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EFFECT OF PROCESSING CONDITIONS ON THE TEXTURE OF RECONSTITUTED CASSAVA DOUGH

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Abstract - Deformability modulus, hardness, cohesiveness and adhesiveness of cassava dough reconstituted from precooked flour were evaluated using a lubricated compression test and texture profile analysis. Cassava parenchyma processed under different cooking conditions and left at either -5ºC or -20ºC for 24 h was used to make flour, which was reconstituted into dough. As temperature decreased to -20ºC during the storage period of cooked parenchyma, deformability modulus, hardness and cohesiveness of dough increased significantly. The temperature during the storage period was the most important factor affecting the textural properties of cassava dough.

Keywords: Reconstituted cassava dough; Cooked cassava flour; Texture.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is grown primarily for its starchy roots and is a staple food crop in many tropical countries (Asaoka et al., 1992). Cassava not only contributes to the food security status of rural populations but is also a raw material for agroindustries. The cassava processing industry suffers from a wide range of problems: low product quality, inadequate processing technology, raw material availability and fluctuating prices (Henry and Gottret, 1998). As cassava becomes more important as industrial crop, the logistic of supplying fresh cassava roots to processing plants becomes more critical (Thro et al., 1996). One alternative is to transform the fresh cassava roots into precooked cassava flour, which can then be used as a raw material for making high added-value products like cassava dough, croquette, fried chips or snacks.

Dough made from starchy tubers and roots can be viewed as a gelatinized starch dispersion consisting of swollen granules and granular fragments dispersed in a continuous biopolymer matrix (Eliasson, 1986). The goal of any process to manufacture a starchy rich instant floury product for making doughs or purees is to keep leaching of starch from cell tissue as low as possible to avoid a pasty, gummy or sticky texture of reconstituted product (Lamberti at al., 2004). Researches on potato processing have demonstrated the beneficial effect of a rest period of the parenchyma at low temperature immediately after heating or a precooking step, giving a more granular product with a lower free starch content (Lamberti et al., 2004; Ooraikul et al., 1974).

Lamberti et al. (2004) examined starch transformation and its role in developing structure in purees prepared by reconstituting potato flakes. They found that the rheological behavior of potato puree is determined by the extent of cell cohesion and integrity, and by the amount and composition of extracellular starch leached in the continuous phase. Hopkins and Gormley (2000), who evaluated the effects of freezing starch grains *in situ* on starch properties, showed that freezing starch increased the

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*To whom correspondence should be addressed degree of retrogradation and cooked paste stability. The resulting gels had higher compressive strength but lower shear and adhesiveness values than grains that were not frozen.

In the case of cassava, some studies have investigated the textural properties of paste or mash doughs using emulsifiers to prevent their sticky texture. Emulsifiers such as glyceryl monostearate (GMS) and sodium steroyl lactylate (SSL) decrease the stickiness of mash doughs reconstituted from fermented cassava flours and drum-dried cassava flakes (Numfor et al., 1998; Muzanila et al., 2001). *Agbelima* is a fermented cassava dough widely consumed in Africa. Studies on *agbelima* were carried out to relate starch conversion and flour particle-size to sensory characteristics of the dough (Dziedzoave et al., 1999; Sefa-Dedeh, 1989). Despite these studies on the effects of ingredients, especially emulsifiers, on the textural properties of cassava paste and mash dough, there is a lack of research on the effects of processing conditions on the texture of cassava doughs.

The influence of cooking method, cooking time and temperature of cooked parenchyma during the storage period on the properties of cassava dough was observed in a preliminary study in order to obtain cassava croquettes from cooked cassava flour (Hernández, 2005). However, these observations were not verified using suitable instrumental texture measurements. The objective of this study was to determine the effect of processing conditions on the textural properties of cassava dough made from different precooked cassava flours using a lubricated compression test and texture profile analysis (TPA).

MATERIALS AND METHODS

Raw Material

Cassava roots, cultivar HMC-1, grown in Jamundi, Cauca Valley Province, Colombia, and harvested 10 months after planting were used in this study. The proximate composition of the fresh roots was analyzed according to standard methods of AOAC for determinations of ash, crude protein, crude fiber and crude fat (AOAC, 1995), using native cassava flour. Starch content was determined by an enzymatic method using thermostable ζ-amylase as proposed by Holm et al. (1986). The amylose content of cassava was measured using a colorimetric method described by Sowbhagya and Bhattacharya (1979). All analyses were performed in duplicate.

