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Rheological properties of Seven Different Yams (*Dioscorea species*) within the Yam Germplasm

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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 rheological 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. Samples were processed into flour and the pasting characteristics along the length of each variety were determined using Brabender Visco-amylograph (Brabender Instrument Inc. Duisburg, West Germany) equipped with a 700 cmg sensitivity cartridge. Significant differences ($p<0.05$) existed among the yam varieties for their pasting characteristics. However, no significant differences were observed in the pasting profile along the tail (T), middle (M) and head (H) regions of each tuber. Pastes from flours of *D. rotundata* had high maximum and final viscosities (333.5-384.5 BU and 343.5-404.0 BU respectively). Breakdown viscosity was low (<10 BU) in all the studied varieties, except *D. dumetorum* (54-71 BU). 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*, Gelatinization, Viscosity, Brabender Visco-amylograph, Pasting characteristics.

1 INTRODUCTION

Yam is an annual or perennial plant that produces mature tubers in 6-10 months and remains dormant for 3-6 months when stored, depending on species and cultivars. The major edible yam species of African origin are white Guinea yam (*D. rotundata* Poir.), yellow Guinea yam (*D. cayenensis* Lam.) and trifoliate or bitter yam (*D. dumetorum* Pax.). Water yam (*D. alata* L.), and lesser yam (*D. esculenta* Burkill) are from Asia, while Cush-cush yam (*D. trifida* L.) originated from the South America [1]. Presently, the different species are distributed all over the world depending on the climatic, cultural and edaphic factors of the environment under which they are cultivated. In Ghana and most West African countries, seven main species are cultivated or harvested from the wild. The wild types of yam may be used as food after processing during the hunger seasons [2].

The time of harvest is critical in terms of tuber maturity, yield and postharvest quality. Depending on the cultivar, the period from planting or emergence to maturity varies from about 6-7 months. In some cases, 6-10 months from planting or emergence to maturity have been recommended [3]; for double-harvesting, harvest first at 5-6 months after planting and then 3-4 months later has also been reported [4].

Starch gelatinization refers to the disruption of the molecular order within starch granules when they are heated in the presence of water. Evidence for gelatinization is characterized by crystalline melting, loss of birefringence and starch solubilization, in which more soluble amylose leaches out into solution with subsequent increased viscosity. The loss of an organized structure includes irreversible granule swelling and crystallinity. Gelatinization of starch takes place over a definite range of temperature known as the gelatinization temperature. Gelatinization is an energy absorbing process that can be followed by differential scanning calorimetry (DSC). Freitas *et al*. [5] studied the amylose contents, rheological properties and gelatinization kinetics of yam (*Dioscorea alata*) and cassava (*Manihot utilissima*) starches. They observed a more defined process of gelatinization that occurred with yam starch which generates a stronger gel, as well as higher activation energy of gelatinization when compared with that of cassava. This behaviour is in accordance with and dependent on the amylose content in the starch samples obtained (36% and 23% amylose for the yam and cassava respectively) [5].

Several authors reported similar compositions of amylose in yams (27-30%) and cassava (17-21%) ([6], [7], [8], [9] & [10]). An empirical rheological test of the gelatinization properties of starches is the measurement of the viscosity of starch dispersions in a temperature/time profile using the Brabender Viscomylograph or Rapid Visco Analyser (RVA) which has been designed as a simple-to-use viscometer. In a typical RVA profile, six significant points identified: pasting temperature, peak viscosity, viscosity at 95 °C (trough or holding strength), viscosity at constant 95 °C (breakdown), viscosity at 50 °C (final viscosity) and viscosity at constant 50 °C (setback). Pasting is the result of a combination of processes that follows gelatinisation from granule rupture to subsequent polymer alignment, due to mechanical shear during the heating and cooling of starches. Pasting characteristics of starches have been associated with cooking quality and texture of various food products ([11] & [12]). The temperature at the onset of the rise in viscosity is the pasting temperature. It provides an indication of the minimum temperature required to cook a given sample, and has implications for the stability of other components in a food formula.

