell contents (containing starch and sugars). Van Soest [14] separated these two components successfully by the use of two detergents: a

neutral detergent (Na-lauryl sulphate, EDTA, pH =7.0) and an acid detergent (cetyltrimethylammonium bromide in 1N H₂SO₄). Neutral Detergent Fibre is a good indicator of "bulk" and thus feed intake while acid detergent fibre is a good indicator of digestibility and thus energy intake.

Acid Detergent Fibre Determination

The procedure outlined by Van Soest and Wine [20] was used with slight modifications. One (1) g of the dry finely ground sample (250 µm) was weighed into a 100 ml round-bottom flask. Then 100 ml of acid detergent solution at room temperature was added to the sample and then heated gently to boiling and refluxed for 60 minutes from onset of boiling. (The acid detergent solution was prepared by dissolving 20 g of cetyltrimethylammonium bromide technical grade (C₁₉H₄₂BrN) in one litre sulphuric acid 1N (H₂SO₄, 49.04 g/l) while stirring and heating gently to promote dissolution. The mixture was allowed to cool to room temperature, 28-30°C). The hot acid detergent treated mixture was poured gently into a porcelain funnel containing a pre-weighed Whatman no. 4 ashless filter paper and drained by applying suction. The insoluble matter in the flask and funnel were washed three times with boiling distilled water and then twice with cold acetone. The insoluble matter was dried overnight at 105°C, cooled in a desiccator and weighed.

Neutral Detergent Fibre

The procedure outlined by Van Soest and Wine [20] was used with slight modifications. One (1) g of the dry finely ground sample (250 µm) was weighed into a 100 ml round-bottom flask. Then 100 ml of neutral detergent solution at room temperature was added with 0.5 g of sodium sulphite. {The neutral detergent solution was prepared by dissolving 6.81 g of sodium borate decahydrate (Borax, Na₂B₄O₇·10H₂O), 18.61g disodium ethylenediaminetetraacetate (EDTA, C₁₀H₁₄N₂Na₂O₈), 30 g sodium lauryl sulphate neutral (C₁₀H₂₅NaO₄S), 10 ml 2-ethoxyethanol (ethylene glycol monoethyl ether, cellosolve, C₄H₁₀O₂) and 4.56 g disodium phosphate anhydrous (Na₂HPO₄) in distilled water while stirring and heating until complete solution was obtained. The solution was made up to one litre with distilled water and the pH was adjusted to be between 6.9 and 7.1}. The mixture was heated gently to boiling and refluxed for 60 minutes from onset of boiling. The hot mixture was poured gently into a porcelain funnel containing a pre-weighed Whatman no.4 ashless filter paper and drained by applying suction. The insoluble matter in the flask and funnel were washed three times with boiling distilled water and then twice with cold acetone. The insoluble matter was dried overnight at 105°C, cooled in a desiccator and weighed.

Hemicelluloses Determination

The hemicellulose content was estimated as the difference between neutral detergent fibre and acid detergent fibre [14].

Cellulose

The cellulose content was determined according to the method described by Updegroff [21]. Cellulose undergoes acetolysis with acetic/nitric reagent forming acetylated cellodextrins which get dissolved and hydrolyzed to form glucose molecules on treatment with 67% H₂SO₄. This glucose molecule is dehydrated to form hydroxymethyl furfural which forms green coloured product with anthrone and the colour intensity is measured at 630 nm using spectrophotometer (Lambda-45 Perkin Elmer, Shelton CT 06484, USA).

Three (3) ml of acetic/nitric reagent (prepared by mixing 150 ml of 80% acetic acid and 15 ml of concentrated nitric acid) was added to one (1) g of the fine flour in a test tube and mixed thoroughly in a vortex mixer. The tubes were placed in a boiling water bath for 30 minutes. The mixture was allowed to cool and then centrifuged for 20 minutes at 3000 rev. The supernatant was discarded while the residue was washed with distilled water. 10 ml of 67% sulphuric acid was added to the tube and allowed to stand for 1 hour. 1 ml of the above solution was diluted to 100 ml with distilled water. 10 ml of anthrone reagent was added to 1ml of this diluted solution and mixed well. (The anthrone reagent was prepared by dissolving 200 mg anthrone in 100 ml concentrated sulphuric acid. This was prepared fresh and chilled for 2 hours before use). The tube and its contents were heated in a boiling water-bath for 10 minutes. It was allowed to cool and the intensity of the colour was measured at 630 nm. A blank was prepared with 1ml distilled water and 10 ml anthrone reagent. A standard stock solution was prepared with 100 mg of cellulose mixed with 10 ml of 67% sulphuric acid in a test tube and the colour was developed as in the case of the sample using a series of volumes 0.5 -3.5 ml corresponding to 50–350 µg of cellulose.

Acid Detergent Lignin

The acid detergent lignin content was estimated as the difference between the cellulose and acid detergent fibre contents [14].

Statistical analysis

Statgraphics (Centurion version) and Minitab (version 14) were used for multivariate analysis and graphical presentation of data. Analysis of variance (ANOVA) was used to test for significant differences between means. A multiple range test (Tukey's 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

Biochemical composition

Starch content of yam varieties

Variations in the starch content along the length of each tuber were not significantly different at $p < 0.05$ (Table 1). The lowest starch content was detected in *D. dumetorum* with 56.90% at the tail end, 58.26% at the middle portion and 59.14% at the head region. *D. cayenensis* recorded the highest starch content of 63.16% at the tail end, 64.03% at the middle portion and 65.69% at the head region. The tail end of *D. rotundata* was observed to contain highest starch in all the varieties analyzed. The trend of starch concentration was the same along each of the varieties considered except *D. alata* which had highest starch at the middle section (Tail: 63.24%, Middle: 65.17% and Head: 64.61%). Similar trend was reported by Ketiku and Oyenuga [10] with starch contents of 61.52% at the tail, 77.28% at the middle portion and 77.57% at the head region.

