Evaluation of Different Industrial End Uses of Improved Cassava Varieties Grown in South-Eastern Africa

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ABSTRACT

This work characterized two local and seven improved Cassava Mosaic Disease [CMD]-tolerant cassava varieties for their biochemical composition and viscoelastic (pasting) properties. The biochemical composition and starch pasting properties were evaluated respectively using standard analytical methods and Brabender Viscoamylograph. Cluster dendrogram and principal component analyses compared similarities in the nine cassava varieties, thus predicting their varied food and industrial end uses. The different cassava varieties had starch, total sugars and reducing sugars content ranging from 53-69%, 6.5-9.2% and 0.9-2.5%, respectively. The starch content of the cassava varieties on dry weight basis (DW) varied from 54.0% to 69.0% with Nalumino having the lowest and Mweru having the highest respectively. Tanganyika, Mweulu, and Bangweru also recorded relatively higher starch content of 62.7%, 63.6% and 63.6% respectively. Mweru, Tangayoka, Mweulu, and Bangweulu had fairly high starch content (>60%) and thus could be used for many commercial products such as starches, alcohols and glucose. The viscoelastic properties of the different varieties had pasting temperature (63.5–67.6°C), peak viscosity (402–595 BU), viscosity at 95°C (394–592 BU), viscosity at 50°C (126–254), breakdown viscosity (236–352 BU) and setback (-100–4 BU). Tanganyika recorded the highest pasting temperature (67.6°C), peak viscosity (595 BU), viscosity at 95°C (592 BU) and viscosity at 95°C-hold (317 BU). Bangweulu, Mweulu, Mweru, Manyokola, Nalumino, Kampolombo and Chila A were clustered differently from Chila B and Tanganyika on the basis of their biochemical qualities and pasting properties. These characterizations showed that Tanganyika would be suitable for products requiring high elasticity and gel strength, easier to cook and also more stable during cooking/preparation such as *fufu* (pounded cassava) and *banku* or *Nshima*. Chila A would also be suitable for use as fillers and binders in the baking, confectionery industries as substitutes of wheat flour. The low viscosities of Chila B make it suitable for household food uses such as snacks where the roots are boiled, roasted or toasted and consumed.

Keywords: Cassava, processing, pasting characteristic, starch quality, variety.

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I. INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important perennial food crop usually found in the tropics [1]. It belongs to the family *Euphorbiaceae* and serves as an important diet for an about 700 million of the world's population [2]-[4]. Grown predominantly by small-scale farmers with limited resources, the crop is widely utilized as staple food and animal feed with a total cultivated area of over 26 million ha [5]-[7]. The importance of cassava to the livelihoods and socio-economic development of many millions of poor people has made the commodity a target for food and nutrition interventions in many developing countries [8]-[13]. Due to its versatility of utilization, total global utilization of cassava is estimated to increase from 230 to 275 million tonnes between 2010 and 2020, making cassava utilization in Africa equivalent to 62% of total quantities of global production [14], [15].

Nutritionally, cassava roots are an important source of carbohydrate for humans and animals, having a higher energy density (610 kJ/100g fresh weight than other root and tuber crops such as sweet potatoes (460 kJ/100g) and taro (490 kJ/100g) [2], [13], [16], [17]. Raw cassava root has more carbohydrate than potatoes but less carbohydrate than wheat, rice, yellow corn, and sorghum on a 100 g basis [11, 18]. The pattern of cassava utilization varies greatly across the various intra and inter-continental boundaries. However, it is utilized primarily as the major staple [19] in the largest part of the developing world mainly Africa and the south-east Asia.

Viscoelastic properties of starchy foods are widely used to assess the gel strengths of different starches and their gelatinization properties [20], [21]. An important processing quality of cassava starch is its ability to gelatinize, forming thick pastes suitable for human consumption. This property is mainly found in cereals and root crops [22]. Pasting characteristics of starches is essential in determining the

industrial applications of the starches [23]. A wide pallet of applications in the food industry is open to cassava flour. For use as binders, fillers and thickeners, the paste formed should not retrograde and should be stable whether cold or hot [24]. Cassava varieties providing flours with these characteristics may be used as thickeners, and in the bakery industry for bread and pastries such as cakes and biscuits. Again, attaining gelatinization at a lower temperature has been reported to improve bread-making quality [25], while high peak viscosity and stability (or low breakdown viscosity) of cassava flour gives acceptable bread [26]. Non-cohesive pastes are normally seen for flours/starches with a low setback value [27]. Such starches cannot be used for products requiring good stability at low temperatures, e.g., products for refrigeration [2].