Production of Cassava Flours

The roots were processed within 20 h after harvesting following the different steps described in Figure 1. The fresh roots were peeled manually and cut into cylindrical pieces (approx. 10 cm long). Three-kg batches of these pieces were cooked using two different methods: (a) steaming using steam blanching equipment (CEV 3/9, Colcocinas, Medellin, Colombia) at a pressure of 15 psi, and (b) boiling in water in a steam jacketed kettle (Essen Ltda, Cali, Colombia). Two different cooking times were also studied: 12 min and 15 min. The cooked pieces were left at either -5ºC or -20ºC for 24 h and then mashed through 1.25 cm holes in a meat mincer (P.12N, Mobba, Baladona, Spain). The mashed samples were air dried at 60°C in a tray dryer to a final moisture content of 7 -10% wet basis (w/b). The dried materials were ground in a hammer mill and sifted in a Ro Tap (Model B, W. S. Tyler Inc., Gastonia, N.C., USA) into a fine flour (<300 σm) and a coarse flour (300 – 850 σm); the loss of this process was 7%. Cooked cassava flour was made by blending coarse and fine flours at a ratio of 30:70 (w/w).

Dough Sample Preparation

For the reconstitution of the dough samples, the moisture content of cooked flour was determined. Flour (1 g) was dried in an oven (M. Chopin & Ciq, Boulogne, France) at 130ºC for 4 h. The moisture content of reconstituted cassava dough was measured by drying 2.5 g dough in an oven at 130ºC for 4 h. Duplicate measurements were performed.

Samples of 80 g cooked cassava flour were reconstituted with water to a final moisture content of 65% (wb.). Water was added to the flour mixture and left to rest for 60 s, after which the mixture was blended for 60 s in a stand mixer (Model 5KPM5, KitchenAid Inc., St Joseph, MI, USA) equipped with a flat beater, and transformed into dough.

Dough samples were molded to a cylindrical shape by placing 10 g dough in a fiber glass cylinder mold (35 mm diameter) and loaded with a cylindrical probe at 60 N for 120 s using a texture analyzer (TAXT2i, Stable Micro Systems, Surrey, UK) equipped with a 25-kg load cell. The cylindrical dough (35 mm diameter, 8.5-9.5 mm height) was carefully removed from the mold, placed immediately in a plastic container to avoid dehydration and left to rest for 20 min before testing in order to relieve residual stresses produced during sample preparation (Campanella and Peleg, 1987; Limanond et al., 1999).

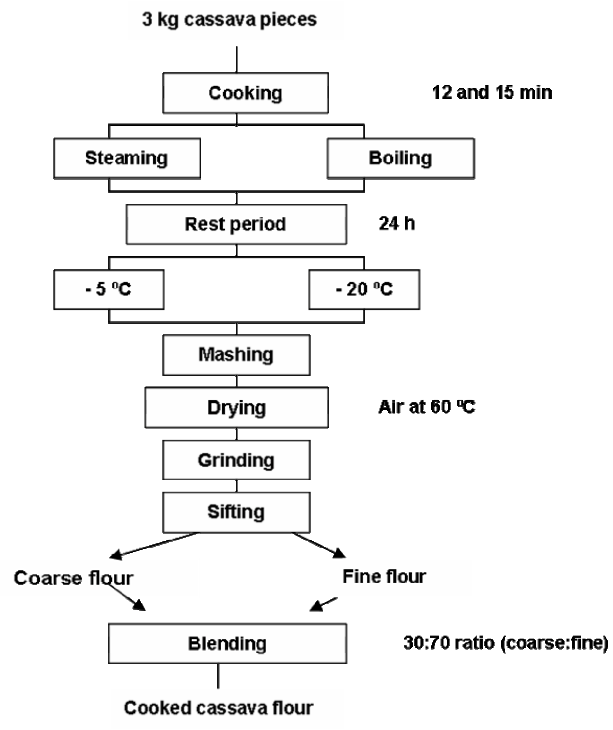


Figure 1: Flow diagram of pilot plant processing of cooked cassava flour

Lubricated Compression Test

Lubricated compression test was performed using a texture analyzer (TAXT2i, Stable Micro Systems, Surrey, UK) equipped with a 25-kg load cell and a cylindrical probe (100 mm diameter). Cylindrical molded dough was placed on a flat aluminium base and compressed to 5 mm of its original height (55 % strain level) with a pre-test speed of 1 mm/s and a test speed of 0.5 mm/s. Sample, base and probe were lubricated with liquid paraffin to minimize frictional effects and to ensure only extensional deformation (Limanond et al., 1999; Osorio et al., 2003). Each test was conducted in three replicates at room temperature (24±1ºC). Experimental stress-strain curves (Figure 2) were generated from force-displacement data, where strain and stress were calculated according to Equation 1 and Equation 3, respectively.

