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Viscoelastic Properties and Physico-Functional Characterization of Six High Yielding Cassava Mosaic Disease-Resistant Cassava (*Manihot Esculenta Crantz*) Genotypes

Emmanuel Ohene Afoakwa[1]*, Agnes Simpson Budu[1], Clement Asiedu[1], Linley Chiwona-Karltun[2] and Drinah Banda Nyirenda[3]

[1]*Department of Nutrition & Food Science, University of Ghana, P. O. Box LG 134, Legon-Accra, Ghana*
[2]*Department of Urban & Rural Development, Swedish University of Agricultural Sciences (SLU), Box 7012, 75007 Uppsala, Sweden*
[3]*Department of Animal Science, University of Zambia, Lusaka, Zambia*

Abstract

Investigations were conducted to characterize six high yielding cassava mosaic disease (CMD) resistant cassava varieties (*Ampong, Broni bankye, Sika, Otuhia, Amakuma* and *Bankye fitaa*) that have been developed by the Crop Research Institute of Ghana in collaboration with the International Institute for Tropical Agriculture for their differences and similarities in viscoelastic properties and physico-functional characteristics. The viscoelastic properties (pasting temperature, peak viscosity, final viscosity, breakdown viscosity and setback viscosity), and physico-functional characteristics (swelling power, solubility and water binding capacity) were determined using standard analytical methods. The results showed wide variations in viscoelastic properties with values ranging from 270.67-380.67 BU for peak viscosity, 37.17-260 BU for final viscosity, 199.83-282.33 BU for breakdown viscosity, 21.83-98.66 BU for setback viscosity and 2.48-10.51 min time to pasting temperature. Similarly, variations in swelling power, solubility and water binding capacity were noted with values ranging between 14.34-17.04%, 73.04-79.98% and 234.53-276.63% respectively for all the different cassava genotypes. Statistical analysis showed significant differences ($P < 0.05$) amongst the studied cassava genotypes with *Sika* (improved variety) having exceptionally high viscoelastic characteristics. The differences noted in the viscoelastic properties and physico-functional characteristics of the six CMD resistant cassava genotypes could be used in their selection for specific food and industrial processing applications.

Keywords: Cassava; *Manihot esculenta Crantz*; Pasting characteristics; Functional properties; Principal component analysis; Cluster analysis

Introduction

Cassava (*Manihot esculenta Crantz*) has been identified as a major food security crop for many developing countries in Africa and Asia. In most African countries, it is ranked first followed by yam and cocoyam in terms of root crop production and yield, where it is a major source of food and industrial raw material and income for rural communities [1,2]. The root is a physiological energy-dense food and therefore ranked high for its calorific value of 250 x 10^3 cal/ha/day as compared to 176 x 10^3 for rice, 110 x 10^3 for wheat, 200 x 10^3 for maize, and 114 x 10^3 for sorghum [3-5]. Raw cassava root has more carbohydrate than potatoes and less carbohydrate than wheat, rice, yellow corn, and sorghum on a 100 g basis [4]. Currently, different cassava cultivars are processed into various intermediate and finished food products including high quality cassava flour (HQCF), cassava dough (*agbelima*), starch, *gari*, cassava chips and instant *fufu* flours on the large scale. Other products such as ethanol, glucose, high fructose syrups and many beverages are being introduced based on the starch and amylose contents of the varieties [6-10].

Physico-functional properties provide information on how food ingredients behave in a food system during processing. These properties include bulk density, swelling power, swelling volume, solubility, water binding capacity and gelation properties. Previous reports have shown that many factors influence the degree and kind of physico-functional properties and these include the starch composition and concentration, ratio of amylose to amylopectin, characteristics of each fraction in terms of molecular weight/distribution, degree/length of branching and conformation of starch [8,11-15]. Swelling power and solubility of cassava flour is dependent on the variety, environmental factors and the age of the crop. Low swelling power accompanied by high solubility is indicative of weak associative forces in starch granules which have been attributed to damage caused by milling to the starch granules of the cassava varieties [16].

Viscoelastic studies have been used to determine the gelatinization of suspensions from a variety of starches as well as their pasting characteristics during heating and subsequent cooling [17-20]. It has been shown [21] that upon heating, the viscosity increased suddenly after a certain temperature was reached and increased to a maximum. Further heating only led to reduction in viscosity. Gelatinization causes disruption of the weak associative bonds in the amorphous region of the granule enabling increased hydration of the starch granules thereby increasing the WBC of starches [9,22]. During the gelatinization process, the water binding sites are increased as the heat starts to disrupt the intragranular bonds. High water binding is attributed to lose association of the starch polymers in the native granule. The

***Corresponding author:** Emmanuel Ohene Afoakwa, Department of Nutrition & Food Science, University of Ghana, P.O. Box LG 134, Legon-Accra, Ghana, Tel: +233 (0) 244 685893; E-mail: eoafoakwa@gmail.com, eafoakwa@ug.edu.gh

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water binding sites are considered to be hydroxyl and the inter-glucose oxygen atoms and the water absorptive nature of starches could be varied by disruption of the crystalline structure by heat, enzyme and/or mechanical forces [22,23].

