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Physico-functional characteristics of Seven Different Yams (*Dioscorea species*) in Ghana

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ABSTRACT: This study was designed to characterize the most cultivated and consumed yam (*Dioscorea*) cultivars within the Ghanaian yam germplasm based on their physico-functional properties in order to assess their potential alternative food and industrial processing applications. Matured yam varieties grown and harvested under the same climatic and edaphic factors were obtained from the Roots and Tuber Conservatory Division of the Council for Scientific and Industrial Research-Plant Genetic Resources Research Institute, Bunso Ghana. Colour of bulk flour for each yam sample was measured using the Hunter Lab Colour Difference Meter. Functional properties such as water absorption capacity, swelling power and solubility index were determined using standard analytical procedures. Significant differences ($p<0.05$) existed among the yam varieties for their colour and functional properties. Flours of *D. bulbifera* and *D. dumetorum* had an attractive yellow colour while flour of *D. esculenta* recorded the highest whiteness (L = 84.09). *D. esculenta* had the highest swelling power (9.4%) and solubility index of 27.6%. No significant difference was observed in water absorption at 27°C and 70°C for all varieties except *D. dumetorum*. *D. dumetorum* flour had relatively high water absorption capacity of 295.9% in water at 27°C and 189.4% in water at 70°C. The findings from this research will be relevant to yam producers and processors in programmes aimed at developing new food/industrial processing applications using Ghanaian yams.

KEYWORDS: *Dioscorea*, physico-functional property, water absorption capacity, solubility index, chromatic index.

1 INTRODUCTION

Yams are edible tubers of the genus *Dioscorea* which are important foods of many countries world wide ([1] & [2]). They are cultivated throughout the subtropical and tropical regions of the world for their edible tubers, which constitute a staple food for many people in these regions [3]. There are several data available in literature on the nutritional composition of yam tubers from various species. These tubers are found to be a good source of protein, lipid, crude fibre, starch and minerals ([4]; [5]; [6] & [7]). The most important edible varieties in Ghana and most West African countries are white yam (*Dioscorea rotundata*), yellow yam (*D. cayenensis*), trifoliate or bitter yam (*D. dumetorum*), water yam (*D. alata),* potato yam (*D. esculenta*)*,* aerial yam (*D. bulbifera*) and bush yam (*D. praehensalis*) [7]. Yams are produced on 5 million hectares in about 47 countries in tropical and subtropical regions of the world [8]. Several researchers have reported that the compositions of yam tubers are affected by differences in growing environment, maturity stage, method and length of storage and type of species ([4]; [6] & [9]).

The basic starch properties of importance during food processing are gelatinization, pasting properties, swelling power and solubility, enzymatic digestibility and retrogradation ([10] & [11]). These properties control the sensory attributes and stability of processed starch products. No other ingredient provides texture to as many foods as starch does. Whether it is a soup, stew, gravy, pie filling, sauce or custard, starch provides a consistent shelf-stable product that consumers rely upon. Starches from this genus could find some industrial applications when sufficiently exploited. Previous studies on yams in

Ghana were centred on nutritional and anti-nutritional properties [7], biochemical composition [12] and pasting properties. This study investigated the physicofunctional properties of yam varieties in the Ghanaian yam germplasm.

2 MATERIALS AND METHODS

2.1 MATERIALS AND SAMPLE PREPARATION

Seven matured yam varieties grown and harvested under the same climatic and edaphic factors were obtained from the Roots and Tuber Conservatory Division of the Council for Scientific and Industrial Research-Plant Genetic Resources Research Institute, Bunso Ghana. The samples were *D. rotundata* (Pona), *D. alata* (Matches), *D. dumetorum* (Yellow flesh), *D. esculenta* (Large tuber), *D. cayenensis* (Pure yellow flesh), *D. bulbifera* (Deep brown skin) and *D. praehensalis* (Bush yam). Each sample was 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, 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 (Wagtech, UK). The dried samples were ground 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%.

2.2 DETERMINATION OF FLOUR COLOUR

The colour of bulk flour for each yam sample was measured using the Hunter Lab Colour Difference Meter (CDM), Model CR-300 (Minolta Camera Co. Ltd. Inc., Tokyo, Japan). Measurements were based on the L a* b* colour scale.