$$\varepsilon_h(t) = \ln\left(\frac{h_0}{h(t)}\right) \tag{1}$$

where $\varepsilon_h(t)$ is the applied strain, h_0 is the initial height of the specimen (m), $h(t)$ is the sample height at any time during the compression test (m). Assuming the material is incompressible, the volume is constant, as shown in Equation 2.

$$A_0 h_0 = A(t)\, h(t) \tag{2}$$

Where A_0 is the initial cross-sectional area of the sample (m^2) and $A(t)$ is the area of the sample at any time during the compression test (m^2).

$$\sigma(t) = \frac{F(t)\, h(t)}{A_0\, h_0} \tag{3}$$

Where $F(t)$ is the applied force perpendicular to the area of the material at any time during the compression test (N) and $\sigma(t)$ is the applied stress (Pa).

The deformability modulus (E) was calculated from the slope of the linear portion of the stress-strain curve as shown in Figure 2 (Ak and Gunasekaran, 1995; Mammarella et al., 2002; Steffe, 1996). This curve was not linear at the beginning of the test; this behavior can be explained because the surface of the sample was not perfectly smooth, so there was a transition period when the probe was brought into contact with the surface of the dough sample.

Texture Profile Analysis Test

Texture profile analysis (TPA) was performed using the texture analyzer equipped with the same load cell and probe as the previous tests. Emery paper was stuck on the probe. The cylindrical dough was placed on a flat aluminium base and compressed to 3 mm of its initial height (33 % strain level), held for 10 s and compressed again. The pre-test speed was 2 mm/s and the crosshead speed was 1 mm/s. Sample, probe and base were not lubricated. Three textural parameters were determined from each TPA curve (Figure 3). Hardness is the maximum compression force during the first cycle in the TPA curve. Cohesiveness, which is a direct function of overcoming the internal bonds of a product, is obtained from the ratio between the positive force area during the second compression cycle to that during the first compression cycle. Adhesiveness is the negative force area of the first compression (Bourne, 2002; Jankowski, 1992).

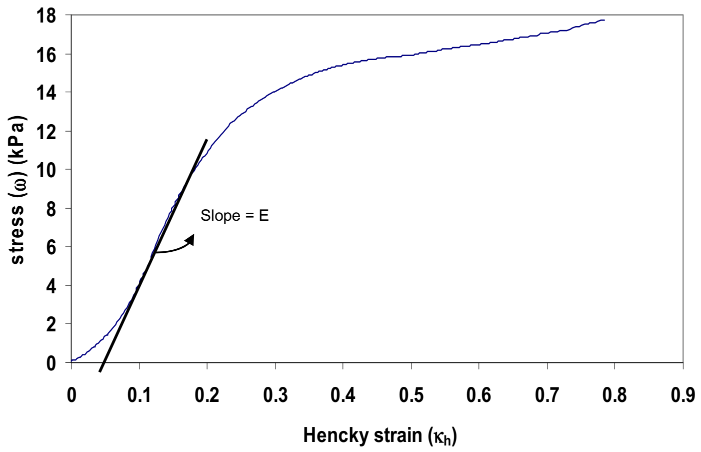


Figure 2: A typical experimental stress-strain curve of reconstituted cassava dough sample

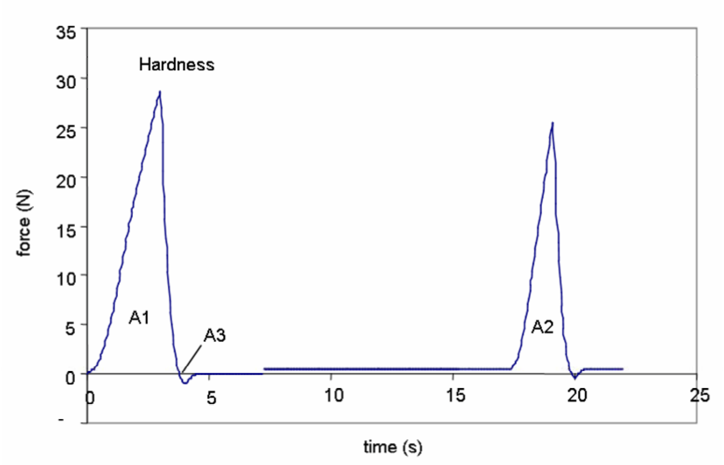


Figure 3: Typical TPA curve of a reconstituted cassava dough sample.