Aryee et al. [8] reported that cassava varieties with high gelatinization temperatures cannot be used directly as brewery adjunct since their gelatinization temperatures do not fall within the range for barley malt. They will have to be either pre-gelatinized or processed further into glucose syrup before they can be used as adjuncts. For use as thickeners, the paste formed should not retrograde and should also have high paste stability, when cold or hot, and such varieties could be used as thickeners and cassava flour. They can also be used in the bakery industry for bread and pastries such as cakes, biscuits, etc., as substitutes of wheat flour. Attaining gelatinization at a lower temperature improves bread-making quality [24]. High peak viscosity and stability (or low breakdown viscosity) of cassava flour gives acceptable bread [25]. A low setback value indicates that flour gives a non-cohesive paste [26]. This means that such starches cannot be used for products in which starch stability is required at low temperatures products that require refrigeration [8]. Cassava flours with very high amylose contents could be used for industrial alcohol, and glucose and high fructose syrups [27]. Low swelling accompanied by the high solubility is indicative of weak associative forces in the starch granules and this implies that starch from such cassava varieties can be hydrolyzed easily to produce starch sugars without using energy as compared to varieties with strong associative forces [16].

Genotypic variations in cassava have been reported to play important roles in the production of diversified food products due to their inherent differences in biochemical, physico-functional and physiological characteristics [4,8,28]. In recent times, many new and improved cultivars (high yielding and resistant to cassava mosaic diseases) have been developed with distinct physiological, morphological and structural characteristics by the Crop Research Institute of the Council for Scientific and Industrial Research (CSIR) in Ghana through collaboration with the International Institute for Tropical Agriculture (IITA) in Nigeria. It is expected that the starches and flours of these new and improved varieties would have different unique physico-chemical and functional properties that could affect their use in various food and industrial processing applications. Thus, the objective of this study was to investigate variations in viscoelastic properties and physico-functional characteristics of the six cassava genotypes for their varied food and industrial applications.

Materials and Methods

Materials

Six varieties of cassava made up of four improved varieties (Ampong-CSIR, Broni bankye-CSIR, Sika-CSIR, Otuhia-CSIR) and two traditional varieties (Amakuma, Bankye fitaa) obtained from the experimental fields of the Crop Research Institute of the Council for Scientific and Industrial Research (CSIR) situated at Pokuase in the Greater Accra Region of Ghana were used in the study.

Sample preparation

The samples were harvested from the fields of Crop Research Institute, Pokuase in the Greater Accra Region of Ghana and transported immediately to the laboratory. At the laboratory, the samples were cleaned, peeled and washed with potable water. Samples from the distal, middle and apical sections of peeled tubers were cut into cube, mixed thoroughly and oven dried at 60°C for 48 h. The oven dried samples were ground in a Hammer mill (Christy and Norris Ltd., Chelmsford, Surrey, UK) into flour to pass through a 250-mm sieve. The flour samples obtained were then packaged into polypropylene bags and kept at room temperature (25-28°C) for analyses.

Analytical methods

Determination of viscoelastic (pasting) characteristics: The viscoelastic (pasting) characteristics of the different cassava samples were determined using a Brabender Visco-Amylograph (Model 802525, Duisburg, Germany). An aqueous suspension of 40 g flour (dry basis) in 420 ml of distilled water was heated from 50 to 95°C at a rate of 1.5°C/min by means of a thermoregulator. At 95°C the sample was held constant for 20 min (first holding period) while being stirred continuously. The paste was cooled to 50°C at 1.5°C/min and held at that temperature for 15 min (second holding period). Pasting temperature, peak (maximum) viscosity at each stage and the peak temperature were taken from the amylograms. From these measurements the setback viscosity, retrogradation tendency and paste stability at 95 and 50°C were computed [29].

Determination of swelling power and solubility: Swelling power and solubility determinations were based on modification of the method of [30]. One gram of flour was weighed into a 50 ml graduated centrifuge tube. Distilled water was added to give a total volume of 40 ml. The suspension was stirred sufficiently and heated at 85°C in a water bath for 30 min with constant stirring. The tubes were cooled to room temperature and centrifuged for 15 min at 2200 rpm. The solubility was determined by evaporating the supernatant and weighing the residue. The swelling power was obtained by directly reading the volume of the swollen sediment in the tube. The % solubility and swelling power were calculated and their mean values reported.