2.3 FUNCTIONAL PROPERTIES

2.3.1 DETERMINATION OF WATER ABSORPTION CAPACITY (WAC)

Water absorption capacity determination was based on the method described by Sefa-Dedeh *et al.*, [13] with minor modifications. Five (5) g of the flour sample was weighed into a 50 ml pre-weighed centrifuge tube and 30 ml of distilled water (at 27°C) was added, mixed thoroughly by shaking, vortexing and inverting the tube. The mixture was allowed to stand for 30 minutes, inverting the sealed tube after every 10 minutes. The mixture was then centrifuged at 3000 rpm for 15 minutes and the amount of water absorbed was calculated as the increase in weight of the slurry formed after decanting the supernatant. The measurement was carried out in triplicate. The procedure was repeated using distilled water at 70°C.

2.3.2 DETERMINATION OF SWELLING POWER AND SOLUBILITY INDEX

Swelling is defined as the weight (g) of the swollen sediment per g of dry starch/flour and solubility is expressed as the percentage (by weight) of the starch/flour sample that is dissolved molecularly after being heated in water between 85 and 95°C. The method of Leach *et al*. [14] was used with minor modifications. One gram of flour sample was weighed into 100 ml conical flask, hydrated with 15ml of distilled water and shaken at 120 rev/min for 15 minutes on an orbital shaker (Gallen-Kamp, Widnes, U.K.). The conical flask with its contents was put in a shaking water bath maintained at 100 rev/min between 80 and 85 °C for 40 minutes. After heating, the sample was quantitatively transferred into centrifuge tube by washing with small quantity of distilled water and making up to 20 ml. The mixture was then centrifuged at 3000 rpm for 15 minutes. The supernatant was decanted into a pre-weighed moisture can and dried at 105°C overnight. The moisture can was allowed to cool in a desiccator and the difference in weight was recorded as the weight of soluble component. The sediment was also weighed, and swelling power and solubility index were estimated as the ratios of sediment weight to sample weight and soluble weight to sample weight respectively.

$$\text{i. e. Swelling power} = \frac{Weight\ of\ Sediment}{weight\ of\ sample - weight\ of\ soluble}$$

and

$$\text{Solubility index (\%)} = \frac{weight\ of\ soluble}{weight\ of\ sample}$$

2.4 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.

3 RESULTS AND DISCUSSION

3.1 COLOUR MEASUREMENTS OF YAM FLOUR VARIETIES

The chromatic indices for the colour of the yam flour varieties studied (Table 1) show that the flour of *D. esculenta* was the whitest ($L^* = 84.09$) of all the varieties while *D. praehensalis* recorded the least value for whiteness ($L^* = 57.29$). The low whiteness index observed for *D. praehensalis* was expected because the cut or peeled tuber browns rapidly.

Significant differences ($p<0.05$) existed in the whiteness of flours; this was seen to be variety specific. The redness of all the flours examined were low, except *D. bulbifera* ($a^* = 2.07$) which also recorded the highest yellowness ($b^* = 21.81$). The colour indices were significantly ($p<0.05$) species specific.

Table 1: Chromatic indices for colour of yam varieties

Yam variety	L*	a*	b*
D. rotundata	80.67 ± 0.17^{d}	-2.48 ± 0.01^{b}	11.86 ± 0.05^{b}
D. alata	82.63 ± 0.14^{e}	-2.71 ± 0.02^{b}	11.78 ± 0.07^{b}
D. dumetorum	74.39 ± 0.08^{c}	-1.86 ± 0.01^{c}	20.40 ± 0.06^{e}
D. esculenta	84.09 ± 0.20^{f}	-3.06 ± 0.03^{a}	9.87 ± 0.04^{a}
D. cayenensis	71.04 ± 0.64^{b}	-0.75 ± 0.04^{d}	12.28 ± 0.06^{d}
D. bulbifera	73.68 ± 0.01^{c}	2.07 ± 0.03^{f}	21.81 ± 0.03^{f}
D. praehensalis	57.29 ± 0.05^{a}	0.45 ± 0.06^{e}	14.47 ± 0.11^{c}

Values are means ± standard deviation of triplicate. Values with the same superscript in a column are not significantly different at P<0.05.