Varietal variation in cassava plays a very important role in the production of diversified food products due to its inherent biochemical characteristics such as starch content, sugar content and pasting characteristics [28]. Biochemical composition and starch pasting properties of cassava are among the most important parameters used to predict the suitability of flours and starches for certain end product uses, and aid the selection of an appropriate variety for use in various food and industrial applications. This study was therefore aimed at characterizing the nine different cassava varieties (Bangweulu, Nalumino, Mweru, Chila A, Chila B, Tanganyika, Kampolombo, Mweulu, and Manyokola) produced within South-eastern Africa for their food and industrial end uses based on their varied biochemical composition and starch pasting properties.

II. MATERIALS AND METHODS

A. Cassava Varieties

Two local and seven improved CMD-tolerant cassava varieties were obtained from the farmers' fields in the Chisamba Community located within the Chongwe District in Zambia. These were: *Kampolombo*, *Bangweulu*, *Chila A* and *Chila B*, *Mweru*, *Mweulu*, *Tanganyika*, *Nalumino* and *Manyokola*. Out of these the two varieties, *Mweulu* and *Tanganyika* were local. The improved varieties were a result of the cassava breeding programme released varieties by the Zambian Agricultural Research Institute (ZARI) [12].

B. Preparation of Flours for Sugars and Viscoelastic Analysis

Root were harvested and transported to the laboratory within three hours of harvest. At the laboratory, the root samples were cleaned, peeled, and washed with room temperature water. Parts of the parenchyma from the different sections of the peeled tubers were cut into cubes and oven dried at 60 °C for 48 hrs. The dry cubes were ground into flour to pass through a 250-µm sieve by means of a Hammer mill (Christy and Norris Ltd., Model 2A, Chelmsford, Surrey, UK). The flour samples obtained were then packaged into polypropylene bags and kept at room temperature (25 °C) for analyses. Duplicate samples were prepared for each variety and triplicate analyses were conducted on each of the replicates. The mean values of all the analyses conducted and standard deviations were reported.

C. Starch Extraction and Analysis

The starch was extracted from the nine varieties by sedimentation method [9]. The tubers were sorted out and washed with clean water. The tubers were peeled, washed, with clean water to remove all the dirt and grated into chunks of about 0.5–1 mm thick. The 400 g of the samples were weighed and milled with 800 ml of water using blender (Philips 8010G, Chicago, IL, USA). The slurry was filtered through cheese cloth. The retained solids were washed with 4000 ml of water and filtered again until little or no starch was found in the residue. The filtrate was allowed to sediment overnight and the starch obtained was dried under room temperature until completely dry. The dried starch was weighed and expressed as a percentage of dry weight.

The total, reducing and non-reducing sugars were determined using the methods outlined by Lane and Eynon [29].

D. Determination of Viscoelastic Properties and Pasting Characteristics

The determination of the viscoelastic properties and the pasting characteristics were done using Brabender Visco-Amylograph (Model No. 802525, Duisburg, Germany) as outlined by Afoakwa *et al.* [24].

E. Data Analysis

Data analysis and graphical presentation were done using Minitab (version 14) and Microsoft Excel (2007 version) respectively. Cluster and principal component analysis (PCA) were performed to establish similarities and investigate the relationships among the various studied indices and the cassava samples

III. RESULTS

A. Biochemical Composition of Cassava Varieties

Table I presents the parenchyma starch content and the sugar composition of the flour from the various cassava varieties studied. The starch content of the cassava varieties on dry weight basis (DW) varied from 54.0% to 69.0% with Nalumino having the lowest and Mweru having the highest respectively. Tanganyika, Mweulu, and Bangweulu also recorded relatively higher starch content of 62.7%, 63.6% and 63.6% respectively. Total sugars ranged from 6.5% (Bangweulu) to 9.2% (Nalumino). The results also indicated that Nalumino which recorded the highest total sugar content (9.2%) recorded the least starch content (53%). The reducing sugar content was observed to range from 0.94% (Chila A) to 2.5% (Kampolombo). Non-reducing sugars formed the major component of the total sugars of the cassava varieties. It varied from 4.8% to 7.5% with Bangweulu being the lowest and Nalumino the highest.