Determination of water binding capacity: Water binding capacity (WBC) was determined by the method of [30]. An aqueous suspension was made by dissolving 2 g of cassava flour in 40 ml of water. The suspension was agitated for 1 h on Griffin flask shaker (Griffin and George Ltd. Birmingham, UK) after which it was centrifuged for 10 min at 2200 rpm. The free water was decanted from the wet cassava flour, drained for 10 min and the wet sample weighed. The analysis were conducted in triplicates and mean value reported as g/100g.

Statistical analysis

Statistical analysis and graphical presentation were done using Minitab (version 14) and Microsoft Excel (2007 version) respectively. Analysis of variance for the cassava varieties was conducted at a level of significance of $P < 0.05$. Cluster Analysis (cluster observation) was carried out to group cassava varieties with similar characteristics. Principal component analysis (PCA) was used to ascertain patterns and explore the relationships between the various parameters and the cassava samples. All the sample treatments and analysis were conducted in triplicates and their mean values reported.

Results and Discussion

Viscoelastic properties of cassava varieties

Viscoelastic properties are among the most important parameters used to ascertain the suitability of flours and starch for certain end uses. It helps in the selection of a variety for use in the industry as a thickener, binder or for any other food and industrial use. Figure 1 shows a time-viscosity plot of the pasting of the different cassava varieties generated from Brabender Viscoamylograph in this study. The amylograms from flours of the six cassava genotypes studied revealed that the viscosity increased to a peak, dropped whilst cooking and increased slightly on cooling (Figure 1). A close examination of the pasting characteristics showed that with the exception of *Sika* (improved) variety which showed relatively higher pasting characteristics, *Ampong*, *Broni bankyi* and *Otuhia* had quite higher and similar pasting behaviours during both the heating and cooling periods. *Amakuma* and *Bankye fitaa* showed relatively lower pasting characteristics with *Bankye fitaa* having the least pasting behaviour (Figure 1).

The viscoelastic properties of the cassava varieties are summarized in Table 1. Significant differences (P<0.05) in the pasting properties among the different varieties of cassava was observed; with the exception of the pasting temperature. Slight variations in pasting temperatures (64.73 to 68.95°C) were observed for the varieties evaluated (Table 1). This is indicative of the fact that gelatinization of starch granule occurs at similar temperatures for different cassava varieties. Aryee et al. [8] observed pasting temperature ranges from 66.8 to 70.4°C when studying flours from different cassava varieties.

Peak time is the duration taken for the samples to reach highest viscosity. Peak time of the samples varied from 2.48 to 10.51 minutes with *Bankye fitaa* (traditional variety) having the lowest value whilst *Sika* (improved variety) had the highest (Table 1). There were significant differences (P<0.05) in peak time amongst the cassava varieties. The low peak time of *Bankye fitaa* is indicative of its ability cook faster as compared to the other cassava varieties and thus could be suitable for the preparation of foods such as *fufu* (pounded cassava), *gari* (fermented and toasted cassava grits) and boiled cassava.

Peak viscosities of the samples ranged from 270.67 to 380.67 BU. *Sika* (improved variety) had the highest peak viscosity whilst *Bankye*

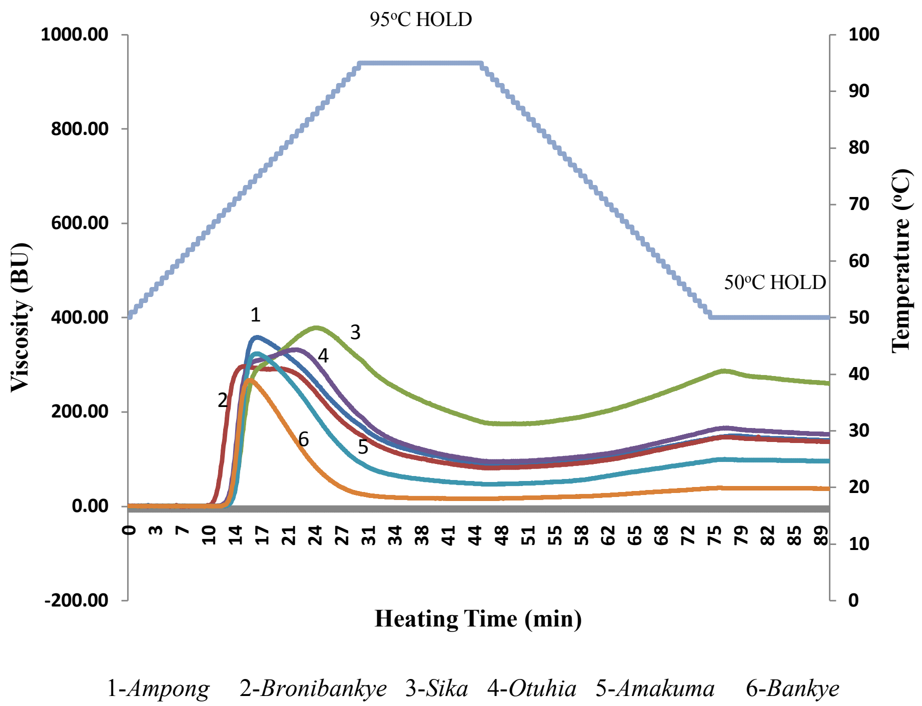

Figure 1: Amylograms showing the viscoelastic (pasting) profiles of the studied cassava genotypes.