***Key**: L* = Lightness of yam flour, a* = redness of yam flour, b* = Yellowness of yam flour.*

3.2 FUNCTIONAL PROPERTIES OF YAM VARIETIES

The functional properties of yam flour were determined to establish the behaviour of the varieties in a food system. The results of the water absorption capacity (WAC), solubility and swelling power of the studied yam varieties are shown in Figures 1, 2 and 3 respectively.

3.2.1 WATER ABSORPTION CAPACITY OF YAM FLOUR

The water absorption capacity (WAC) is an important criterion in the development of ready to eat foods. According to Houson and Ayenor [15], a high water absorption capacity may assure product cohesiveness. The WAC of the flour from these yam varieties ranged from 160.8% for *D. cayenensis* to 295.9% for *D. dumetorum* at 27 °C and 118.3% for *D. esculenta* to 189.4% for *D. dumetorum* at 70 °C (Figure 1). Significant differences ($p<0.05$) were noted in the WAC values of the yam varieties. Processing factors such as fermentation have been found to increase water absorption of flours [16].

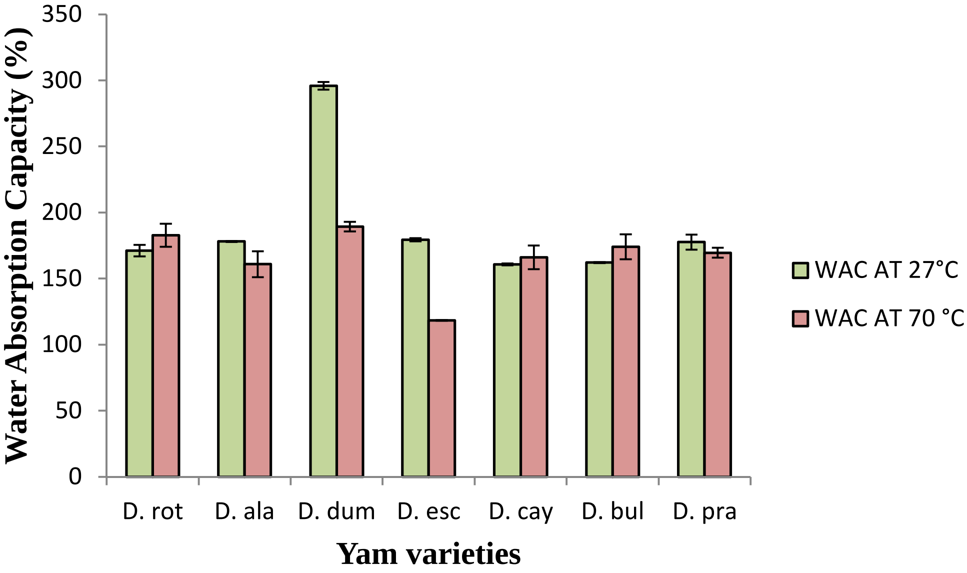

Figure 1: Water Absorption Capacity of yam varieties

Error bars represent standard deviation of mean from three replicates
***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*

3.2.2 Solubility of yam varieties

The solubility of the different yam starches varied significantly ($p<0.05$) with *D. alata* having the lowest of 7.0% and *D. esculenta* the highest with 27.6% (Figure 2). The solubility of starches is believed to be affected by factors such as inter-associative forces, swelling power, presence of surfactants and other associative compounds ([17] & [18]).