Statistical Analysis

One-half fraction of a 2^k factorial design of three factors (cooking method, cooking time and resting temperature) was used in this study. The experimental design model was used to analyze the results obtained by the texture evaluation of doughs from different cooked cassava flours (24). Analysis of variance (ANOVA) was used to determine differences among treatments at the 5% significance level. Statistical analysis was performed using Design Expert 6.0 (Stat-Ease Inc., Minneapolis, USA).

RESULTS

Proximate Analysis

The proximate composition of native cassava flour is shown in Table 1. This analysis was performed to establish the characteristics of the raw material used in this study. Protein content, crude fat, crude fiber and ash were in the range expected for cassava flour (Fernandez-Quintero, 1996; Moorthy et al., 1996; Pereira and Beléia, 2004). The starch content of flour was consistent with levels of starch in cassava root reported by both Fernandez-Quintero (1996), and Pereira and Beléia (2004). Amylose content of cassava flour was in agreement with the results reported elsewhere (Asaoka et al., 1991; Gunaratne and Hoover, 2002; Padonou et al., 2005).

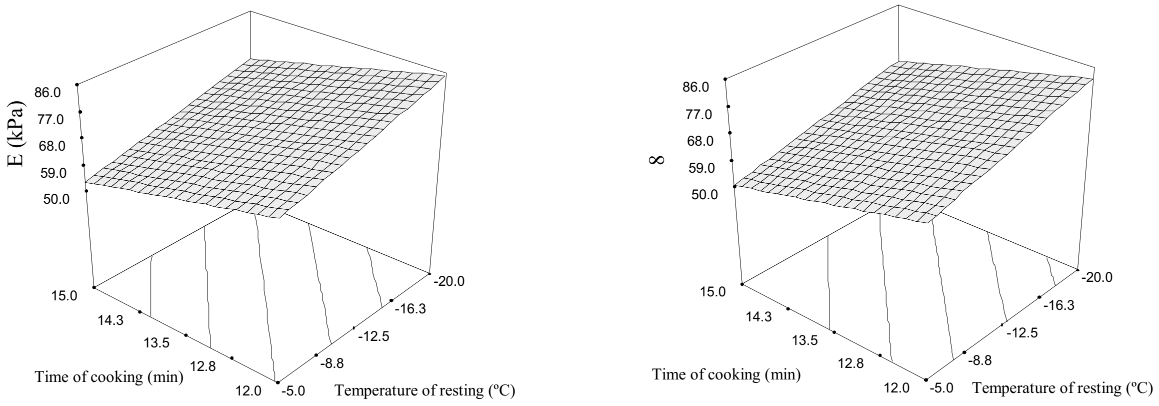
Deformability Modulus

The deformability modulus (E) of reconstituted cassava doughs is shown in Figure 4 and Table 2. The value of E was affected significantly ($P<0.05$) by cooking time and the temperature at which the cooked cassava parenchyma was left for 24 h. These results indicate that flour made from cooked cassava parenchyma left at -20ºC developed a more rigid dough than that left at -5ºC. At both temperatures during the storage period, the values of E for dough samples reconstituted with flour prepared from parenchyma cooked for 12 min were higher than dough samples where the parenchyma was cooked for 15 min. However, the deformability modulus for dough samples prepared from flour where the parenchyma was cooked for 12 min and left at -5ºC was fairly similar to dough made with flour from parenchyma cooked for 15 min and left at -20ºC. The cooking method did not, however, affect the dough deformability modulus significantly ($P<0.05$).

Table 1: Proximate analysis of native cassava flour from cv. HMC-1.