Variety	Pasting temperature (°C)	Peak time (min)	Peak viscosity (BU)	Trough (BU)	Final viscosity (BU)	Breakdown (BU)	Setback (BU)
Ampong[1]	66.38[a,b]	6.73[c]	373.83[b]	91.67[b]	140.67[b]	282.33[b]	53.33[b]
Broni Bankye[1]	64.73[a]	5.96[b,c]	312.17[a,b]	82.50[b]	136.33[b]	229.33[a,b]	59.50[b]
Sika[1]	68.95[b]	10.51[d]	380.67[b]	180.33[c]	260.00[c]	199.83[a]	98.66[c]
Otuhia[1]	67.95[a,b]	8.53[c,d]	344.50[a,b]	96.83[b]	152.00[b]	247.67[a,b]	65.00[b]
Amakuma[2]	68.83[b]	3.24[a,b]	326.00[a,b]	47.33[a,b]	96.00[a,b]	278.67[b]	49.67[b]
Bankye fitaa[2]	68.38[a,b]	2.48[a]	270.67[a]	15.50[a]	37.17[a]	254.00[b]	21.83[a]

In each column means followed by different letters (a, b, c, etc.) are significantly different at p < 0.05.

[1]improved variety and [2]traditional variety

Table 1: Viscoelastic properties of the flours from the studied cassava genotypes.

fitaa (traditional variety) had the lowest. Even though *Bankye fitaa* had large starch granules (41.33µm) it recorded a low peak viscosity which was probably due to low content of starches and fibre in the sample [31]. *Sika* cassava variety had the highest peak viscosity and this was probably resulted from the high content of sugars which has an anti-plasticizing effect on the starch granules and thus reduced the amount of amylose leaching out. There was no clear difference between improved and traditional varieties but significant differences ($P<0.05$) existed amongst the cassava varieties except *Amakuma*, *Broni bankye* and *Otuhia* which showed similar behavior in peak viscosity. Generally for starches, high viscosity is desirable for industrial uses, for which a high thickening power at high temperatures is required [26].

The trough (hot paste) viscosity is an indication of the paste stability during heating. This varied from 15.50 BU for *Bankye fitaa* to 180.33 BU for *Sika*. *Bankye fitaa* was very different from the rest of the varieties in having a significantly lower hot paste viscosity than the rest. This observation is consistent with its low peak viscosity. The improved varieties showed relatively higher resistance to fragmentation of their starches during cooking.

Breakdown viscosity ranged from 270.67 BU to 380.67 BU for *Bankye fitaa* and *Sika* respectively (Table 1). Significant differences ($P<0.05$) existed amongst the varieties except for *Broni bankye, Otuhia* and *Amakuma*. Breakdown viscosity is the measure of the tendency of swollen starch granules to rupture when held at high temperatures and continuous shearing [32] and it is indicative of the stability of the starch on heating. Breakdown viscosities was significantly higher in the other cassava varieties studied than *Sika* (improved variety), which makes *Sika* very stable during heating. Aryee et al. [8] reported that high paste stability is an indication of very weak cross-linking within the starch granules. This means that such starches cannot be used for products where starch stability is required at very high temperatures, because they will breakdown.

The cassava varieties varied significantly ($P<0.05$) in their final

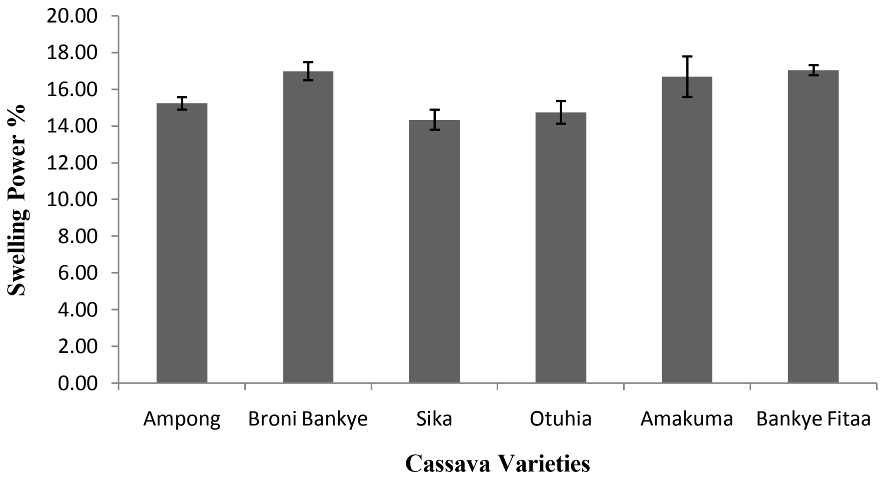

Figure 2: Swelling power of the studied cassava genotypes.

