Journal of Root Crops, 2011, Vol. 37 No. 2, pp. 174-181
Indian Society for Root Crops
ISSN 0378-2409

Textural and Rheological Attributes of the Tubers of Some Exotic Cassava Genotypes

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Received: 1 December 2011; Accepted: 27 December 2011

Abstract

Cassava or tapioca (*Manihot esculenta* Crantz) is one of the widely utilized tuber crops valued for its high carbohydrate content. Cassava is used after boiling as vegetable for consumption purpose. It is also processed into starch and flour. Textural properties of the raw and cooked tubers depend on variety, maturity, growing environment, physico-chemical properties, starch content and their properties. This study evaluated the textural properties of the raw and cooked tubers of selected exotic cassava genotypes. Also, the flours extracted from these genotypes were subjected to rheological characterisation by measuring their pasting properties. Cluster analysis was used to classify the genotypes based on the textural properties of raw tubers, texture profile of the cooked tubers and rheological properties of the flour. The textural and rheological properties significantly varied among the genotypes and based on these properties, the genotypes were classified into four groups: Group I- CE615, CE181, CE328, CE430, CE341, CE459, CI46, CE282, CI21 and CE440; Group II- CE423; Group III- CE365, CE364 and CE170 and Group IV- CE311, CE367, CE273, CE500, CE384 and CE215. This grouping based on the texture and rheology together was closer to the grouping based on the rheological properties alone, with the exception of CE423, which was most dissimilar in properties to the other genotypes. This clearly indicated that the rheological properties of starch can be the most important determining factor than the texture of the tubers for the classification of the cassava genotypes.

Key swords: Cassava genotypes, starch, texture, rheology, cluster analysis

Introduction

Cassava (*Manihot esculenta* Crantz), being an important source of starch among the tropical tuber crops, finds extensive applications in food, feed and industrial sectors. Of the total production of 228.55 million tones from an area of 18.42 million hectares globally, India's share is about 8.06 million tones from an area of 0.232 million hectares. Among the different cassava growing countries in the world, India ranks first in the productivity of cassava with 34.76 t ha^{-1}, whereas world average is only 12.41 t ha^{-1} (FAO, 2012). The tuber is generally consumed as primary/secondary staple food after boiling or cooking; as value added products after drying the sliced tubers and milling into flours, as starch after crushing, sieving and settling or as fermented products.

In the case of fresh fruits and vegetables, the overall quality and consumer acceptability are determined by their texture. Textural properties of the raw tubers as measured by objective methods are very much useful to understand their behaviour under mechanical forces which in turn help in the design of appropriate post harvest machineries for their processing. The main post harvest unit operations involved in cassava processing include washing, peeling, slicing, crushing, sieving, settling, drying etc. Among these operations, peeling, slicing and crushing need mechanization for saving time and reducing drudgery involved in the process. Design of such machineries depends upon the engineering/

mechanical properties of the tubers. Several studies were conducted on the mechanical and textural properties of cassava roots relevant to the design of its processing machineries (Odigboh, 1983; Ohwovoriole et al., 1988; Raja et al., 1990; Nanda and Mathew, 1996; Sajeev et al., 2008; Sajeev et al., 2009).

The new cassava genotypes developed by breeding or varietal improvement programmes should possess higher yield, starch content and good culinary properties. Several exotic varieties were imported to India from different cassava growing countries in the world to study their adaptability, agronomic traits and production performance in the prevailing climatic conditions of the country. Ravi and James George (2005; 2006; 2007) studied the performance of different exotic genotypes from CIAT, Cali, Columbia in the rainfed conditions prevailing in Kerala and Tamil Nadu to study their drought tolerance. They reported that the yield potential ranged from 16.4-43.2 t ha^{-1} and extractable starch content from 15.2 to 27.8%. The acceptability of the tubers depends not only on the yield and starch potential but also on the processing quality, for which texture and pasting properties assume significant role. Cassava tubers contain high amount of starch and their thermal softening behaviour during cooking is of utmost importance as they are consumed after boiling. Cooking quality of the tubers is mainly influenced by the age, growing environment, genetic make up, physico-chemical constituents, structural properties of starch etc. (Safo and Owusu, 1992; Eggleston and Asiedu, 1994; Ngeve, 2003; Baleia et al., 2004a; 2004b; Padanou et al., 2005; Sajeev et al., 2008; 2009)

Being a crop which is consumed either by boiling or by producing value added products from its starch/flour, it is necessary to study the textural and pasting properties of the tubers. However, the studies on the textural and rheological properties of the raw and cooked tubers of different exotic genotypes of cassava, especially suited to Indian conditions are scanty. Hence the present investigation was carried out to study the genotypic variation on the textural (both raw and cooked) and rheological attributes of the tubers from 18 exotic cassava genotypes and to compare with two indigenous genotypes. Attempts have also been made to group the varieties based on their textural and rheological attributes by cluster analysis.