Amylose content was observed to range from 9.22%, 9.58% and 10.39% for *D. esculenta* to 19.53%, 17.45% and 21.66% for *D. rotundata* along the tail, middle and head sections respectively (Table 1). Amylose values of 18.3%, 17.1% and 18.8% for tail, middle and head have been reported by Ketiku and Oyenuga [10]. No identifiable trend was observed for the amylopectin content along the length between the varieties investigated. *D. bulbifera* recorded the lowest amylopectin content of 41.29%, 43.59% and 44.63% while *D. esculenta* had the highest with 49.84%, 50.24% and 50.13% along the tail, middle and head sections respectively.

Free sugars in yam varieties

Total sugar content in the yam varieties varied significantly ($p < 0.05$) from 2.58%, 2.16% and 2.18% in *D. cayenensis* to 4.84%, 4.74 and 4.82% in *D. bulbifera* at the tail, middle and head regions respectively (Table 2). The total sugar at the tail portions for all the varieties studied was higher than the head regions; the middle portions recorded the least. This trend agrees with the results obtained by other researchers elsewhere [10, 13]. Reducing sugars were only about 1% while sucrose content ranged from 1.36%, 1.11% and 1.15% in *D. cayenensis* to 3.61%, 3.64% and 3.58% in *D. bulbifera* at the tail, middle and head sections. In all, the sucrose content represented 51.4 to 76.8% of the total sugar in the studied varieties. These values compare well with the 1.20%, 0.78% and 0.72% for reducing sugar; 3.32%, 0.96% and 1.63% for sucrose (representing 53-68% of total sugar) at the tail, middle and head portions, respectively, reported by Ketiku and Oyenuga [10]. There were no significant differences in the sugars along the length of each of the varieties examined.

Cell Wall Constituents

There were variations in the cell wall constituents of the yam varieties that were studied. Neutral detergent fibre found in this study ranged from 1.18 g/100g in *D. alata* to 5.46 g/100g in *D. esculenta*. The range compares favourably with the 1.34 –

2.57% in four Nigerian yams as reported by Abara *et al.* [15] and with the 1.6 – 8.6 g/100g found in Cameroonian yams by Agbor-Egbe and Treche [22]. There were significant differences ($p < 0.05$) in the values of neutral detergent fibre found in *Dioscorea esculenta* and the other yam species (Table 3).

Acid detergent fibre was the least component in the varieties analyzed; the highest recorded was 0.89 g/100g in *D. esculenta* while *D. bulbifera* had as low as 0.11 g/100g. These values fell below the 1.2 – 7.6%, 11.34 – 13.75% and 1.13 – 2.30% detected by earlier researchers [15, 22, 23]. Lignin content ranged from 1.56 g/100g in *D. dumetorum* to 2.87 g/100g for *D. praehensalis* relative to the 5.34 – 5.89% and the 0.08 – 0.27% reported by Afoakwa and Sefa-Dedeh [23] and Abara *et al.* [15], respectively. There was no significant difference among yam varieties in the 2.41 – 3.53 g/100g cellulose content. These values agreed with the 2.33 - 3.04% reported by Ketiku and Oyenuga [10] but lower than the 17.10 – 19.73% reported by Afoakwa and Sefa-Dedeh [23] and higher than the 0.80 – 1.13% by Abara *et al.* [15]. Hemicellulose was low in *D. alata* (0.42 g/100g) and highest in *D. esculenta* (4.58 g/100g) which is comparable to the 1.22 – 1.85% discovered by Ketiku and Oyenuga [10] but lower than 0.15 – 0.27% Abara *et al.* [15].

DISCUSSION

Starch is the most significant form of carbon reserve in plants in terms of the amount made, the universality of its distribution among different plant species, and its commercial importance. In yams, starch is produced in the leaves which accumulates in the tuber and becomes converted to sugars when the tissues require energy for respiration. Variability in biochemical composition and cell wall constituents of yams grown in the same environment with the same quantity, quality and duration of light, temperature and carbon (IV) oxide concentration can be attributed to differences in genetic constituents of the yam varieties. The starch, amylase and amylopectic concentrations along the length of each tuber of the yam varieties investigated are summarized in Table 1.

Cluster and principal component analysis for biochemical characteristics of yam varieties

Cluster observation analysis was conducted to group yam varieties based on similarities in their biochemical characteristics; patterns and interrelationships between the samples and the characteristics were also displayed using principal component analysis. The cluster observation dendrogram for the starch and sugars in the yam varieties investigated is shown in Figure 1. The varieties were divided into five clusters based on similarity of starch and sugar composition.

The dendrogram shows that differences do exist in the samples on the basis of their biochemical characteristics. *D. rotundata* and *D. alata* in the first cluster are similar; *D. cayenensis* and *D. praehensalis* in the second cluster are also similar while each of

D. dumetorum, *D. bulbifera* and *D. esculenta* has separate biochemical compositions that make them to differ one from the other.