B. Pasting Temperature

Table II gives the viscoelastic properties of all the cassava varieties studied. The pasting temperature ranged from 63.5 °C to 67.6 °C with Mweulu recording the least whiles Tangayoka recorded the highest (Table II). Kampolombo and Bangweulu also recorded fairly high pasting temperatures of 66.6 °C and 65.9 °C, respectively. Chila A and Nalumino recorded the same pasting temperature of 64.2 °C.

TABLE I: BIOCHEMICAL COMPOSITION OF CASSAVA VARIETIES

Variety	Starch (%) ¹	Total sugars (%) ²	Reducing sugars ² (%)	Non-reducing sugars ² (%)
<i>Mweulu</i>	63.60±0.58	8.06±0.08	1.58±0.01	6.48±0.05
<i>Mweru</i>	69.01±0.34	8.32±0.07	1.81±0.04	6.51±0.04
<i>Chila A</i>	57.59±0.42	6.72±0.03	0.94±0.01	5.78±0.08
<i>Chila B</i>	57.03±0.35	7.34±0.09	1.91±0.02	5.43±0.05
<i>Bangweulu</i>	63.61±0.48	6.48±0.06	1.68±0.03	4.80±0.04
<i>Manyokola</i>	58.40±0.63	7.64±0.01	1.06±0.02	6.58±0.05
<i>Kampolombo</i>	58.06±0.85	8.94±0.08	2.53±0.02	6.41±0.07
<i>Tanganyika</i>	62.77±0.86	8.99±0.04	2.46±0.01	6.53±0.03
<i>Nalumino</i>	52.99±0.56	9.20±0.06	1.68±0.03	7.52±0.06

Values reported on dry weight basis.

¹: As isolated from the fresh paranchyma.

²: As analysed in dried, sieved flour.

C. Peak Viscosity

Peak viscosities of all the cassava varieties are shown in Table II. Tangayoka gave the highest peak viscosity of 595 BU while Chila B recorded the least peak viscosity of 402 BU. ANOVA conducted on the results showed significant differences ($p < 0.05$) in the peak viscosities of the cassava samples. With the exception of Kampolombo and Chila B which recorded peak viscosities of 490 BU and 402 BU respectively, the rest of the cassava varieties recorded peak viscosities above 500 BU.

D. Heating Cycle (Viscosity at 95 °C and Viscosity at 95 °C-hold)

Viscosity at 95 °C ranged from 394 BU to 592 BU for all the cassava varieties with Chila B recording the least of 394 BU and Tanganyika recorded the highest of 592 BU. Kampolombo, Manyokola, Chila A, Mweru and Mweulu also recorded fairly high viscosities of above 460 BU at 95 °C. Chila B was observed to produce the least viscosity of 166 BU at 95 °C-hold while Tanganyika gave the highest of 317 BU. With the exception of Chila B, Kampolombo and Nalumino which recorded viscosities below 220 BU, the rest of the cassava varieties recorded values above 220 BU. This suggests that cassava varieties with high viscosity (> 220 BU) at 95°C-hold experienced little breakdown in starch, thus, may be considered stable.

E. Cooling cycle (Viscosity at 50 °C and Viscosity at 50 °C-hold)

Viscosity at 50 °C ranged from 126–254 BU for all the cassava varieties with Chila B recording the least of 126 BU and Chila A recording the highest of 254 BU. Mweulu, Tanganyika and Bangweulu also recorded fairly high viscosities of above 200 BU at 50°C. It was observed that the

viscosity of the samples at 50°C-hold was lower than the viscosity at 50 °C for all the samples except Chila A and Tanganyika.