Materials and Methods

Eighteen exotic (CE170, CE181, CE215, CE273, CE282, CE328, CE311, CE341, CE364, CE365, CE367, CE384, CE423, CE430, CE440, CE459, CE500 and CE615) and two indigenous (CI21 and CI46) cassava genotypes grown under rainfed conditions harvested at 12 months of maturity were used for the study. Fresh tubers free from external cuts or bruises were thoroughly washed with tap water to remove the adhering soil, clay and other foreign materials and kept overnight at ambient conditions to remove the surface moisture.

Textural properties of raw tubers

Textural properties were measured using a food texture analyzer TA HDi (Stable Microsystem, Surey, England) with built in software, Texture Expert Exceed. For raw tubers, measurements were made at a test speed of 2 mm s^{-1} for a distance of 20 mm using 5 mm stainless steel cylindrical probe and HDP/BSK blade set with knife, respectively for compression/penetration and cutting mode. The following parameters were calculated from the force-deformation curve obtained from the compression/penetration studies: first peak force as bioyield force; maximum peak force as firmness; area under the curve as toughness. From the cutting/shearing experiments, the peak force obtained in the graph was referred as shear force and area under the curve as shear energy. All the determinations were done on 50 tubers taken from each genotype.

Texture profile analysis of cooked tubers

The tubers after peeling and washing in water were cut into cubes of 10 × 10 × 10 mm using a hand slicer. These were placed in wire mesh baskets and immersed in boiling water bath and cooked for 20 min (as preliminary experiments showed that after 20 min, changes in degree of cooking/softening were not very significant). Cooked samples were allowed to cool at room temperature, before being analysed with the texture analyzer. Texture profile analysis (TPA) was performed at a test speed of 1 $mm^{-1}s$ for 25% compression with a time lag of 3s. From the TPA curve, the following parameters were calculated by the method of Bourne (2002) : hardness (height of the force peak on the first compression cycle), adhesiveness (negative force area of the first compression cycle), cohesiveness (ratio of the positive force areas under the first and second compression), springiness (distance by which the food recovers its height during the time between the end of the first bite and the start of the second bite) and chewiness (energy required to masticate a food).

Rheological properties of cassava flour

The dried chips prepared by sun drying the peeled, washed and sliced (3 mm thick) tubers from the different genotypes were powdered in a pulveriser (Cyclotec 1093 sample mill) and the flours so obtained were used for the analysis. The pasting characteristics of each sample were measured using a Rapid Visco Analyser (RVA-4, New Port Scientific, Warriewood, NSW, Australia) at a fixed starch concentration of 10% and a constant speed of 160 rpm using standard I profile as described by Garcia and Walter (1998). The temperature profile employed was as follows: heating range: 50-95°C at the rate of 12°C min^{-1}, holding at 95°C for 2 min, cooling to 50°C at 12°C min^{-1} and holding at 50°C for 2 min. The viscosity profile recorded by the RVA reflects the peak, trough, break down, final and set back viscosity and pasting temperature. The experiments were replicated twice and average values are reported.

Statistical analysis

The data were analysed using the statistical package SAS 9.3 to perform analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) for testing pair wise comparison. Multivariate analysis was carried out to group the varieties based on the various properties studied by cluster analysis by the complete linkage method