Proximate testing	Native flour*
Crude protein (%)	2.9 ∂ 0.2
Crude fat (%)	0.4 ∂ 0.04
Crude fiber (%)	2.6 ∂ 0.04
Ash (%)	1.9 ∂ 0.02
Starch content (%)	86.5 ∂ 2.1
Amylose content (%)	18.8 ∂ 0.8

*Values are expressed on a dry weight basis. Average ∂ standard deviation



(a) (b)

Figure 4: Deformability modulus of reconstituted cassava dough samples (kPa) made with flour prepared from boiled parenchyma (a) and steamed parenchyma (b)

Table 2: Deformability modulus of reconstituted cassava dough samples (kPa)

Cooking methods	Cooking time (min)	Storage temperature (°C)	Deformability modulus* (kPa)
Steaming	12	-5	69.4±1.2
		-20	85.1±0.8
	15	-5	53.2±1.8
		-20	68.9±0.7
Boiling	12	-5	66.6±1.7
		-20	82.3±2.2
	15	-5	50.5±1.1
		-20	66.2±0.2

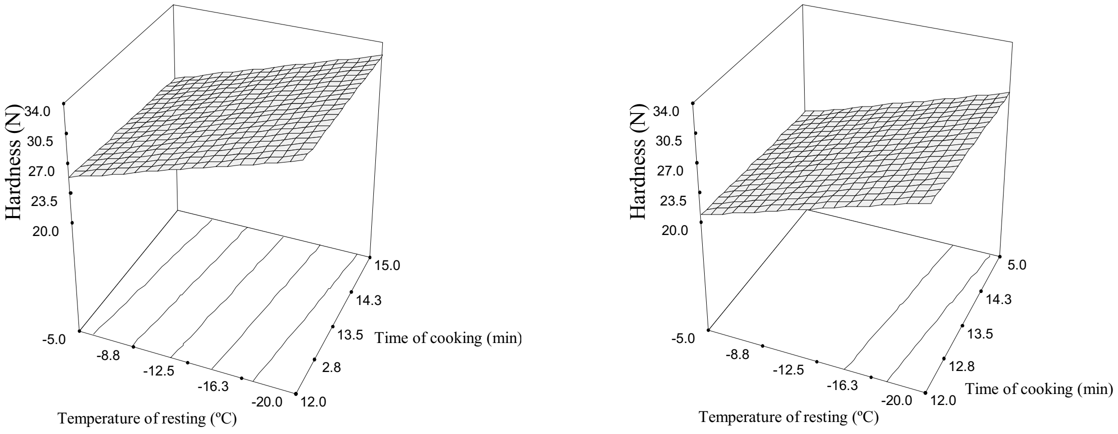
*Average ∂ standard deviation

Texture Profile Analysis

In this study TPA parameters were used to verify their sensibility to the changes of textural attributes of reconstituted cassava doughs and then to assess the influence of the processing factors on the final texture of the dough. The textural parameters of food products have been established using the TPA methodology, which gives excellent correlations with the results of sensory analyses (Bourne, 2002). At the stage of this research, a sensory analysis correlation was not included.

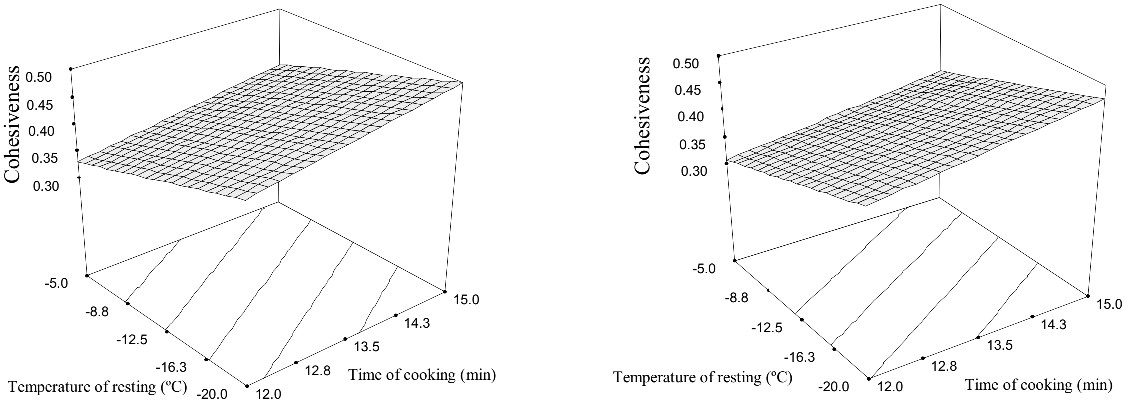
Evolution of hardness and cohesiveness attributes of the reconstituted cassava dough submitted to different processing conditions is shown in Figure 5 and Figure 6, respectively. The coefficients of variation of adhesiveness were higher than 30%; therefore this textural parameter was discarded. The other parameters had coefficients of variation in the range of 1.7-14%. Hardness was affected significantly ($P<0.05$) by the cooking method and the temperature at which cooked cassava parenchyma was left for 24 h. Flour made from parenchyma boiled in water and left at -20ºC resulted in a firmer dough than that made of flour from steamed parenchyma left at -5ºC.