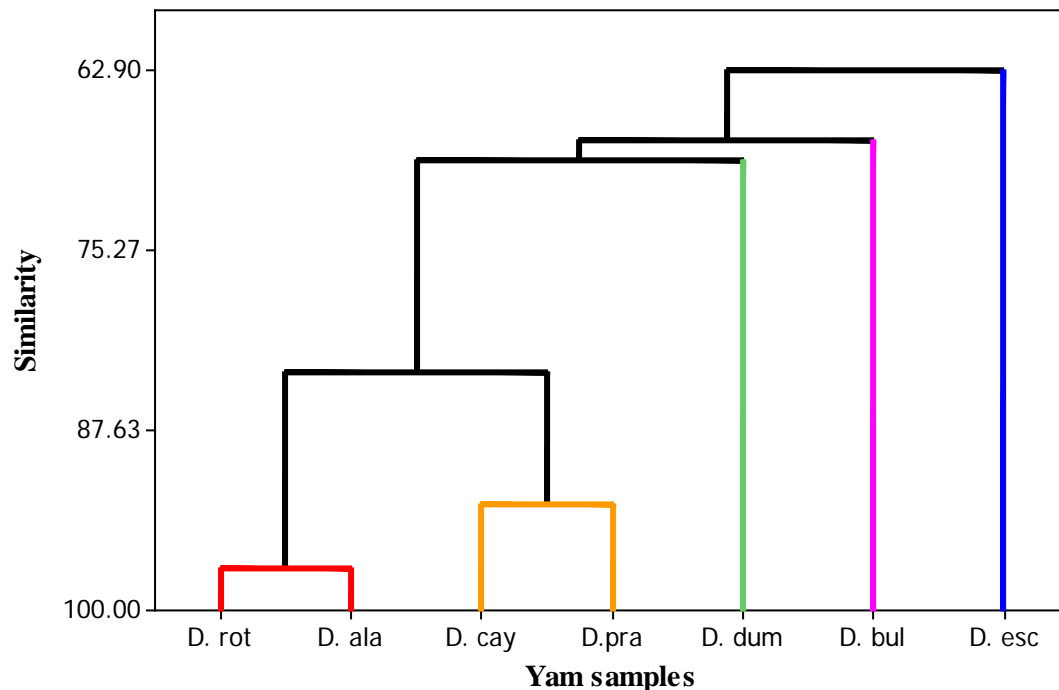


Figure 1: Cluster observation dendrogram for biochemical characteristics of yam varieties

KEY: **D. rot** = *D. rotundata*, **D. ala** = *D. alata*, **D. cay** = *D. cayenensis*, **D. bul** = *D. bulbifera*, **D. pra** = *D. praehensalis*, **D. esc** = *D. esculenta*, **D. dum** = *D. dumetorum*

A total of two principal components (PC) described 77.4% of variability in the biochemical characteristics of the yam varieties. PC1 and PC2 accounted for 54.2% and 23.2% of the variability respectively (Figure 2). Amylose content, total sugar and sucrose content dominated PC1 while starch and amylopectin content contributed the most to the variation in PC2. The principal component scores plot (Figure 3) revealed that *D. rotundata* and *D. alata* were related by having identical starch content. They loaded to the same positive quadrant of PC1 (Figures 2 and 3). *D. cayenensis* and *D. praehensalis* had similar levels of amylose and reducing sugars while *D. dumetorum*, *D. esculenta* and *D. bulbifera* loaded to negative side of PC1 differed by various levels of amylopectin, total sugar and sucrose. *D. bulbifera* stood out with low amylopectin content but high total sugar and sucrose contents. *D. dumetorum* on the contrary, recorded high amylopectin with low sugars while *D. esculenta* contain relatively high contents of amylopectin and sugars.

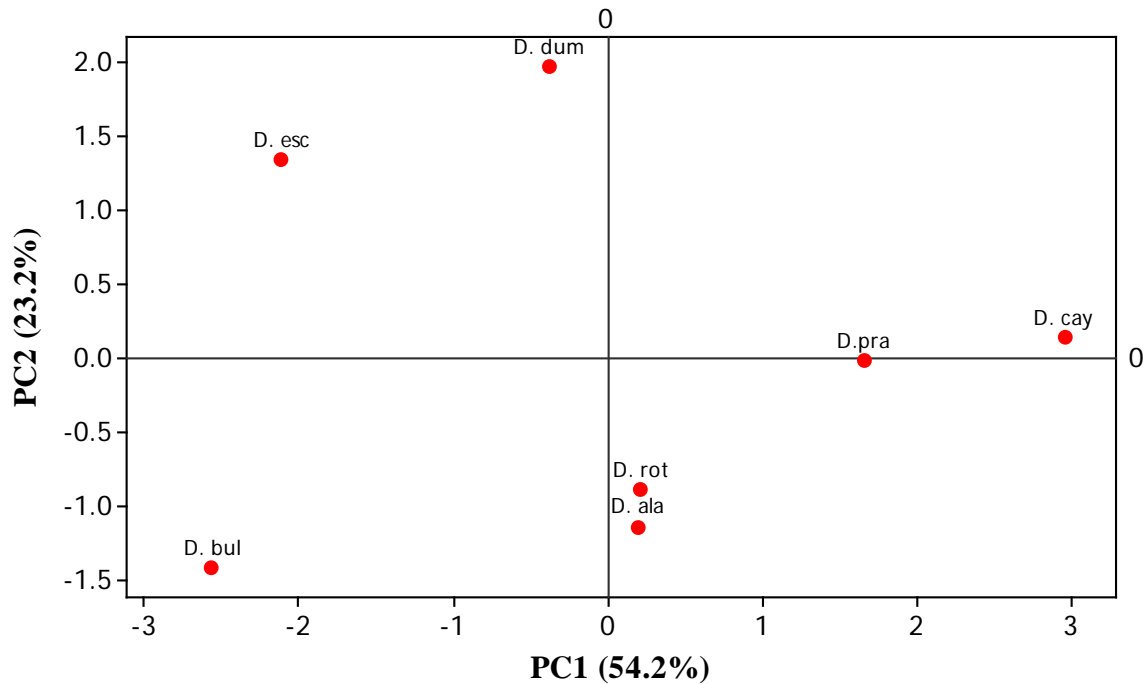


Figure 2: Sample score plot for the principal component analysis of the biochemical characteristics of the yam varieties

KEY: **D. rot** = *D. rotundata*, **D. ala** = *D. alata*, **D. cay** = *D. cayenensis*, **D. bul** = *D. bulbifera*, **D. pra** = *D. praehensalis*, **D. esc** = *D. esculenta*, **D. dum** = *D. dumetorum*