F. Breakdown Viscosity and Setback

Breakdown viscosity ranged from 236 BU (Chila B) to 352 BU (Bangweulu) (Table II). ANOVA results on the data indicated that the differences amongst the varieties were significant ($p < 0.05$). Breakdown viscosities were significantly higher (> 300 BU) in the other cassava varieties studied with the exception of Mweru, Chila B, Kampolombo and Tanganyika which recorded breakdown viscosities below 300 BU. Chila A registered the highest setback value of 4 BU which was significantly different ($p < 0.05$) from the other studied varieties whilst Tangayoka recorded the least setback (-100 BU).

G. Pasting Characteristics of Cassava Varieties

Fig. 1 shows a typical pasting profile curve (amylogram) generated from Brabender Viscoamylograph. Region A represents the beginning of gelatinization (pasting temperature). Regions B, C and D represent the peak viscosity, viscosities at 95 °C and 95 °C-hold, respectively. Regions E and F show viscosity at 50 °C and viscosity at 50 °C-hold respectively while region B-D represent breakdown viscosity and E-D shows setback. Fig. 2 shows amylogram generated from Brabender Viscoamylograph for the cassava varieties studied. A closer look at the amylograms for all the studied cassava varieties (Fig. 2) revealed that the viscosity of all the cassava varieties increased to a peak (peak viscosity) with Tanganyika recording the highest peak viscosity of 595 BU while Chila B recorded the least (402 BU). The viscosity of all the cassava paste decreased during the heating cycle (95 °C and 95 °C-hold).

With an exception for Chila A, the viscosity of the pastes observed for all the cassava varieties decreased remarkably during the cooling cycle from 95 to 50 °C; as compared to the viscosity of the pastes observed during the heating cycle. The increase in the viscosity of the paste of Chila A sample during the cooling cycle could probably be due to the gelation and swelling of the starch granules [21]. The amylograms also revealed that the viscosity of the samples at 50 °C hold was lower than the viscosity at 50 °C for all the samples except Chila A and Tanganyika. A close examination of the pasting characteristics showed that Tanganyika showed higher pasting characteristics. Bangweulu and Mweru also showed relatively higher pasting characteristics. Chila B however, showed the least pasting characteristics.

TABLE II: VISCOELASTIC CHARACTERIZATION OF CASSAVA VARIETIES

Variety	Pasting temperature (°C)	Peak viscosity (BU)	Viscosity at 95°C (BU)	Viscosity at 95°C-Hold (BU)	Viscosity at 50°C (BU)	Viscosity at 50°C-Hold (BU)	Break down (BU)	Setback (BU)
<i>Mweulu</i>	63.5	563	485	237	211	193	327	-25
<i>Mweru</i>	65.0	545	537	258	183	173	286	-75
<i>Chila A</i>	64.2	558	486	248	254	238	309	4
<i>Chila B</i>	64.6	402	394	166	126	106	236	-38
<i>Bangweulu</i>	65.9	593	412	242	205	188	352	-36
<i>Manyokola</i>	64.5	554	479	230	168	158	323	-62
<i>Kampolombo</i>	66.6	490	467	219	196	171	271	-23
<i>Tanganyika</i>	67.6	595	592	317	218	219	277	-100
<i>Nalumino</i>	64.2	518	441	216	173	155	301	-43

Fig. 1. A typical pasting profile curve (amylogram) from the Brabender Viscoamylograph.

Fig. 2. Amylograms showing the pasting characteristic profiles of the studied cassava varieties.

KEY: 1-Bangweulu; 2-Chila A; 3-Nalumino; 4-Mweulu; 5-Kapolombo; 6-Manyokola; 7-Tangayoka; 8-Mweru; 9-Chila B.