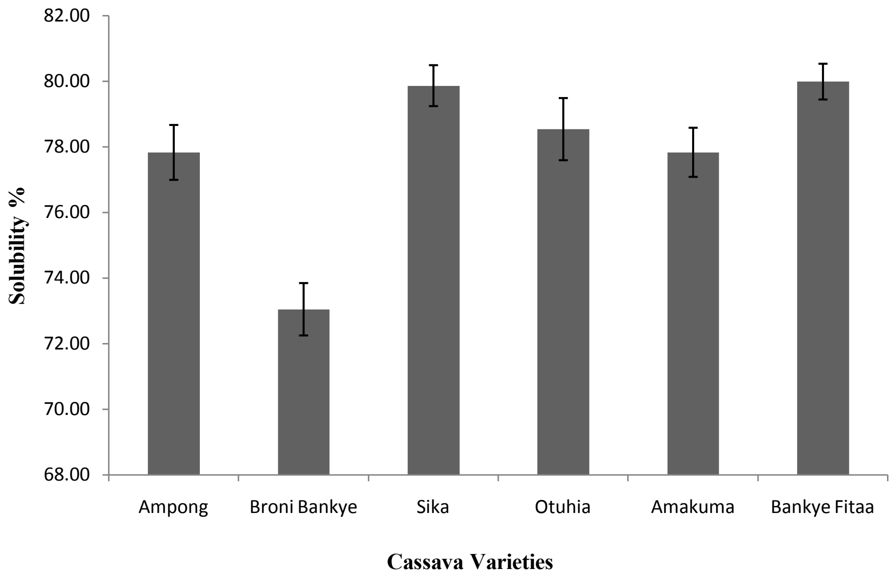

Figure 3: Solubility of the studied cassava genotypes.

viscosities which were observed to be in the range of 37.17BU to 260BU for *Bankye fitaa* and *Sika* respectively (Table 1). The final viscosity relates to the ability of the starch to form a viscous paste during cooling. This ability to form a viscous paste on cooling was higher in the improved varieties than the traditional varieties. The increase in final viscosity might be due to the aggregation of amylose molecules [33]. A large increase in viscosity during the cooling stage is indicative of quick retrogradation [34]. The differences in their final viscosities resulted in significant differences ($p<0.05$) in their setback characteristics.

Setback (which is the measure of the paste hardening on cooling) ranged from 21.83BU to 98.66BU. *Sika* registered the highest setback value which was significantly different ($p<0.05$) from the other studied varieties (Table 1). This indicates that *Sika* recovered most of its amylose content during cooling than all the other studied varieties. *Bankye fitaa* being the least [17] which indicates that the flour gives a non-cohesive paste [26]. This means that such starches cannot be used for products in which starch stability is required at low temperatures, such as adhesives, fillings and products that require refrigeration.

Physico-functional properties

The physico-functional properties (swelling power, solubility and water binding capacity) of cassava varieties were determined to ascertain how the varieties behave in a food system. The results of the swelling power, solubility and water binding capacity of the studied cassava varieties are shown in Figures 2 to 4 respectively.

Swelling power of cassava varieties: Swelling power is the maximum increase in volume and weight which starch undergoes when allowed to swell freely in water. It gives the behaviour of starch in the food systems. The swelling power (Figure 2) of the cassava flour samples ranged from 14.34% to 17.04%. *Otuhia* had the lowest, while *Bankye fitaa* had the highest swelling power. Significant differences ($p < 0.05$) existed in the swelling power of the cassava flour samples.