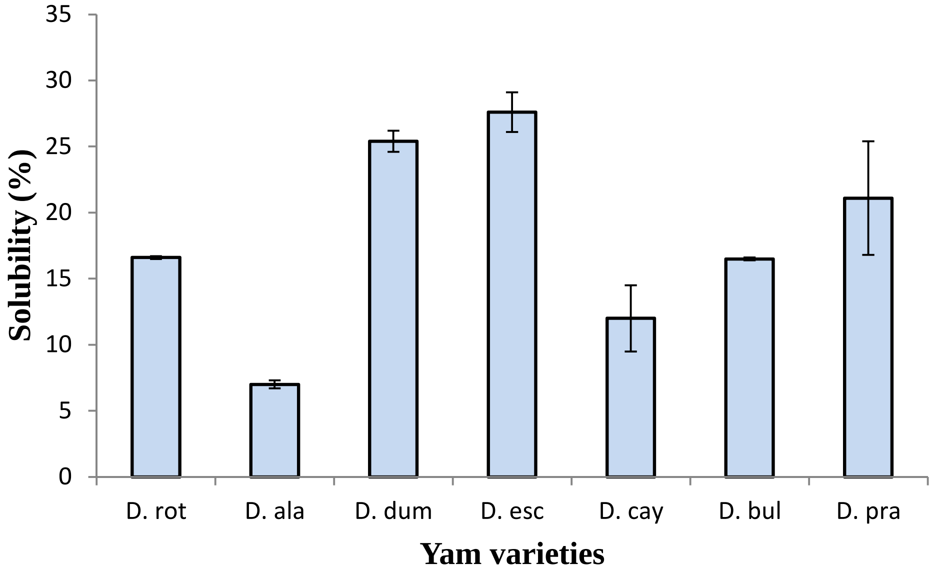

Figure 2: Solubility of yam varieties

Error bars represent standard deviation of mean from three replicates.
***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*

3.2.3 SWELLING POWER

Swelling capacity is regarded as quality criterion in some food formulations such as bakery products. It is an evidence of non-covalent bonding between molecules within starch granules. The observed swelling power of the yam varieties ranged from 5.4% for *D. cayenensis* to 9.4% for *D. esculenta*.

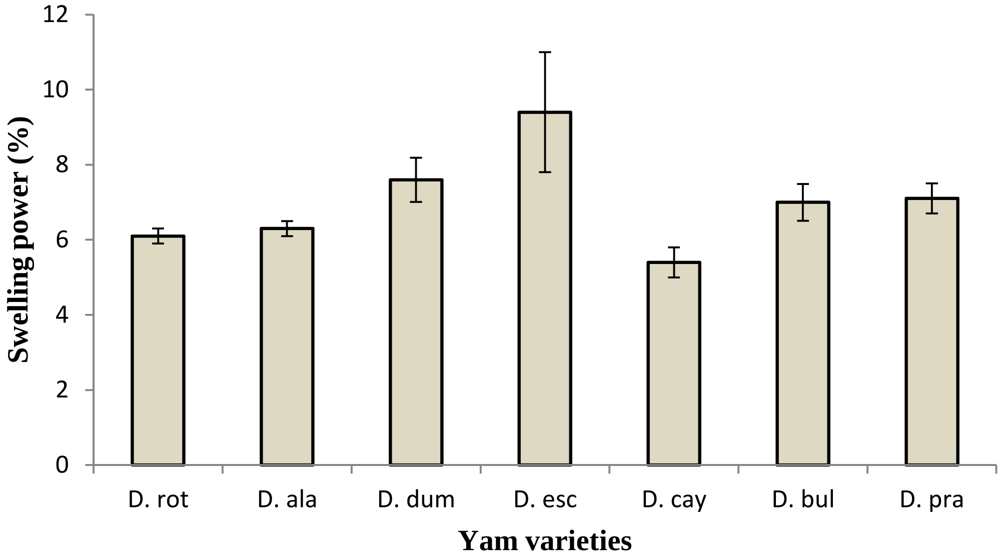

Figure 3: Swelling power of yam varieties at 80-85 °C

Error bars represent standard deviation of mean from three replicates.
***<u>KEY</u>*: 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*

Swelling power and solubility index provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains and also evidence of association bonding within the granules of yam starches [19]. The low swelling power observed in *D. cayenensis* may be due to stronger bonding force in its starch granules (Figure 3).

3.3 CLUSTER AND PRINCIPAL COMPONENT ANALYSIS FOR PHYSICO-FUNCTIONAL CHARACTERISTICS OF YAM VARIETIES

The yam varieties for this study were statistically analyzed for similarities in physical and functional characteristics using observations and principal component (PC) analyses to establish the patterns and interrelationships that exist between the varieties. The cluster observation dendogram (Figure 4) grouped the yam varieties into four clusters based on their similarities.