H. Cluster and Principal Component Analyses for Biochemical Composition and Viscoelastic Properties of Cassava Varieties

Cluster and principal component analyses were applied to the biochemical composition and viscoelastic properties of the cassava samples. This was done by grouping cassava varieties with similar characteristics to display pattern and interrelationship between samples and their chemical characteristics. Fig. 3 shows the cluster observations dendrogram for biochemical composition and viscoelastic properties of the cassava varieties. This partitioned the samples into three clusters based on similarity of characteristics. Mweulu, Manyokola, Kampolombo, Nalumino, Chila A, Mweru and Bangweulu formed the first cluster. Chila B and Tanganyika formed the second and third clusters respectively (Fig. 3).

Principal component analysis applied to the biochemical composition and viscoelastic properties of the cassava varieties showed that the two components (PC1 and PC2) explained a variability of 67.5% in the results. PC1 alone accounted for 39.0% of the variation in the results while PC2 explained 28.5% (Fig. 4). The sample score explained the portioning observed in the cluster analysis. Chila A, Bangweulu, Mweulu, Mweru, and Tanganyika were found loaded to the positive side while Manyokola, Nalumino, Kampolombo and Chila B and were found loaded to the negative side of the PC1. The variable weights plot (Fig. 5) showed a loading of all the biochemical indices (starch, total sugars, reducing sugars and non-reducing sugars) and pasting

temperature close to each other on the positive side of the x-axis (PC1) and peak viscosity and setback viscosity loaded on the negative and positive side of PC1 which are related to the loadings of Tanganyika and Chila B, respectively.

Fig. 3. Cluster observations dendrogram for biochemical composition and viscoelastic properties of cassava varieties.

Fig. 4. Sample scores of plots for the principal component analysis of biochemical composition and viscoelastic properties of cassava varieties.

IV. DISCUSSION

A. Biochemical Composition of Cassava Varieties

Starch content in cassava is an important determinant of the industrial applications of the cassava variety. The use of starch for industrial food applications has been discussed extensively [2], [11], [30], [31]. Starches are commonly used to thicken liquid foods, such as soups and sauces. Even though the starch content of all the varieties were below the up to 80% reported by Gil and Buitrago [16], Mweru, Tangayoka, Mweulu, and Bangweulu had fairly high starch content (>60%) and thus could be used for many commercial products such as starches, alcohols and glucose. Total sugars content were noted to be similar to previous reported on cassava. Aryee et al. [2] and Padonou *et al.* [31] reported values from 1.57% to 7.50% for study on different cassava genotypes. Similarly, results on reducing sugars were comparable to the value of 1.67 g/100 g (1.67%) reported by Mégnanou et al. [32] from Cote d'Ivoire.

B. Viscoelastic Properties of Cassava Varieties

The ability of starch to swell and give a viscous paste when an aqueous suspension of the starch granules is heated above

the gelatinization temperature is one of the most important functional properties of starch [20]. Prolonged heating of the starch granules leads to disintegration of the granules, which brings about significant change in the viscosity and other rheological properties of the paste. The pasting and gelatinization processes form the two most important characteristics which influence the quality and aesthetic values in the food processing industry as they affect texture and digestibility of starch-based foods [9].

Afoakwa *et al.* [33] explained that the pasting temperature is the point at which the first measurable viscosity is noticed, and it is identified by an abrupt change in the viscosity resulting from swelling of the starch granules. The initiation of gelatinization of the starch granules during heat processing is denoted by the pasting temperature, and this is affected by the starch concentration [34]. A suspension of high starch concentration results in low pasting temperatures and the presence of monosaccharides and oligosaccharides lead to increases in pasting temperatures [35]. Pasting temperatures relate to water binding capacity of starches [9], and a higher pasting temperature implies higher water binding capacity, higher gelatinization, and lower swelling capacity of the starches, and these are caused by the organization of starch granules [36]-[38]. Pasting temperature was significantly ($p<0.05$) affected by the cassava varieties (Table III). The high pasting temperature observed suggest that these cassava varieties would have relatively high cooking temperature and time profile compared to Mweulu which recorded the least pasting temperature. The similar pasting properties recorded for Chila A and Nalumino indicates that cooking time for these cassava varieties and their products will be similar. The low pasting temperature recorded by Mweulu, could be attributed to the relatively lower cross bondings in its starch granule [20].