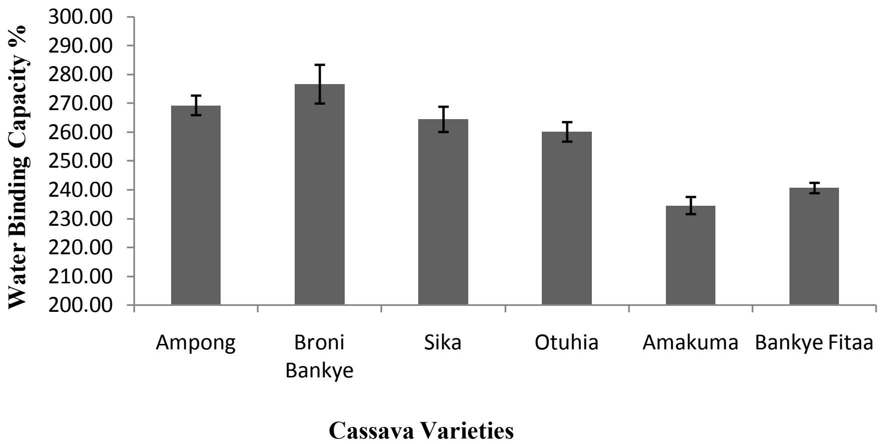

Figure 4: Water binding capacity of the studied cassava genotypes.

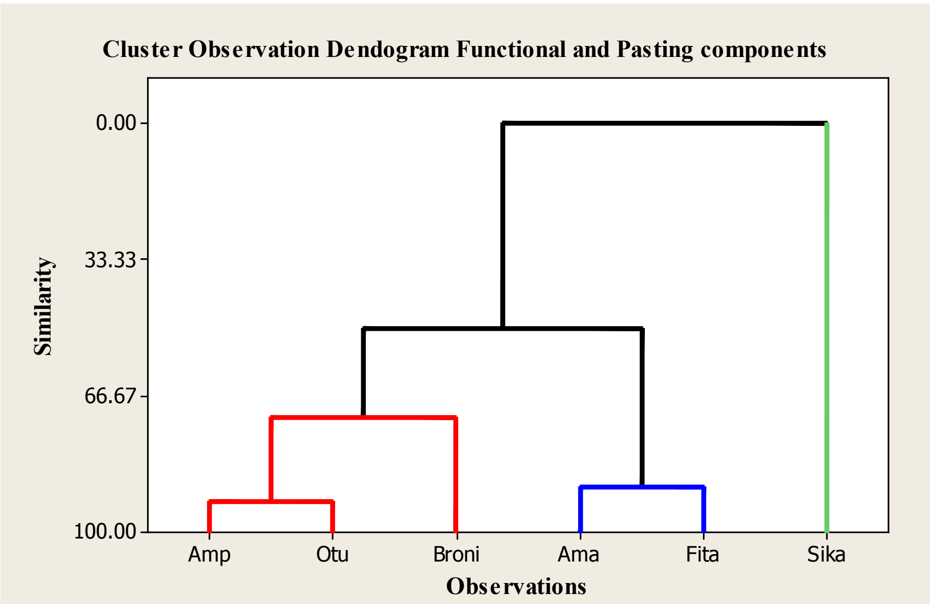

Figure 5: Cluster observation dendogram for viscoelastic properties and physico-functional characteristics of traditional and improved cassava genotypes.
Abbreviations: *Amp: Ampon; Broni: Broni bankye; Sika: Sika; Out: Otuhia; Ama: Amakuma; Fita: Bankye fitaa.*

Moorthy and Ramanujam [16] reported that swelling power of cassava flour is dependent on the variety, environmental factors and the age of the crop. Aryee et al. [8] also reported that the swelling power of the flour samples of cassava varieties to be 5.87% to 13.48%. In another study, Shittu et al. [14] reported values ranging from 13.16% to 16.17% for different cassava flours. Values obtained were within the reported range except for *Broni Bankye* (16.98%), *Amakuma* (16.68%) and *Bankye fitaa* (17.04%) which had relatively higher values probably due to varietal differences. According to Zheng and Sosulski [35], the swelling power of starch is associated more with granule structure and chemical composition, particularly amylose and lipid content, than with granule size. Higher amounts of lipid-complexed amylose would inhibit swelling. Differences in swelling power for the cassava samples could be caused by differences in lipid and amylose content.

Solubility of cassava varieties: Solubility of the cassava flour samples varied significantly ($p < 0.05$), giving a range of 73.04 – 79.98% (Figure 3). *Broni bankye* had the lowest (73.04%), with *Bankye fitaa* having the highest (79.98%). Solubility is dependent on variety, environmental factors and age of the crop [16]. Aryee et al. [8] also reported that low swelling accompanied by the high solubility is indicative of the weak associative forces in the starch granules in these varieties. This may be attributed to the damage caused by milling to the starch granules. This implies that starch from these varieties can be hydrolyzed easily to produce sugars without using energy as compared to varieties with strong associative forces [16]. Ranges from 47.32% to 78.38% have been reported for solubility of the cassava flour [8]. All values obtained were above the reported range for solubility except that of *Broni bankye* (73.04%). The solubility of cassava varieties was significantly different at $p<0.05$.