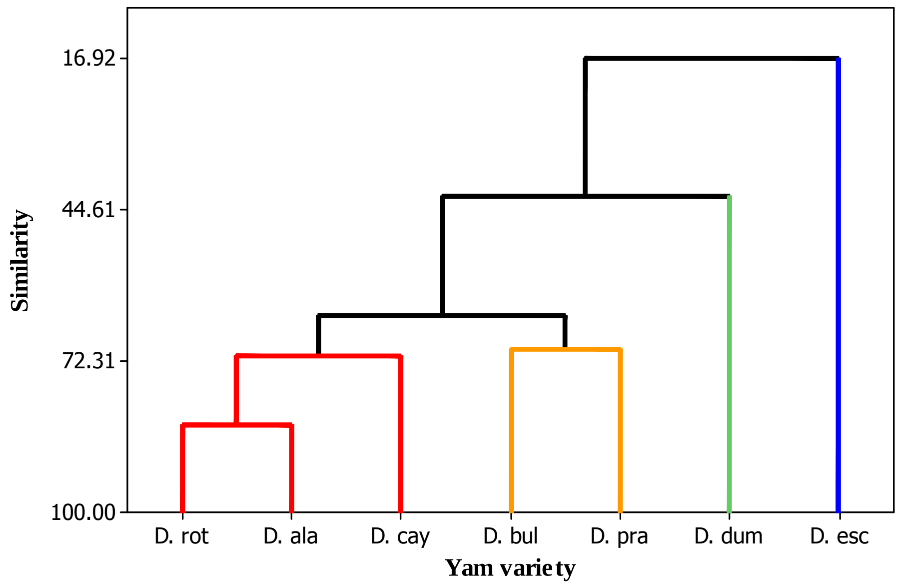

Figure 4: Cluster observation dendogram for physico-functional characteristics of yam varieties

__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*

D. rotundata, *D. alata* and *D. cayenensis* formed the first cluster while *D. bulbifera* and *D. praehensalis* were in the second cluster. *D esculenta* and *D. dumetorum* stood alone in the third and fourth clusters respectively. A total of 65.9% of the variations for colour and functional properties in the varieties were explained by two principal components (Figure 5). PC1 accounted for 37% of the variation while PC2 accounted for 28.9%.

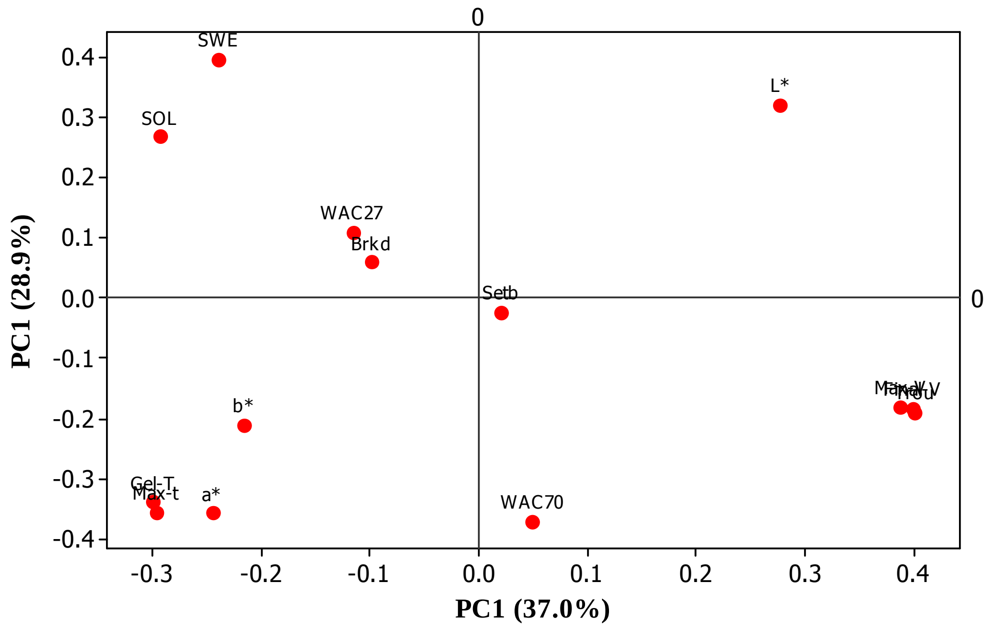

Figure 5: Variable weights plot for the principal component analysis of physico-functional characteristics of the yam varieties