TABLE III: ANOVA SUMMARY SHOWING F-RATIOS OF THE VISCOELASTIC CHARACTERIZATION OF CASSAVA VARIETIES

Process variables	F-ratios
Pasting temperature	13045.45*
Peak viscosity	30705.19*
Viscosity at 95°C	1.85
Viscosity at 95°C-Hold	17347.18*
Viscosity at 50°C	4844.43*
Viscosity at 50°C-Hold	9864.50*
Breakdown	4131.53*
Setback	6382.54*

* Significant at $p<0.05$.

The highest viscosity attained during the heating cycle (25–95 °C) of starch-based foods is the peak viscosity and this is related to the easiness of cooking of the samples being analyzed [33], [38], and it reflects the ability of starch granules to swell before their physical breakdown [39]. Peak viscosities are directly linked to damage and lower damages result in lower peak viscosities [40], [41]. High peak viscosity indicates high starch content which also relate to water binding capacity of starch [42]. The results (Table I) showed that Tangayoka recorded fairly high starch content of 62.77%. Rosenthal *et al.* [43] suggested that high peak viscosity contributes to good texture of paste, which basically depends on high viscosity and moderately high gel strength. The relatively high peak viscosity exhibited by most of the cassava varieties in this study suggest that flours from these

cassava varieties may be suitable for products requiring high elasticity and gel strength.

The viscosity at 95 °C measures the ease of cooking of the sample by the amylograph. A low viscosity at 95 °C is reported to be indicative of how the sample will be difficult to cook [33]. The relatively high viscosities of these cassava varieties at 95 °C suggest that these cassava varieties would be relatively easier to cook compared to Nalumino, Bangweulu and Chila B which recorded low viscosities of below 460 BU at 95 °C. No significant differences ($p<0.05$) were noted in viscosities at 95 °C among the studied cassava varieties (Table III).

The viscosity after holding the temperature of the sample constant at 95 °C for 30 min indicates the easiness of breakdown of the cooked sample and this shows the cooked stability of the sample [10]. During the hold period there is further disruption of the starch granules and amylose molecules generally leach out into the solution and align in the direction of the shear [9]. Significant differences ($p<0.05$) were seen in the viscosity of the different cassava varieties at 95 °C-hold. A gradual decrease of the paste viscosity during the hold period indicates thermal breakdown of starch and, thus, may be considered a measure of stability. This period is sometimes called shear thinning, holding strength, hot paste viscosity, or trough, due to the accompanied breakdown in viscosity [9].

Viscosity at 50 °C indicates the gelation ability of the cooked paste and this reflects the eating consistency of the product [33]. An increased retrogradation property of the paste can be attributed to the strong propensity of hydrogen bond between the hydroxyl groups in the starch structure [20]. Significant differences ($p<0.05$) were noted in viscosity at 50°C among the cassava varieties (Table III). The viscosity at 50°C-hold measures the paste stability as it is used in products. Significant differences ($p<0.05$) were found in the viscosities at 50 °C and 50 °C-hold for all the cassava varieties.

Breakdown viscosity relates to the stability of the starch during heating [24]. Findings from the breakdown viscosities suggested that these varieties (i.e., Mweru, Chila B, Kampolombo and Tanganyika) are very stable during heating. Afoakwa *et al.* [24] explained that setback is the measure of the paste hardening on cooling and a stage where retrogradation of starch molecules occurs. Adeyemi and Idowu [44] reported that a high setback value indicates lower retrogradation tendency during cooling and the lower the staling rate of the product made from the flour. Oduro *et al.* [45] explained that high setback value is valuable for flours to be used for the processing of products such as *fufu*, which requires high viscosity and paste stability at low temperatures. The observed setback value indicated that Chila A recovered most of its amylose content during cooling than all the other studied varieties. Tangayoka recording the least setback value indicates that the flour gives a non-cohesive paste [27]. This means that such flours cannot be used for the processing of foods requiring starch stability at low temperatures such as adhesives and fillings.