Pasting temperature is characterized by an initial change in viscosity, due to the swelling properties of the starch [13]. Peak viscosity is a measure of the ability of starch to form a paste; it indicates the highest value of viscosity during the heating cycle. Otegbayo [14] found that pastes from *D. rotundata* had higher values for peak viscosity, breakdown, holding strength, final viscosity, and setback viscosity of 375, 173, 202, 398, and 195 RVU respectively with lower value for pasting temperature (79°C) and comparatively lower values for peak viscosity (231), breakdown (77), holding strength (160), final viscosity (202), and setback viscosity (43) with a higher pasting temperature (83°C) for *D. alata*. Similar results have been reported for various yam varieties by other researchers ([11], [13], [15] & [16]). Starches with low paste stability or breakdown are reported to have weak cross-linking among their granules [17]. This study investigated the rheological properties of yam varieties in the Ghanaian yam germplasm, in order to establish their potential food and industrial applications.

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.

2.2 Determination of Rheological (Pasting) Characteristics

The rheological properties of the yam flours were determined by the use of Brabender Visco-amylograph (Brabender Instrument Inc. Duisburg, West Germany) equipped with a 700 cmg sensitivity cartridge.

2.3 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 Pasting Characteristics of Yam Varieties

The pasting characteristics along the length of each tuber of the yam varieties studied are summarized in Table 1. There were significant differences (p<0.05) in the pasting properties among the different yam varieties, however, no significant differences were observed along the tail (T), middle (M) and head (H) regions of each tuber. Gelatinization temperatures (77.65 to 86.00 °C) were obtained for the studied varieties. The range is comparable to the 73.5 to 82.4 °C reported in literature by other researchers ([13], [18], [19] & [20]).

Maximum time, the duration for sample to reach highest viscosity, varied from 4.11 minutes for the head region of *D. esculenta* to 5.33 minutes for the tail region of *D. Praehensalis*. This is similar to values in literature ([14] & [19]). Maximum viscosity of the samples ranged from as low as 34 BU in *D. esculenta* to 384.5 BU in *D. rotundata*.

Table 1: Pasting characteristics of yam varieties

Yam variety	Yam part	Gelatinization Temperature °C	Maximum Time (Min)	Maximum Viscosity (BU)	Final Viscosity (BU)	Break down (BU)	Setback (BU)	Trough (BU)
D. rotundata (Pona)	Tail	$78.75^{a,b,c}$	4.36	337.0^{g}	343.5	1.0^{a}	$31.5^{a,b,c}$	332.5
	Middle	$78.60^{a,b,c}$	4.31	384.5^{g}	404.0	3.0^{a}	$43.5^{c,d}$	381.5
	Head	$79.00^{a,b,c}$	4.37	333.5^{g}	347.0	0.5^{a}	$39.0^{b,c,d}$	333.0
D. alata (Matches)	Tail	$78.75^{a,b,c}$	4.30	316.0^{g}	367.5	1.0^{a}	91.0^{g}	315.0
	Middle	$78.20^{a,b}$	4.23	297.5^{g}	322.5	8.0^{a}	$47.5^{c,d,e}$	289.5
	Head	$78.95^{a,b,c}$	4.36	$215.5^{e,f}$	249.5	0.5^{a}	$44.0^{c,d}$	215.0
D. dumetorum (Yellow)	Tail	$80.60^{a,b,c,d}$	4.66	$185.5^{d,e,f}$	181.5	54.0^{b}	$53.5^{c,d,e}$	131.5
	Middle	$79.70^{a,b,c,d}$	4.53	$196.0^{d,e,f}$	190.0	$55.0^{b,c}$	$56.0^{d,e,f}$	141.0
	Head	$79.50^{a,b,c,d}$	4.49	$200.5^{d,e,f}$	177.0	71.0^{c}	$48.0^{c,d,e}$	129.5
D. esculenta (Large)	Tail	$79.55^{a,b,c,d}$	4.40	$102.0^{b,c}$	137.5	1.0^{a}	$42.5^{c,d}$	101.0
	Middle	$78.75^{a,b,c}$	4.30	$81.0^{a,b}$	112.0	0.0^{a}	$35.5^{b,c,d}$	81.0
	Head	77.65^{a}	4.11	34.5^{a}	57.0	0.0^{a}	$25.0^{a,b}$	34.5
D. cayenensis (Pure Yellow)	Tail	$80.65^{a,b,c,d}$	4.57	295.5^{g}	273.5	7.0^{a}	8.5^{a}	288.5
	Middle	$83.15^{d,e}$	4.95	$203.5^{d,e,f}$	214.0	0.0^{a}	$29.0^{a,b,c}$	203.5
	Head	$80.40^{a,b,c,d}$	4.55	236.0^{f}	236.5	0.5^{a}	$25.0^{a,b}$	235.5
D. bulbifera (Deep brown skin)	Tail	$82.15^{c,d}$	4.79	155.5^{d}	204.0	1.0^{a}	$61.0^{f,g}$	154.5
	Middle	$81.90^{b,c,d}$	4.76	$152.0^{c,d}$	206.5	0.5^{a}	$59.5^{e,f,g}$	151.5
	Head	$81.90^{b,c,d}$	4.75	$153.0^{c,d}$	206.0	1.0^{a}	$60.5^{e,f,g}$	152.0
D. praehensalis	Tail	86.00^{e}	5.33	$77.0^{a,b}$	97.5	0.0^{a}	$30.5^{a,b,c}$	77.0
	Middle	$79.65^{a,b,c,d}$	4.41	$172.0^{d,e}$	188.0	0.0^{a}	$34.5^{b,c,d}$	172.0
	Head	85.90^{e}	5.31	95.5^{b}	123.5	0.0^{a}	$41.5^{c,d}$	95.5