Results and Discussion

Texture of exotic cassava genotypes

The textural characteristics of the tubers of 18 exotic and two indigenous genotypes of cassava measured under compression/penetration and cutting mode are presented in Table1, which showed wide genotypic variation on the various textural properties ($p<0.05$). The textural values ranged from 7.29 (CE215) to 10.0 kg (CE341), 9.48 (CE423) to 17.99 kg (CE430), 73.11 (CE423) to 128.99 kg s (CE430), 22.51(CE170) to 49.66 kg (CE459), 158.52 (CE170) to 313.04 kg s (CE615) for the bioyield, firmness, toughness, shear force and shear energy respectively. No significant variation in bioyield force was observed among CE341, CI21, CE430 and CE384 and the value ranged from 9.9-10.0 kg or between CI46 and CE316 (9.05-9.19 kg). All other varieties had comparable bioyield values and the genotype CE215 showed significantly different value from all the other varieties ($p<0.05$). The firmness of the tubers of CE341, CI21, CI46, CE311, CE282, CE459, CE364, CE328 and CE615 did not vary significantly. Similarly for the varieties within the following groups CI21, CE384, CE500, CI46, CE282, CE440, CE364 and CE615 or CE384, CE500, CE282, CE440 and CE367 or CE384, CE500, CE440, CE367, CE181 and CE215 or CE367, CE273, CE181, CE365 and CE215 or CE181, CE365 and CE170 or CE365, CE423 and CE170 had comparable firmness values. Toughness of the tubers of the genotypes CE341 and CE430 or CE341, CI46 and CE311 did not vary significantly. The shear force of CE384, CE500, CE282, CE367, CE273, CE181 and CE365 did not have much variation when compared to other varieties. Sajeev et al. (2008), in their study on the textural attributes of the tubers of short duration lines of cassava reported that the bioyield force ranged from 73.69 to 92.21 N, firmness from 81.06 to 123.15 N, toughness from 1.13 to 1.74 Nm, shear force from 171.59 to 256 N and shear energy from 2.34 to 3.47 Nm.

Cluster analysis was carried out to group the genotypes based on the various textural properties of the raw tubers measured

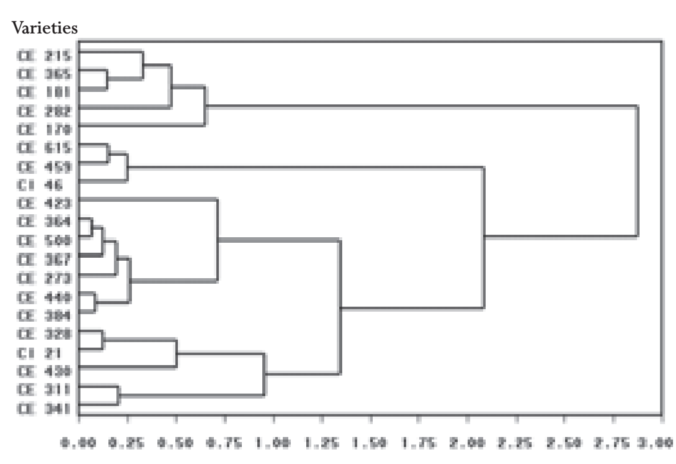

Fig. 1. Classification of exotic cassava genotypes based on the textural properties of raw tubers

Table 1. Textural properties of raw tubers of some exotic cassava genotypes

Cassava genotypes	Bioyield force (kg)	Firmness (kg)	Toughness (kg s)	Shear force (kg)	Shear energy (kg s)
CE341	10.0a*	15.81b	121.80ab	36.96cd	268.60abc
CI21	9.94a	14.74bc	106.38cdef	32.72de	232.15cde
CE430	9.93a	17.99a	128.99a	32.77de	216.29def
CE384	9.90a	13.12cde	100.71efg	28.69efg	212.51def
CE500	9.26ab	13.26cde	100.42efg	28.05efg	204.24efg
CI46	9.19ab	14.75bc	114.51bc	42.91bc	302.80ab
CE311	9.05b	15.16b	115.28bc	38.25cd	259.38bcd
CE282	8.75bc	14.06bcd	102.29defg	27.64efg	185.05efg
CE440	8.75bc	13.14cde	97.25fgh	31.55def	213.66def
CE459	8.69bcd	15.67b	109.85cde	49.66a	305.39ab
CE367	8.42bcde	12.39def	95.29ghi	28.94efg	199.63efg
CE273	8.38bcde	11.97ef	89.91hij	28.33efg	206.29efg
CE364	8.36bcde	14.25bc	98.75fgh	30.98def	204.86efg
CE328	8.14cdef	15.83b	111.86cd	32.77de	228.40cdef
CE181	8.09cdef	11.53efg	84.91jk	26.85efg	189.39efg
CE365	7.81def	10.66fgh	76.85kl	28.11efg	190.87efg
CE423	7.76ef	9.48h	73.11l	32.39de	232.21cde
CE615	7.74ef	14.58bc	107.01cdef	48.12ab	313.04a
CE170	7.53ef	10.16gh	78.43kl	22.51g	158.52g
CE215	7.29f	12.02ef	86.68ijk	24.82fg	179.81fg