*__KEY__: **a*** = Redness of flour, **b*** = Yellowness of flour, **L*** = Whiteness of flour, **SOL** = Solubility, **SWE** = Swelling power, **WAC27** = Water Absorption Capacity at 27°C, **WAC70** = Water Absorption Capacity at 70°C.*

PC1 is dominated by solubility index while PC2 is dominated by water absorption capacity at 70°C, swelling power, whiteness and redness of flour.

Comparing the Variable weights plot (Figure 5) and the samples on the score plot (Figure 6) revealed that the shared characteristics which related *D. rotundata, D. alata* and *D. cayenensis* were their water absorption at 70°C and whiteness. *D. cayenensis* differ from the group by having low whiteness and high water absorption. No significant difference was observed between the water absorption at 27°C and 70°C in *D. cayenensis.*

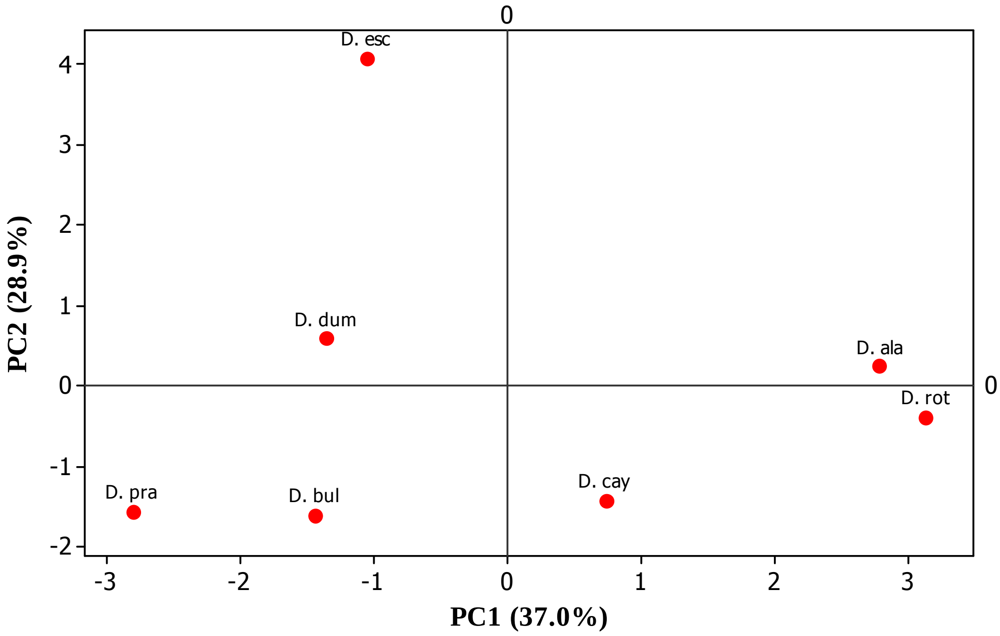

Figure 6: Sample score plot for the principal component analysis of the rheological and physico-functional characteristics of the yam varieties

***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*

The flours of *D. bulbifera* and *D. praehensalis* were related by their red and yellow colours. *D. dumetorum* and *D. esculenta* stood out by their functional properties. *D. dumetorum* had distinctly high water absorption at 27°C while *D. esculenta* had high swelling capacity.

4 CONCLUSION

In all, significant differences ($p<0.05$) existed among the yam varieties for their colour and functional properties. Flours of *D. bulbifera* and *D. dumetorum* had an attractive yellow colour while flour of *D. esculenta* recorded the highest whiteness (L = 84.09). *D. esculenta* had the highest swelling power (9.4%) and solubility index of 27.6%. *D. dumetorum* (Yellow-flesh) flour had relatively high water absorption capacity of 295.9% in water at 27°C and 189.4% in water at 70°C.

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