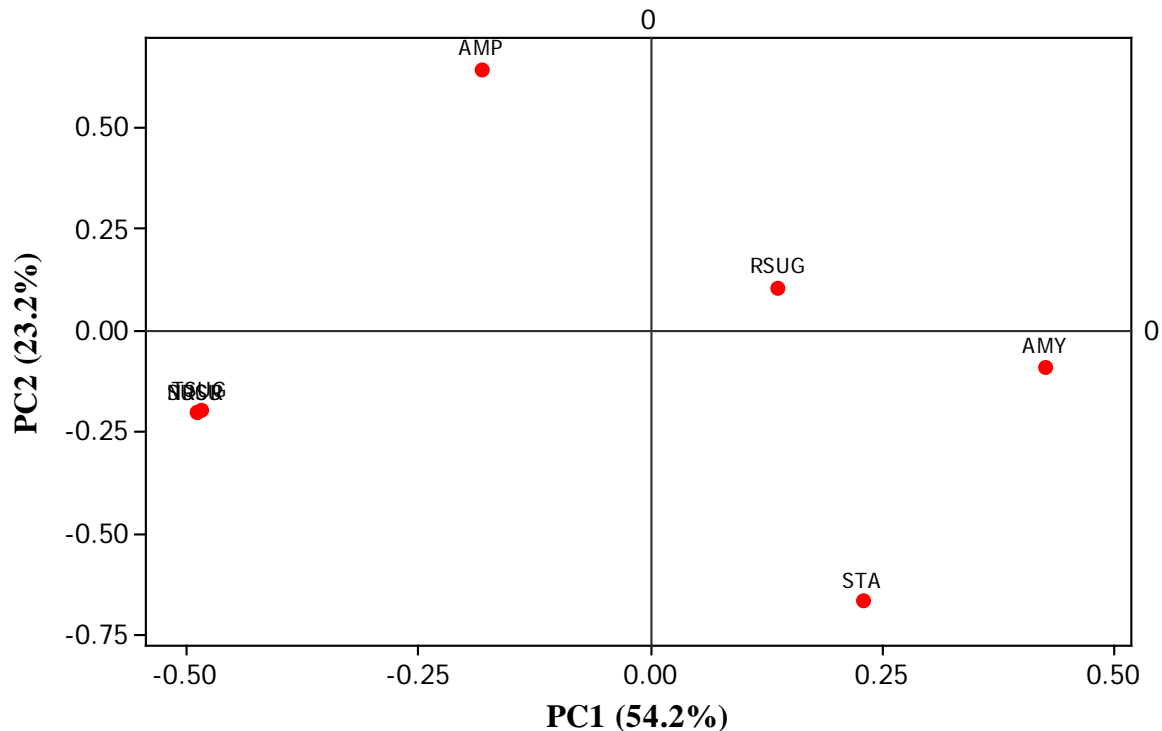


Figure 3: Variable weights plot for the principal component analysis of the biochemical characteristics of the yam varieties

KEY: STA= Starch, AMY= Amylose, AMP= Amylopectin, TSUG= Total Sugars, RSUG= Reducing Sugars, NRSU = Non-reducing Sugars, SUCR= Sucrose

Significant differences at $p < 0.05$ existed between the biochemical characteristics of studied yam varieties. *D. cayenensis*, *D. rotundata* and *D. alata* had high starch contents and could be used as thickeners to improve or maintain the quality of food products. All the yam varieties, except *D. dumetorum* and *D. esculenta*, contained high contents of amylose. *D. bulbifera* with high sugar contents would be suitable raw materials for fermentation during industrial production of alcohol and organic acids.

Cluster and principal component analysis for cell wall constituents of yam varieties

Cluster analysis was used to group yam varieties into three clusters (Figure 4) based on similarities of cell wall constituents. *D. rotundata*, *D. praehensalis* and *D. bulbifera* form the first cluster; *D. alata* and *D. cayenensis* for the second cluster while *D. dumetorum* and *D. esculenta* constitute the third cluster.

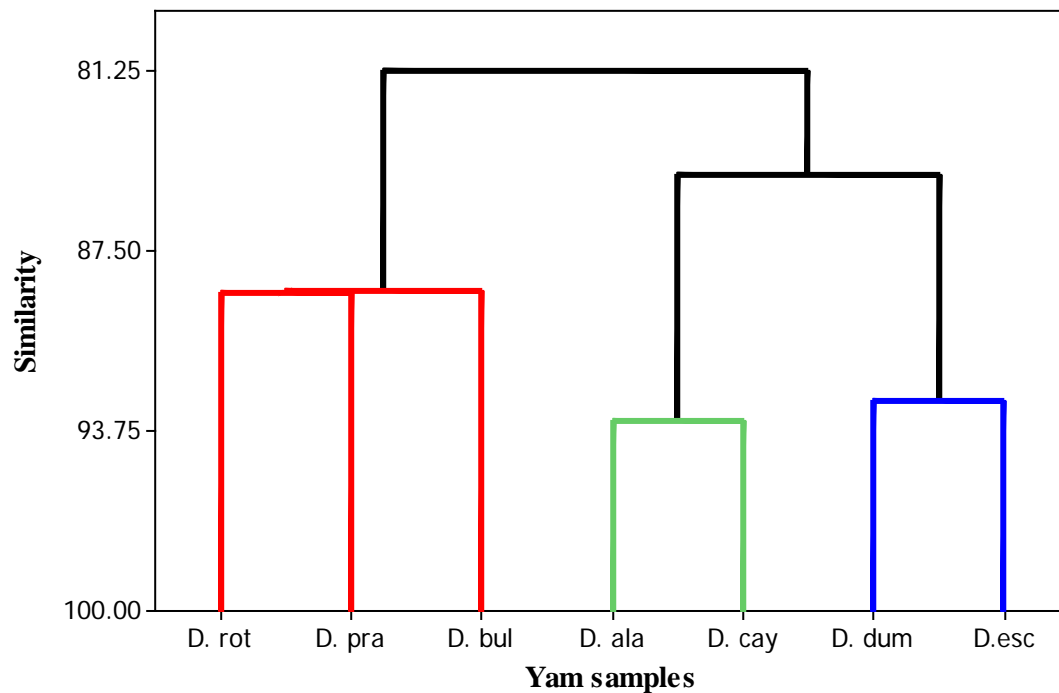


Figure 4: Cluster observation dendrogram for cell wall constituents of yam varieties