*The values followed with the same letters in a column are not significantly different at $p<0.05$ by Duncan's multiple range test

under compression/penetration and cutting mode. The results obtained are represented by a dendrogram in Fig.1. When the dendrogram was cut at a distance of 1, four clusters were obtained as, Cluster I: CE215, CE365, CE181, CE282 and CE170; Cluster II: CE615, CE459 and CI46; Cluster III: CE423, CE364, CE500, CE367, CE273, CE440 and CE384 and Cluster IV: CE328, CI 21, CE430 and CE311. This information may be helpful in breeding and varietal improvement programme for selecting varieties with similar textural properties for further studies. The textural variation of plant tissue is attributed to the presence of biopolymers and cellular and molecular organisation of the plant materials (Tisjkens et al., 1999; Van Dijk and Tisjkens, 2000; Kilcast, 2004). Sajeev et al. (2008, 2009) also observed wide variability of textural attributes in different short duration lines and also local and hybrid varieties of cassava.

Texture profile analysis of cooked tubers

The texture profile parameters of the cooked tubers are presented in Table 2. The data revealed that firmness, adhesiveness, springiness and chewiness differed significantly among the genotypes ($P<0.05$) whereas, variation in cohesiveness was not significant. The firmness of the cooked samples ranged from 1.92 kg for CI21 to 10.99 kg for CI46, which showed wide variability in these values. Adhesiveness was minimum for CE273 (-0.979 kg s) and maximum for CE459 (-57.55 kg s) indicating that stickiness of CE273 during mastication of the cooked tubers in the mouth was very less and thereby less force was required to remove sample adhering to the mouth during chewing of these tubers. Springiness varied from 0.626 to 0.834, indicating that the range of variation in the recoverable deformity was narrow among genotypes. The cohesiveness of the cooked samples did not differ significantly except for the highest values of 15.57 for CE615 and for all other varieties, values ranged from 1.47 to 2.20. Chewiness, the measure of the energy required to masticate the cooked sample to make it suitable for swallowing ranged from 2.59 (CI21 and CE170) to 16.11 (CI46). The chewiness of the tubers

Table 2. Textural profile analysis of the cooked tubers of some exotic cassava genotypes

Cassava genotypes	Firmness (kg)	Adhesiveness (kg s)	Springiness	Cohesiveness	Chewiness
CI46	10.99a*	-46.99fg	0.757abcd	1.92b	16.11a
CE341	8.41b	-4.34ab	0.760abcd	1.47b	9.57bc
CE440	7.92b	-26.9de	0.772abc	1.93b	11.21b
CE328	7.77b	-3.87ab	0.732bcd	1.68b	9.42bcd
CE423	7.46bc	-18.03abcd	0.834a	2.20b	14.24a
CE430	6.00cd	-26.39cde	0.751abcd	1.63b	7.06cde
CE615	5.66de	-9.14ab	0.626e	15.57a	8.95bcd
CE311	5.48de	-2.73ab	0.690cde	2.10b	8.14bcde
CE500	5.05def	-43.76fg	0.711bcde	1.84b	6.38cdef
CE459	4.96def	-57.55g	0.711bcde	1.86b	7.30cde
CE367	4.88def	-4.23ab	0.753abcd	1.61b	5.93defg
CE384	4.67def	-47.15fg	0.694cde	1.97b	6.36cdef
CE365	4.27def	-5.49ab	0.800ab	1.57b	5.37efg
CE282	3.82efg	-10.80abc	0.713bcde	1.74b	4.75efg
CE273	3.54fg	-0.98a	0.677cde	2.17b	4.95efg
CE364	3.43fg	-6.87ab	0.741abcd	1.75b	4.58efg
CE215	2.33g	-2.55ab	0.672de	2.05b	3.08fg
CE181	2.23g	-8.52ab	0.740abcd	1.91b	3.13fg
CE170	1.98g	-18.85bcd	0.716bcde	1.77b	2.59g
CI21	1.92g	-36.65ef	0.681cde	1.98b	2.59g

*The values followed with the same letters in a column are not significantly different at $p<0.05$ by Duncan's multiple range test

of CI46 and CE423 were not significantly different, but significantly higher than those of other varieties. Chewiness bears a positive correlation with firmness of the cooked samples. Sajeev et al. (2008) studied the texture profile analysis of some short duration lines of cassava and found significant difference except for chewiness, among varieties. In another study on the kinetics of thermal softening and rheological modelling of the starch from the local and hybrid varieties of cassava, they found that firmness, adhesiveness and springiness of the cooked tubers as measured from the texture profile analysis showed significant variation among different varieties ($p<0.05$), whereas, cohesiveness and chewiness were not significantly different (Sajeev et al., 2009).