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

There were significant differences (p<0.05) in maximum viscosity among the samples due to varietal differences. The result is indicative of high swelling capacity for the starches from varieties with high maximum viscosity and hence their ability to resist breakdown on cooking [21].

Varieties differ significantly (p<0.05) in their final viscosities which were observed to be in the range of 57.0 BU in *D. esculenta* to 404.0 BU in *D. rotundata*. Final viscosity is the ability of the starch to form viscous paste on cooling as a result of aggregation of amylose molecules. The pasting profile curves of the yam flour from the varieties as generated from Brabender Visco-amylograph are presented in Figure 1.

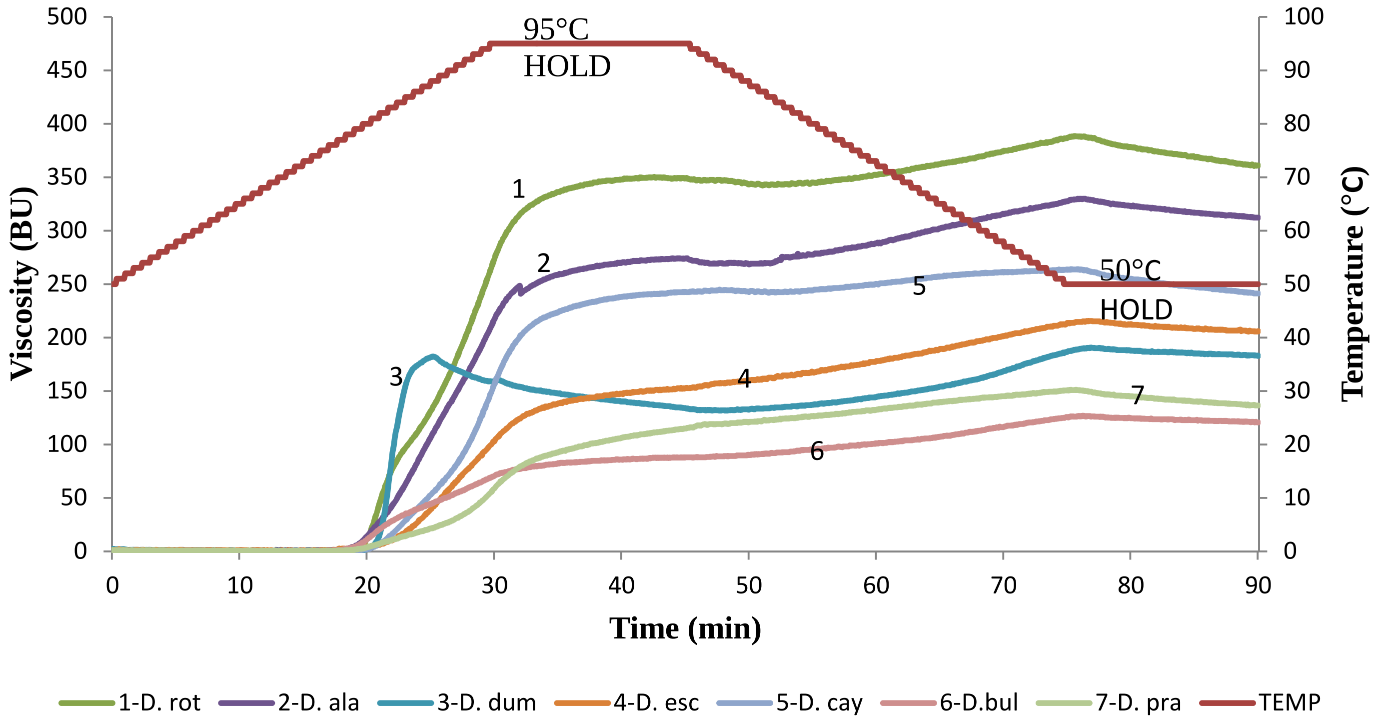

Figure 1: Pasting profile curves of yam varieties from Brabender Visco-amylograph

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*

Breakdown viscosity observed for all the studied varieties was very low (below 10.0 BU) except *D. dumetorum* that recorded 54.0 BU for the tail region, 55.0 BU for the middle portion and 71.0 for the head section. Breakdown viscosity measures the tendency of the starch granules to rupture when held at high temperatures with continuous shearing. It is indicative of the stability of the starch on heating. This implies that the starch granules of *D. dumetorum* have a high tendency to rupture during cooking at high temperature [21]. Setback values, which measure paste hardening on cooling, differed significantly from 8.5 BU in *D. cayenensis* to 61.0 BU in *D. bulbifera*. The range obtained in this study fell below that reported in literature ([14] & [18]).

The trough (hot paste) viscosity is an indication of the paste stability during heating. This varied from 34.5 BU for *D. esculenta* to 381.5 BU for *D. rotundata*. The head region of *D. esculenta* which recorded the lowest hot paste viscosity was observed to consistently, have the lowest value in all rheological parameters studied, except setback viscosity. This means that it is more susceptible to fragmentation of its starch granules during cooking than the rest.

3.2 Trend in Rheological Properties along the length of Yam Varieties

No identifiable trend was observed along the head, middle and tail regions of each variety investigated and this was consistent in all the measured attributes (Figure 2).