Water binding capacity of cassava varieties: The water binding capacity (WBC) of the cassava varieties ranged from 234.53 for *Amakuma* to 276.63% for *Broni bankye* (Figure 4). Significant differences ($p<0.05$) existed in the WBC values of the cassava varieties. The relatively high WBC values obtained are indicative of weak associative forces between the starch granules, which allows for more molecular surfaces to be available for binding with water molecules [36], whereas is vice versa for low WBC. Aryee et al. [8] reported water binding capacity of flour from cassava samples to be from 113.66% to 201.99% whilst Shittu et al. [14] using multivariate techniques to study flour making properties of some CMD resistant cassava clones reported WBC ranges from 136.03% to 213.02%. Values obtained in this study were above ranges reported for other studies on cassava samples. It was observed that the improved varieties (*Ampong*, *Broni bankye*, *Sika* and *Otuhia*) had high WBC which is indicative of weak associative forces between their starch granules, which allows for more molecular surfaces to be available for binding with water molecules.

Cluster and principal component analysis for viscoelastic (pasting) properties and physico-functional characteristics of the studied cassava varieties

Similarities and differences were observed in the viscoelastic properties and physico-functional characteristics of the cassava varieties used for the study. Figure 5 shows the cluster observation dendogram for the viscoelastic (pasting) properties and physico-functional characteristics of the cassava varieties studied. The varieties have been divided into three clusters based on similarity of characteristics (Figure 5). The first cluster is composed of *Ampong, Otuhia* and *Broni bankye*. The second cluster is made up of *Amakuma* and *Bankye fitaa* whilst *Sika* constituted the third cluster. Although *Sika* distinguished itself from the others, it was observed that the samples were partitioned along improved and traditional lines which mean differences do exist on the basis of their functional and pasting characteristics. However, among the improved varieties *Ampong* and *Otuhia* were more similar than *Broni bankye*.

Principal component analysis applied to the functional and pasting characteristics of the six cassava varieties shows that two components

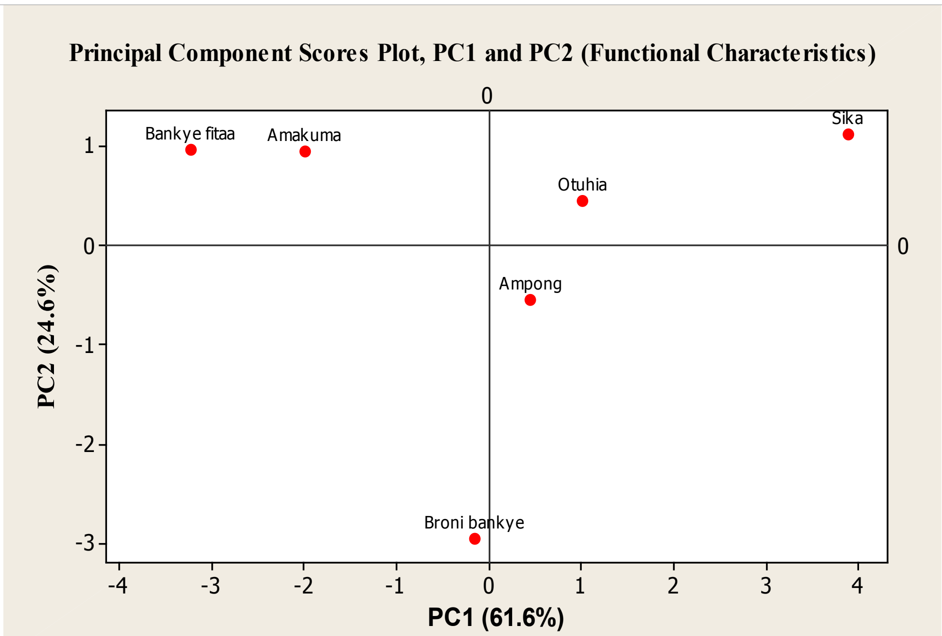

Figure 6: Sample score plot for the principal component analysis of viscoelastic properties and physico-functional characteristics of traditional and improved cassava genotypes

Abbreviations: *Amp: Ampong; Broni: Broni bankye; Sika: Sika; Out: Otuhia; Ama: Amakuma; Fita: Bankye fitaa*