The dendrogram based on the various textural profile parameters of the cooked tubers of different genotypes is represented in Fig. 2 and

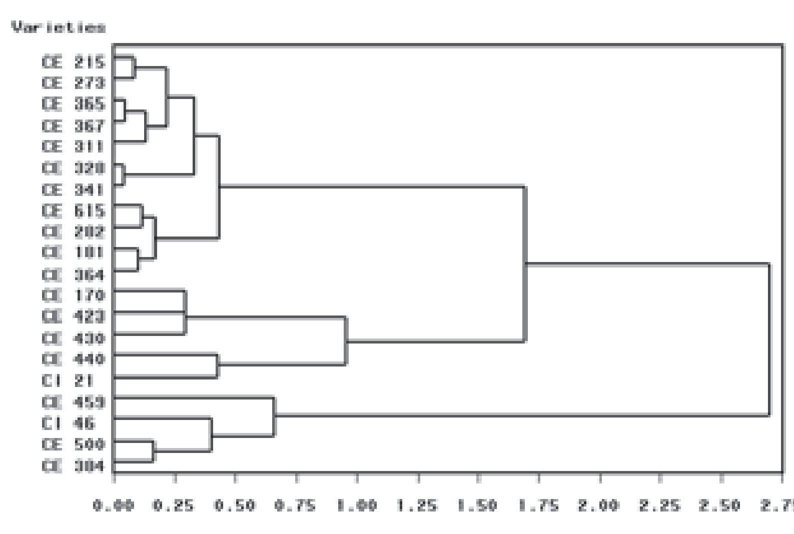

Fig. 2. Classification of exotic cassava genotypes based on the textural profile parameters of cooked tubers

three clusters were obtained as, Cluster I: CE215, CE273, CE365, CE367, CE311, CE328, CE341, CE615, CE282, CE181 and CE364; Cluster II: CE170, CE423, CE430, CE440 and CI21 and Cluster III: CE459, CE CI46, CE500 and CE384. The large number of genotypes in Cluster I indicated that they all had similar cooking qualities. The variability in texture of the cooked tubers are mainly due to the chemical composition, physico-chemical properties, morphology and molecular structure of starch, quality and quantity of other root components, macro structure of cassava root, interaction between various physico-chemical components and the structural make up of the tuber tissues like cell solid content, turgor pressure of the cell, mechanical capacity of deformation of cell walls and cohesiveness provided by the cementing material of the middle lamella and also by the hydration rate of the cooked tubers (Asaoka et al., 1991; Eggleston and Asiedu, 1994; Baleia et al., 2004a; 2004b; Charoenkul et al., 2006; Sajeev et al., 2008; 2009).

Rheology of flours of exotic genotypes

The primary pasting properties *viz.*, peak, trough and final viscosities and pasting temperature of the flours prepared from different genotypes are represented in Fig.3. The data showed a significant variation in viscosity properties among different genotypes ($p<0.05$). The peak viscosity was highest for CE440 and lowest for CE365, the values being 2495 and 1656 cP, respectively. The values for the trough viscosity ranged from 513 cP for CE463 to 1330 cP for CE615, final viscosity from 649 cP for CE463 to 1872 cP for CE328. The breakdown viscosity was lowest for CE170 (902 cP) and highest for CE367 (1488 cP). The differences in the associative linkage in the granules

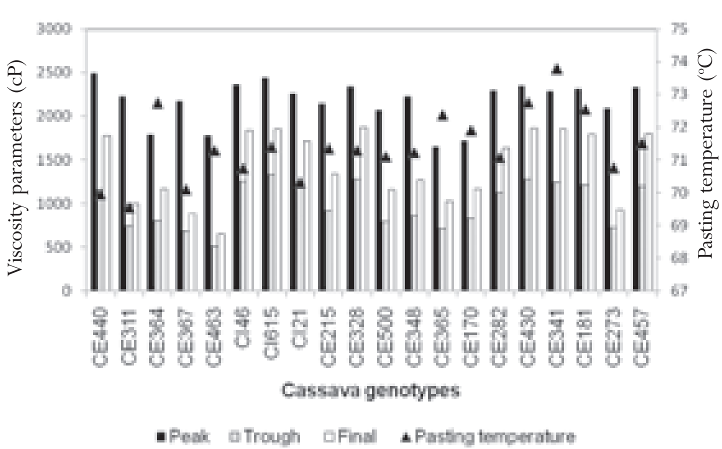

Fig. 3. Pasting properties of flours extracted from different exotic genotypes of cassava