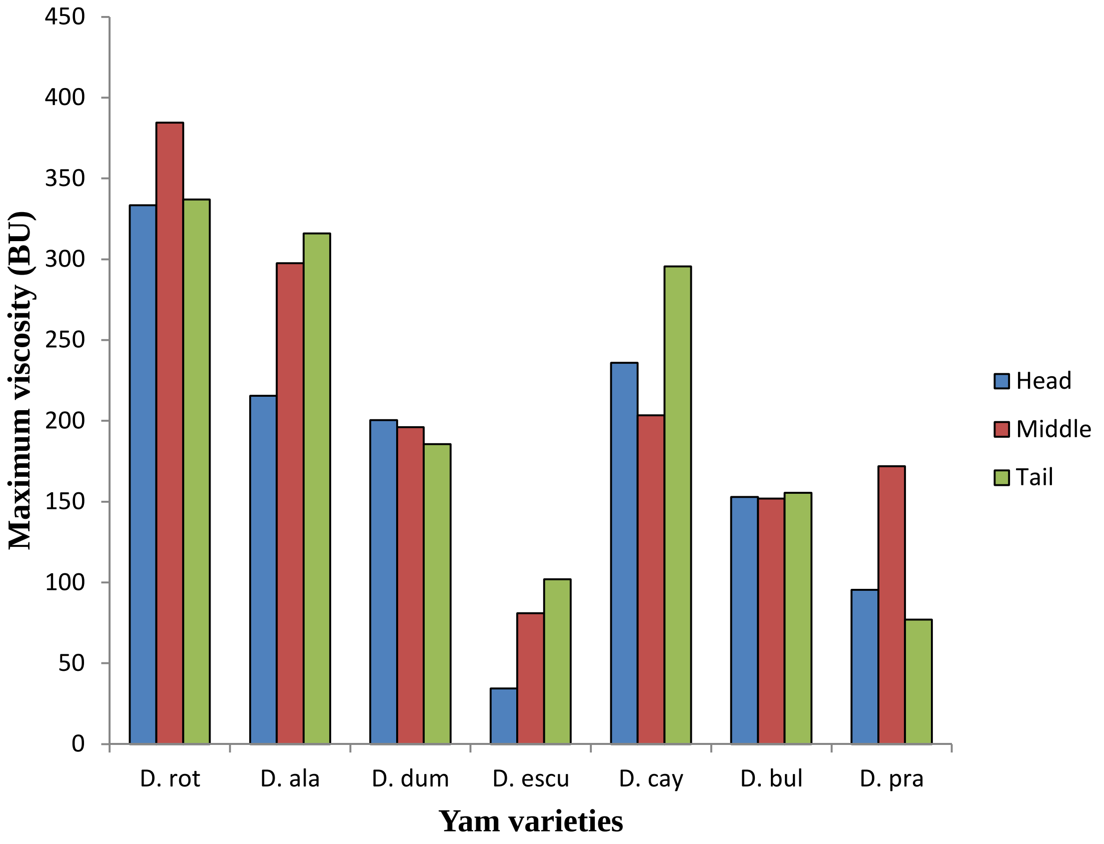

Figure 2: Trend in viscosity of yam flour along each tuber

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*

3.3 Cluster and Principal Component Analysis for Rheological Characteristics of the Yam Varieties

The yam varieties for this study were statistically analyzed for similarities in pasting characteristics using observations and principal component (PC) analyses to establish the patterns and interrelationships that exist between the varieties. The cluster observation