C. Pasting Characteristics of the Different Cassava Varieties

Table II shows that Tanganyika recorded the highest pasting temperature (67.6 °C), peak viscosity (595 BU), viscosity at 95 °C (592 BU) and viscosity at 95 °C-hold (317 BU). These suggest that flour from Tanganyika would have high cooking temperature and time profile and may be suitable for foods that require high elasticity and gel strength, easier to cook and also more stable during cooking/preparation such as *fufu* (pounded cassava) and cassava flour meant for mixing cereals for the preparation of products such as *banku* or *Nshima* (Thick maize gruels consumed in West and South-eastern Africa respectively). Chila A registered the highest setback value of 4 BU suggesting that Chila A could be used for products which requires high viscosity and paste stability at low temperature and would be suitable for use as fillers and binders or as substitutes for wheat flour in the baking, and confectionery industries. Tanganyika recorded the least setback (-100 BU) suggesting that flour from Tanganyika cannot be used for products requiring good starch stability at low temperatures, i.e. for example adhesives, fillings and products for refrigeration. Chila B recorded the lowest values in all the viscoelastic properties with the exception of pasting temperature and setback value. These suggest that Chila B would not be suitable for products that require high viscosity and paste stability such as *fufu* (pounded cassava) or *Nshima*, as well as flours for industrial uses such as adhesives, fillings, and binders. However, it would be suitable for household food uses such as snacks where the roots are boiled, roasted, or toasted and consumed

D. Cluster and Principal Component Analyses for Biochemical Composition and Viscoelastic Properties of Cassava Varieties

Bangweulu, Mweulu, Mweru, Manyokola, Nalumino, Kampolombo and Chila A (Cluster A) were different from Chila B (Cluster B) and Tanganyika (Cluster C) on the basis of their pasting properties such as peak viscosity, viscosity at 95 °C, breakdown and setback viscosity. These suggest that the seven local and improved cassava varieties forming Cluster A have similar biochemical and viscoelastic characteristics and would all be suitable for all basic household cassava based food products such as boiled cassava, pounded cassava and roasted cassava grits (*gari*).

V. CONCLUSIONS

The biochemical composition and viscoelastic properties varied with all the cassava varieties studied. The starch content of all the studied cassava varieties was below 80%. Mweru, Tanganyika, Mweulu, and Bangweulu had fairly high starch content (>60%) and could be employed in industrial products such as starches, alcohol and glucose. Tanganyika recorded the highest pasting temperature (67.6 °C), peak viscosity (595 BU), viscosity at 95 °C (592 BU) and viscosity at 95 °C-hold (317 BU). These suggest that flour from Tanganyika would have high cooking temperature and time profile and may be suitable for products that require high elasticity and gel strength, easier to cook and also more stable during cooking/preparation such as *fufu* (pounded

cassava) and cassava flour meant for mixing cereals for the preparation of products such as *banku* or *Nshima* (Thick maize gruels consumed in West and South-eastern Africa respectively). Chila A registered the highest setback value of 4 BU suggesting that Chila A could be used for products which requires high paste stability and viscosity at low temperatures and would be suitable for use as fillers and binders in the baking and confectionery industries. Tanganyika recorded the least setback (-100 BU) suggesting that flour from Tanganyika cannot be used for products that requires high starch stability at low temperatures, such as adhesives, fillings and products that require refrigeration. Chila B recorded the lowest values in all the viscoelastic properties with the exception of pasting temperature and setback value. These suggest that Chila B would not be suitable for products which require high viscosity and paste stability such as *fufu* (pounded cassava) or *Nshima*, as well as flours for industrial uses such as adhesives, fillings, and binders. However, it would be suitable for household food uses such as snacks where the roots are boiled, roasted, or toasted and consumed. Bangweulu, Mweulu, Mweru, Manyokola, Nalumino, Kampolombo and Chila A (Cluster A) were different from Chila B (Cluster B) and Tanganyika (Cluster C) on the basis of their pasting properties such as peak viscosity, viscosity at 95°C, breakdown and setback viscosity. These suggest that the seven local and improved cassava varieties forming Cluster A have similar biochemical and viscoelastic characteristics and would all be suitable for all basic household cassava-based food products. The differences noted in the viscoelastic properties suggest that different cassava varieties could be predicted for use in different food and industrial products largely due to their varied viscoelastic and pasting properties.

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