KEY: **D. rot** = *D. rotundata*, **D. ala** = *D. alata*, **D. cay** = *D. cayenensis*, **D. bul** = *D. bulbifera*, **D. pra** = *D. praehensalis*, **D. esc** = *D. esculenta*, **D. dum** = *D. Dumetorum*

Principal component (PC) analysis explained a total of 94.3% of the variability in the sample score plot (Figure 5). PC1 explained 64.6% of the variation while PC2 accounted for 29.7%. The sample score plot confirmed the cluster dendrogram by loading varieties with similar characteristics to the same side of PC1 and PC2. The variable weights plot (Figure 6) revealed that, PC1 is strongly influenced by cellulose content and acid detergent fibre, while PC2 is dominated by neutral detergent fibre and hemicellulose. Thus, *D. rotundata*, *D. praehensalis* and *D. bulbifera* (first cluster) were related in their content of high levels of acid detergent lignin and cellulose. *D. cayenensis* and *D. alata* (second cluster) generally contain low levels of the components, except acid detergent fibre. *D. dumetorum* and *D. esculenta* (third cluster) generally contain high levels of the cell wall components, except acid detergent lignin. Whatever variations that were observed between this study and those of other workers might be due to species differences, stage of maturity and growing environment as dietary fibre depends on these factors.

The results obtained for cell wall components in this study showed that these components are low in yam species generally. However, among the yam species analyzed in this study for dietary fiber components, *Dioscorea esculenta* and *D. dumetorum* showed the highest values for the components except in acid detergent lignin content which was found to be highest in *Dioscorea rotundata* (3.36 g/100g).

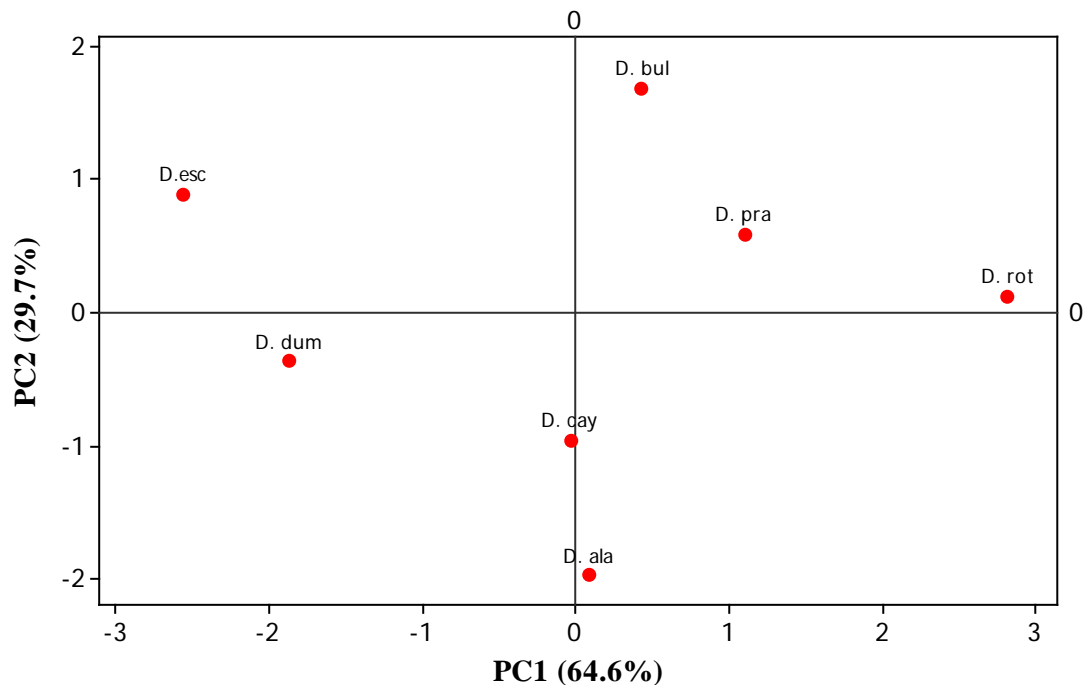


Figure 5: Sample score plot for the principal component analysis of the cell wall characteristics of the yam varieties

KEY: **D. rot** = *D. rotundata*, **D. ala** = *D. alata*, **D. cay** = *D. cayenensis*, **D. bul** = *D. bulbifera*, **D. pra** = *D. praehensalis*, **D. esc** = *D. esculenta*, **D. dum** = *D. Dumetorum*