dendogram (Figure 3) grouped the yam varieties into four clusters based on their similarities.

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.

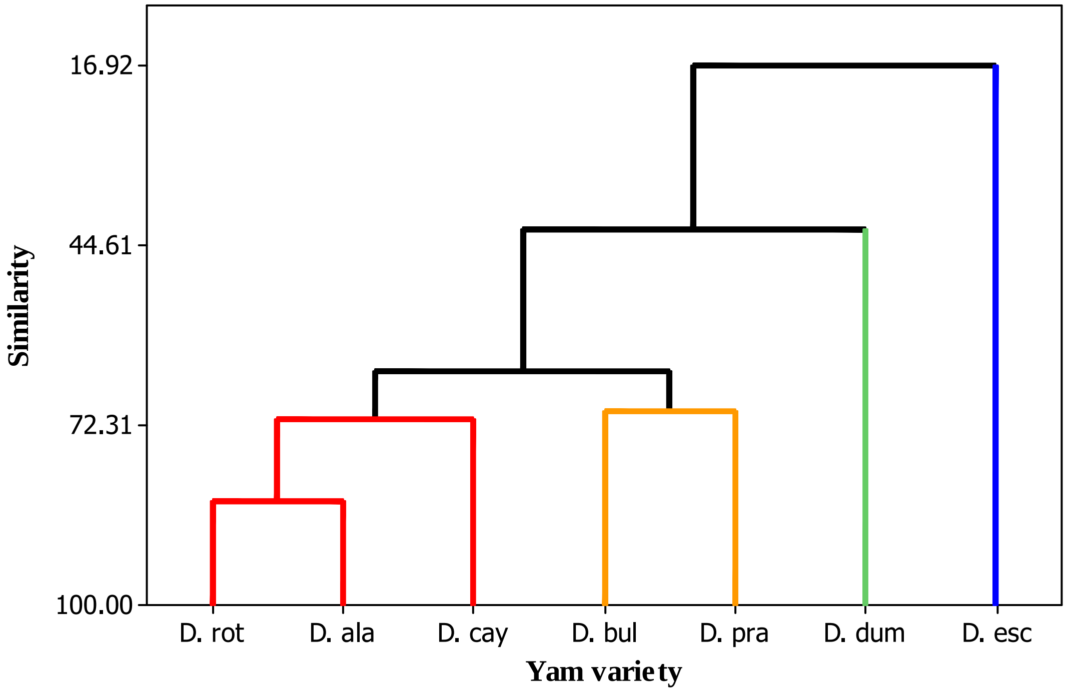

Figure 3: Cluster observation dendogram for rheological characteristics of yam varieties

***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 65.9% of the variations for pasting properties in the varieties were explained by two principal components. PC1 accounted for 37% of the variation while PC2 accounted for 28.9%.