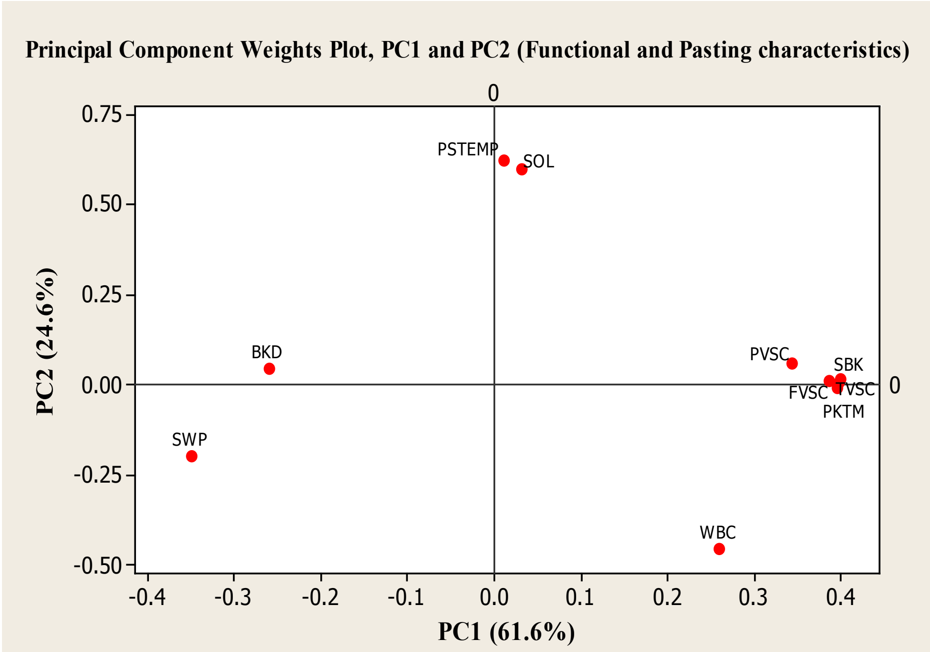

Figure 7: Variable weights plot for the principal component analysis of viscoelastic properties and physico-functional characteristics of traditional and improved cassava genotypes.

Abbreviations: SWP: Swelling power; BKD: Break down; PVSC: Peak viscosity; SOL: Solubility; WBC: Water Binding Capacity; PKTM: Peak time; FVSC: Final Viscosity; SBK: Setback; TR: Trough; PSTEMP: Pasting Temperature

explained a total of 86.2% of the total variability in the data. PC 1 accounted for 61.6% of the total variation in the functional and pasting characteristics while PC 2 explained 24.6% (Figures 6 and 7). From the principal component score plot (Figure 6) it was observed that *Sika* was far on its own in the positive side of the PC 1 whilst majority of the improved varieties were the loaded around the origin of the y-axis of PC 1. The traditional varieties were found on the negative side of PC 1. The variable weights plot (Figure 7) shows a loading of the most functional and pasting characteristics on the positive side of the x-axis (PC 1). By virtue of their position on PC 1, the improved varieties were related based on their solubility, pasting temperature, water binding capacity, final viscosity, peak viscosity, peak time, setback and trough. But *Sika* an improved variety was exceptionally different from the other improved varieties (*Ampong, Otuhia* and *Broni bankye*) by its peak viscosity, setback, final viscosity, peak time and trough. However, *Ampong, Otuhia* and *Broni bankye* also had quite higher viscoelastic properties suggesting that all four improved varieties could be recommended for use in the production of various industrial products that require high viscoelastic/pasting properties. Whilst the traditional varieties (*Amakuma* and *Bankye fitaa*) were similar based on their low breakdown and swelling power and could be recommended for use as raw materials for the preparation of various food products that require quite lower pasting properties and swelling power.

Conclusion

All the studied cassava varieties had significant variations in their viscoelastic properties and physico-functional characteristics. The viscoelastic properties showed that *Sika* (improved variety) had the highest peak viscosity, paste stability and setback viscosity. However, *Ampong, Otuhia* and *Broni bankye* also had quite higher and comparable viscoelastic properties and physico-functional characteristics, suggesting that the four improved varieties (*Sika, Ampong, Otuhia* and *Broni bankye*) could be recommended for use as raw materials for industrial applications such as adhesives, fillings, cassava flour and thickeners for bakery and pharmaceutical industries as well as for the production of ethanol, and glucose and fructose syrups. Similarly significant differences existed among the studied cassava varieties for their physico-functional characteristics. Although pasting characteristics did dictate the differences that existed between *Sika* and the other improved varieties, high breakdown and swelling power contributed significantly to the differences observed in the traditional varieties. The traditional varieties (*Amakuma* and *Bankye fitaa*) were similar based on their low breakdown and swelling power and could be recommended for use as raw materials for the preparation of various African foods such as *gari* (fermented and roasted cassava grits), *fufu* (pounded cassava paste), boiled cassava and cassava-based snack foods as these food products require low viscoelastic/pasting properties and swelling power. All the six studied cassava varieties had appreciably high viscoelastic properties and physico-functional characteristics which could be harnessed for food and industrial applications but the most outstanding one was *Sika* which had high peak viscosity, stability, set back, swelling power, water binding capacity and low solubility.

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