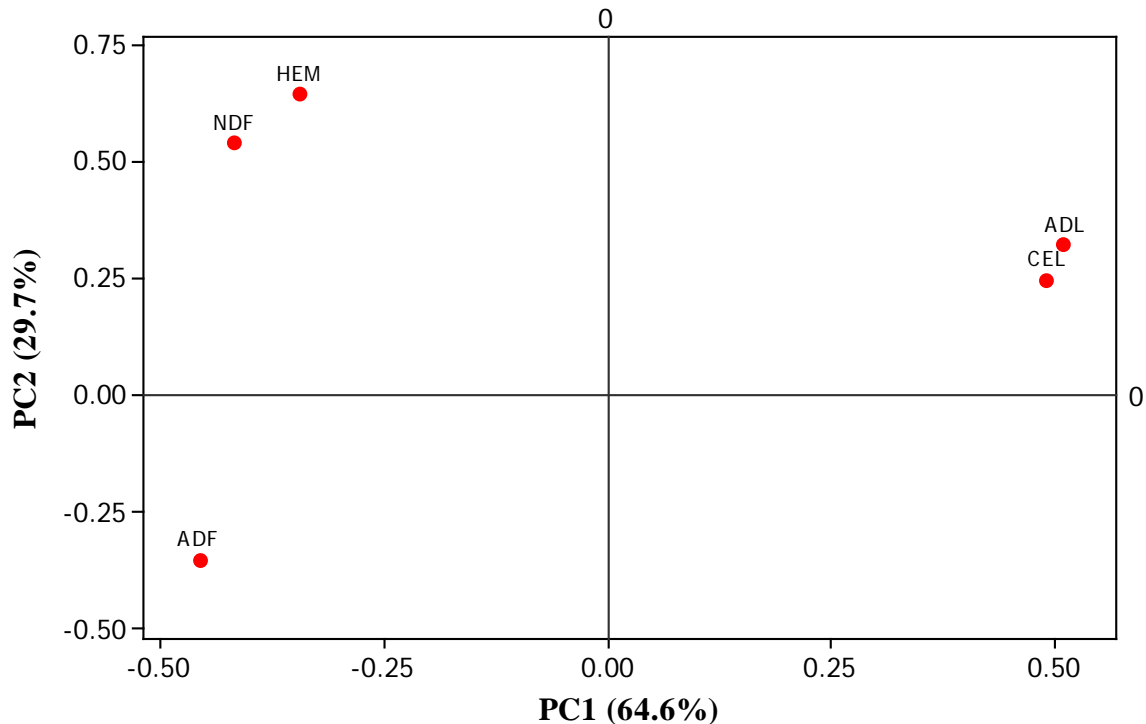


Figure 6: Variable weights plot for the principal component analysis of the cell wall characteristics of the yam varieties

KEY: ADF=Acid Detergent Fibre, NDF=Neutral Detergent Fibre, ADL=Acid Detergent Lignin, HEM= Hemicellulose, CEL=Cellulose

CONCLUSION

The biochemical composition and cell wall constituents of the seven different yam (*Dioscorea*) species grown and consumed in Ghana were significantly different. However, no significant difference was observed along the length of each tuber. *D. cayenensis* (Pure-yellow), *D. rotundata* (Pona) and *D. alata* (Matches) were found to have high starch contents (63.16-65.69%, 63.54-65.30% and 63.24-65.17% respectively). *D. alata* was observed to contain the highest amylose content of 19.66-20.64%. *D. bulbifera* recorded highest total sugar contents (4.74-4.84%). Cellulose was found to be the most common cell wall component with *D. rotundata* having the highest level of 3.36% whilst *D. dumetorum* had the least (1.56%). Hemicellulose content ranged between 0.42 g/100g in *D. alata* to 4.58 g/100g in *D. esculenta*, and only < 1% of acid detergent fiber was identified in the yam varieties. These suggest that the different yam varieties have different biochemical and structural characteristics and may be suitable for different food and industrial processing applications.

ACKNOWLEDGEMENT

The authors express their gratitude to Dr. Lawrence Abbey, Mr Charles Diako, Mr. Freeman Aidoo, and Mr. Clement Asiedu for technical support. Special thanks also go to the management and workers of the Root and Tuber Conservatory Department of the Council for Scientific and Industrial Research-Plant Genetic Resource Research Institute, Bunso for supplying the yam samples.

Table 1: Starch content of yam varieties

Yam variety	Yam part	Starch (%)	Amylose (%)	Amylopectin (%)
<i>D. rotundata</i> (Pona)	Tail	63.54 ± 0.84 ^{e,f}	19.53 ± 0.19 ^{e,f}	44.01 ± 0.65 ^{a,b}
	Middle	64.89 ± 0.16 ^{f,g}	17.45 ± 1.59 ^d	47.45 ± 1.75 ^{c,d}
	Head	65.30 ± 0.24 ^{f,g}	21.66 ± 0.19 ⁱ	43.64 ± 0.43 ^{a,b}
<i>D. alata</i> (Matches)	Tail	63.24 ± 2.38 ^{d,e}	19.66 ± 0.14 ^{e,f}	43.58 ± 2.24 ^{a,b}
	Middle	65.17 ± 0.12 ^{f,g}	20.17 ± 0.15 ^{f,g}	45.00 ± 0.27 ^{a,b}
	Head	64.61 ± 0.18 ^{f,g}	20.64 ± 0.52 ^{h,i}	43.98 ± 0.70 ^{a,b}
<i>D. dumetorum</i> (Yellow)	Tail	56.90 ± 0.33 ^a	9.88 ± 0.39 ^{a,b}	47.03 ± 0.72 ^{b,c}
	Middle	58.26 ± 0.12 ^{a,b}	10.48 ± 0.34 ^{a,b}	47.78 ± 0.46 ^{d,e}
	Head	59.14 ± 1.24 ^{a,b}	11.10 ± 0.01 ^b	48.04 ± 1.23 ^{e,f}
<i>D. esculenta</i> (Large)	Tail	59.06 ± 0.12 ^{a,b}	9.22 ± 0.15 ^a	49.84 ± 0.27 ^f
	Middle	59.82 ± 0.86 ^{a,b}	9.58 ± 0.13 ^{a,b}	50.24 ± 0.99 ^f
	Head	60.52 ± 1.77 ^{b,c}	10.39 ± 0.01 ^{a,b}	50.13 ± 1.78 ^f
<i>D. cayenensis</i> (Pure Yellow)	Tail	63.16 ± 0.46 ^{d,e}	19.98 ± 0.15 ^{f,g}	43.19 ± 0.31 ^{a,b}
	Middle	64.03 ± 0.22 ^{f,g}	18.57 ± 0.29 ^{d,e}	45.52 ± 0.44 ^{b,c}
	Head	65.69 ± 0.73 ^g	20.71 ± 0.24 ^{h,i}	44.98 ± 0.97 ^{a,b}
<i>D. bulbifera</i> (Deep brown skin)	Tail	59.30 ± 1.18 ^{a,b}	18.01 ± 0.15 ^{d,e}	41.29 ± 1.03 ^a
	Middle	63.77 ± 0.87 ^{e,f}	20.17 ± 0.15 ^{f,g}	43.59 ± 1.02 ^{a,b}
	Head	65.04 ± 0.10 ^{f,g}	20.41 ± 0.20 ^{g,h}	44.63 ± 0.11 ^{a,b}
<i>D. praehensalis</i>	Tail	62.11 ± 0.09 ^{c,d}	15.42 ± 0.19 ^c	46.70 ± 0.11 ^{b,c}
	Middle	62.51 ± 0.02 ^{c,d}	18.82 ± 0.39 ^{d,e}	43.69 ± 0.40 ^{a,b}
	Head	62.99 ± 0.53 ^{d,e}	21.41 ± 0.09 ⁱ	41.58 ± 0.62 ^a