PC1 is dominated by maximum viscosity, final viscosity and trough viscosity; PC2 is dominated by gelatinization temperature of the paste. Comparing the Variable weights and the samples on the score plot (Figure 4) revealed that the shared characteristics which related *D. rotundata, D. alata* and *D. cayenensis* were their maximum, final, setback and trough viscosities.

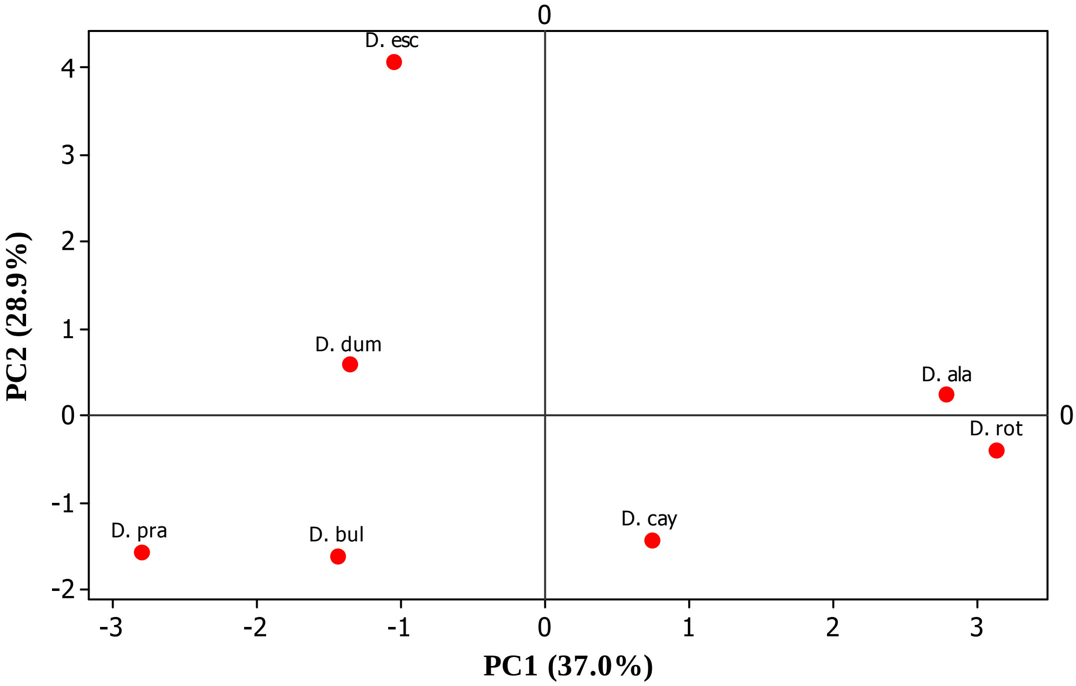

Figure 4: Sample score plot for the principal component analysis of the rheological characteristics of the yam varieties

***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*

Pastes made from *D. rotundata* also recorded relatively high maximum, final and trough viscosities suitable for use in products that require paste stability during heating and hardening on cooling, than *D. alata*. *D. dumetorum* had distinctly high breakdown viscosity while *D. esculenta* had very low breakdown.

4 CONCLUSION

In all, significant differences (p<0.05) existed among the yam varieties for their pasting properties. Pastes from flours of *D. rotundata* had high maximum and final viscosities (333.5-384.5 BU and 343.5-404.0 BU respectively). Breakdown viscosity was low (<10 BU) in all the studied varieties, except *D.* dumetorum (54-71 BU).

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