among the varieties were evident with starch from CE170 having relatively stronger associative force when compared to CE367 starch. The set back viscosity was lowest for CE463 (136 cP) and highest for CE341 (617 cP). The pasting temperature showed only minor variation (4.25°C), maximum observed for CE341 (73.8°C) and minimum for CE311 (69.55°C).

The dendrogran based on the various pasting properties showed that the genotypes could be grouped into three clusters as Cluster I: CE215, CE384, CE500, CE273, CE367 and CE311; Cluster II : CE170, CE364, CE365 and CE423 and Cluster III: CE615, CE181, CE341, CE328, CE430, CI46, CE459, CI21, CE282 and CE440.

The variation in the pasting properties is caused due to the genetic make up and structural variability of the starch extracted from the tubers. Variation in the associated force in the starch granules can also be responsible for the observed differences in the pasting properties among varieties. The results obtained in this study are similar to that obtained by other researchers on various cassava tubers (Rickard et al., 1991; Asoaka et al., 1991; Asoaka et al., 1992; Defloor et al., 1998; Moorthy, 2001; Sajeev et al., 2008; 2009).

From the above results, it is clear that wide variability existed between the textural and rheological properties of the cassava genotypes studied. The classification based on these parameters showed different groups. Hence, to attain a specific classification based on the textural properties of raw tubers, cooked tubers and the rheological properties of the flour extracted from these genotypes, a dendrogram was constructed by considering all these values (Fig. 4). The data on the dendrogram were analysed in the same way as that was done for classification based on the individual values by cutting at a distance of 1. Based on the textural and rheological properties, the genotypes could be categorized into four groups: Group I - CE 615, CE181, CE328, CE430, CE341, CE459,

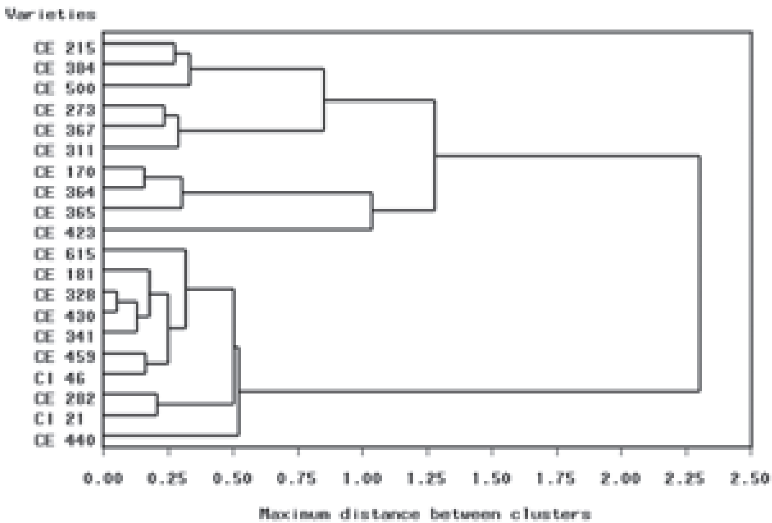

Fig. 4. Classification of cassava varieties based on the textural and rheological properties of the tubers of different cassava genotypes

CI46, CE282, CI21 and CE440; Group II- CE423; Group III- CE365, CE364 and CE170 and Group IV: CE311, CE367, CE273, CE500, CE384 and CE215. These groupings when compared to the other grouping based individually or separately on texture of raw tubers, texture profile of cooked tubers and rheology of the flours showed that it was very similar to that of the classification based on the rheological properties, except for CE423, which was most dissimilar in properties to other genotypes. This clearly indicated that the rheological properties of starch are the most important determining factor for the classification of the cassava genotypes than that of the textural properties.

Conclusions

The study showed that significant variation existed in the textural and rheological properties of different cassava genotypes. The cassava genotypes were classified based on the texture of raw tubers, texture profile of cooked tubers, rheology of the flours as well as all these properties considered together. Rheological properties of the flour were found to have greater influence on the classification of the genotypes. This will help to identify the varieties based on their similarities in these properties, which could be used for breeding and varietal improvement programmes.

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