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: Free sugars in yam varieties

Yam variety	Yam part	Total Sugars (%)	Reducing Sugars (%)	Non-Reducing Sugars (%)	Sucrose (%)
<i>D. rotundata</i> (Pona)	Tail	4.39±0.03 ^{h,i}	1.12±0.02 ^{d,e}	3.16±0.05 ^{g,h}	3.00±0.04 ^{g,h}
	Middle	3.74±0.10 ^{d,e}	1.11±0.00 ^{d,e}	2.63±0.10 ^{c,d}	2.49±0.10 ^{c,d}
	Head	4.00±0.10 ^{f,g}	1.04±0.06 ^{c,d}	2.96±0.04 ^{e,f}	2.81±0.04 ^{e,f}
<i>D. alata</i> (Matches)	Tail	4.06±0.01 ^{g,h}	1.10±0.02 ^{d,e}	2.96±0.03 ^{e,f}	2.81±0.03 ^{e,f}
	Middle	3.87±0.09 ^{e,f}	1.05±0.01 ^{c,d}	2.81±0.07 ^{d,e}	2.66±0.07 ^{d,e}
	Head	3.92±0.02 ^{e,f}	0.95±0.00 ^{a,b}	2.98±0.03 ^{f,g}	2.82±0.02 ^{f,g}
<i>D. dumetorum</i> (Yellow)	Tail	3.80±0.01 ^{e,f}	1.14±0.02 ^{e,f}	2.67±0.03 ^{c,d}	2.53±0.02 ^{c,d}
	Middle	3.49±0.08 ^d	1.12±0.01 ^{e,f}	2.37±0.09 ^c	2.25±0.09 ^c
	Head	3.67±0.02 ^{d,e}	1.14±0.01 ^{e,f}	2.53±0.01 ^{c,d}	2.40±0.01 ^{c,d}
<i>D. esculenta</i> (Large)	Tail	4.53±0.14 ^{i,j}	0.95±0.01 ^{a,b}	3.58±0.12 ^{i,j}	3.40±0.11 ^{i,j}
	Middle	3.91±0.00 ^{e,f}	0.92±0.00 ^{a,b}	2.99±0.00 ^{f,g}	2.85±0.00 ^{f,g}
	Head	4.31±0.12 ^{h,i}	0.94±0.01 ^{a,b}	3.37±0.11 ^{h,i}	3.20±0.11 ^{h,i}

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

Table 2 continued: Free sugars in yam varieties

Yam variety	Yam part	Total Sugars (%)	Reducing Sugars (%)	Non-Reducing Sugars (%)	Sucrose (%)
<i>D. cayenensis</i> (Pure Yellow)	Tail	2.58±0.00 ^b	1.14±0.02 ^{e,f}	1.43±0.02 ^a	1.36±0.01 ^a
	Middle	2.16±0.04 ^a	0.99±0.02 ^{b,c}	1.17±0.06 ^a	1.11±0.06 ^a
	Head	2.18±0.02 ^a	0.97±0.01 ^{a,b}	1.22±0.00 ^a	1.15±0.00 ^a
<i>D. bulbifera</i> (Deep brown skin)	Tail	4.84±0.03 ^k	1.03±0.01 ^{b,c}	3.81±0.04 ^j	3.61±0.03 ^j
	Middle	4.74±0.14 ^{i,k}	0.90±0.04 ^{a,b}	3.83±0.18 ^j	3.64±0.17 ^j
	Head	4.82±0.03 ^k	1.05±0.04 ^{c,d}	3.77±0.08 ^j	3.58±0.07 ^j
<i>D. praehensalis</i>	Tail	2.98±0.06 ^c	1.22±0.09 ^f	1.76±0.03 ^b	1.67±0.03 ^b
	Middle	2.80±0.02 ^{b,c}	0.90±0.91 ^{a,b}	1.89±0.03 ^b	1.80±0.03 ^b
	Head	2.83±0.05 ^{b,c}	0.84±0.06 ^a	1.99±0.11 ^b	1.89±0.11 ^b

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

Table 3: Cell wall constituents in yam varieties (g/100g)

Yam variety	Neutral Detergent Fibre	Acid Detergent Fibre	Acid Detergent Lignin	Cellulose	Hemicellulose
<i>D. rotundata</i> (Pona)	1.20±0.27 ^a	0.16±0.03 ^a	3.36±0.00 ^c	3.53±0.03 ^a	1.04±0.02 ^a
<i>D. alata</i> (Matches)	1.18±0.34 ^a	0.77±0.09 ^c	1.91±0.48 ^{a,b}	2.68±0.38 ^a	0.42±0.04 ^a
<i>D. dumetorum</i> (Yellow)	3.85±0.52 ^c	0.85±0.07 ^c	1.56±0.25 ^a	2.41±0.18 ^a	2.99±0.06 ^{c,d}
<i>D. esculenta</i> (Large)	5.46±0.31 ^d	0.89±0.02 ^c	1.62±0.06 ^{a,b}	2.50±0.04 ^a	4.58±0.28 ^e
<i>D. cayenensis</i> (Pure yellow)	1.94±0.13 ^{a,b}	0.45±0.05 ^b	2.03±0.67 ^b	2.49±0.62 ^a	1.49±0.07 ^{a,b}
<i>D. bulbifera</i>	3.94±0.07 ^c	0.11±0.01 ^a	2.81±0.04 ^{b,c}	2.91±0.04 ^a	3.84±0.07 ^{d,e}
<i>D. praehensalis</i>	2.80±0.11 ^{b,c}	0.43±0.06 ^b	2.87±0.06 ^{b,c}	3.30±0.11 ^a	2.37±0.17 ^b

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

REFERENCES

1. **Jayakody L, Hoover R, Liu Q and E Donner** Studies on tuber starches. II. Molecular structure, composition and physicochemical properties of yam (*Dioscorea* sp.) starches grown in Sri Lanka. *Carbohydr Polym* 2007; **69**: 148–163.
2. **FAO. Food and Agricultural Organisation of the United Nations.** FAO Statistics 2009. FAO, Rome. 2008 <http://faostat.fao.org/> Date retrieved: October 15, 2010.
3. **Charles AL, Sriroth K and TC Huang** Proximate composition, mineral contents, hydrogen cyanide and phytic acid of 5 cassava genotypes. *Food Chem* 2005; **92**: 615–620.
4. **Coursey DG** Yam storage. 1: A review of yam storage practices and information on storage losses. *J Stored Prod Res.* 1967; **2**: 229-244.
5. **Amani NG, Kamenan A, Rolland-Sabaté A and P Colonna** Stability of yam starch gels during processing. *Afr J Biotechnol.* 2005; **4** (1): 94-101.
6. **Riley CK, Wheatley AO and HN Asemota** Isolation and characterization of starches from eight *Dioscorea alata* cultivars grown in Jamaica. *Afr J Biotechnol.* 2006; **5** (17): 1528-1536.
7. **DeCock P** Functional properties of starch (Methods and applications). *Agro-Food-Industry Hi-Tech.* 1996; **7**(4): 18-22.
8. **Alanazi FK, El-Bagory IM, Alsarra IA, Bayomi MA and MA Abdel-kawy** Saudi-corn starch as a tablet excipient compared with imported starch. *Saudi Pharm. J.* 2008; **16**(2): 112-121.
9. **Osagie AU** The yam in storage. Postharvest Research Unit, University of Benin, Nigeria, 1992.
10. **Ketiku AO and VA Oyenuga** Changes in the carbohydrate constituents of yam tuber (*Dioscorea rotundata*, Poir) during growth. *J Sci Food Agric.* 1973; **24**: 367-373.
11. **Treche S and T Agbor-Egbe** Biochemical changes occurring during growth and storage of two yam species. *Int J Food Sci Nutr.* **47**(2): 93-102.
12. **Afoakwa EO and S Sefa-Dedeh** Chemical composition and quality changes occurring in *Dioscorea dumetorum* pax tubers after harvest. *Food Chem.* 2001; **75**: 85–91.

13. **Dje M, Dabonne S, Guehi ST and LP Kouame** Monitoring of some biochemical parameters of two yam species (*Dioscorea* Spp.) tubers parts during post-harvest storage. *Adv J. Food Sci Technol.* 2010; **2 (3)**: 178-183.
14. **Van Soest PJ** Dietary fiber: Their definition and nutritional properties. *Am. J. Clin. Nutr.* 1978; **31**: 12-20.
15. **Abara AE, Tawo EN, Obi-Abang ME and GO Obochi** Dietary fibre components of four common Nigerian *Dioscorea* species. *Pak J Nutr.* 2011; **10 (4)**: 383-387.
16. **AOAC. Methods of the Association of Official Analysis Chemists.** Official methods of analysis. 15th ed., Virginia Assoc. Off. Anal. Chem. USA, 1990: 1141.
17. **Bainbridge Z, Tomlins K, Wellings K and A Westby** Methods for Assessing Quality Characteristics of Non-Grain Starch Staples. Part 3. Laboratory Methods. Chatham, U.K.: Natural Resources Institute, 1996.
18. **Sowbhagya CM and KR Bhattacharya** A simplified colometric method for determination of amylase content in rice. *Starch* 1971; **23**: 53-56.
19. **Pearson D** The chemical analysis of foods. Longman Group Limited, Seventh edition, UK, 1976: 126-129.
20. **Van Soest PJ and RH Wine** Use of detergents in the analysis of Dibrous Feeds. IV. Determination of plant cell-wall constituents. *J. Assoc. Off. Anal. Chem.* 1967; **50**: 50-55.
21. **Updegroff DM** Semi-micro determination of cellulose in biological material. *Anal Biochem* 1969; **32**: 420-424.
22. **Agbor-Egbe T and S Treche** Evaluation of the chemical composition of Cameroonian yam germplasm. *J Food Compos Anal* 1995; **8**: 274-283.
23. **Afoakwa EO and S Sefa-Dedeh** Changes in cell wall constituents and mechanical properties during post-harvest hardening of trifoliate yam *Dioscorea dumetorum* (Kunth) pax tubers. *Food Res Int* 2002; **35**: 429-434.