The cooking time and the storage period at low temperature influenced the cohesiveness of reconstituted cassava dough significantly ($P<0.05$). Dough made with flour from parenchyma cooked for 12 min and left at -5 ºC was less cohesive than that made with flour from cassava roots cooked for 15 min and left at -20 ºC. The cooking method did not affect the cohesiveness of the cassava dough significantly, which was in the range of 0.31-0.50. Numfor et al. (1998) found cohesiveness of 0.68-0.79 for pastes of both native and fermented cassava flours



(a) (b)

Figure 5: Hardness of reconstituted cassava dough sample (N) made with flour prepared from water-cooked parenchyma (a) and from steam-cooked parenchyma (b)



(a) (b)

Figure 6: Cohesiveness.of reconstituted cassava dough made with flour prepared from water-cooked parenchyma (a) and from steam-cooked parenchyma (b)

DISCUSSION

Reconstituted cassava dough can be regarded as swollen granules, granular fragments and minor components such as fiber, protein and minerals dispersed in a continuous biopolymer matrix. The characteristic of this matrix, which consists mainly of free starch in an aqueous medium, is probably the major structural component affecting the textural properties of reconstituted cassava dough. It could be considered analogous to potato flake processing, where reconstituted potato flakes consist mainly of whole single potato cells as well as some ruptured cells and cell fragments embedded in an extracellular starch phase, which contains whole and disintegrated starch granules (Lamberti et al., 2004).

Hardness and E are parameters for quantifying the stiffness of a material using different methodologies (Mammarella et al., 2002; Peleg, 1987). The results of these parameters suggest that decreasing the temperature during the storage period of the cooked cassava parenchyma from -5 to -20ºC increased the stiffness of dough. This behavior was probably due to the increase in volume fraction of free starch, which developed an elastic network in the continuous phase within the system. Moreover, the hardness of dough was also increased due to the interactions between starch granules, which act as the filler in the matrix, and the elastic network. Jankowski (1992) reported that the increase in cohesiveness and hardness of cooked potato was accelerated by a lower conditioning temperature, which was a characteristic of the starch retrogradation process. Retrogradation is used to describe the changes that occur upon cooling and storage of gelatinized starch (Fredriksson et al., 1998; Karim et al., 2000). In the retrogradation process, the short-term development of crystallinity in starch gels is attributed to the crystallization of the amylose fraction; while long-term changes are due to the amylopectin fraction (Miles et al., 1985). According to Miles et al. (1985) the changes in the mechanical properties of starch gels are related to the crystalline network formation following the amylose association. Hence the behavior of reconstituted cassava dough was interpreted in terms of retrogradation, which could reflect an increase in rigidity of starch granules and the biopolymer matrix by amylose aggregation at low temperature. This hypothesis needs to be confirmed in tests that measure the retrogradation of cooked cassava flour, prepared as described herein.

According to Szymonska et al. (2000) and Redmond et al. (2002), the gelatinized starch granule structure could suffer damage at frozen temperatures due to the pressure exerted on the granules by the ice matrix. This change could leach out more free starch, forming a matrix in the continuous phase.The degree of modification or possible destruction of frozen granules depends on moisture content of the sample, the granule size and the temperature applied (Hopkins and Gormley, 2000; Szymonska et al., 2000). The foregoing observations may explain why dough samples made with flour prepared from the cooked parenchyma left at -20 ºC for 24 h were stiffer than those made with cooked parenchyma left at -5 ºC. On the other hand, cassava parenchyma cooked in boiling water resulted in a 4% increase in weight due to absorption of water; while the weight of parenchyma cooked in steam was almost constant. This difference should be taken into account to explain the results of hardness of cassava dough according to the cooking method.

The high deformability modulus of dough reconstituted from flour cooked for 12 min could be attributed to the granular content and size (Hadziyev and Steele, 1979; Okechukwu and Rao, 1996). If the reconstituted cassava dough is regarded as a composite material with the starch granules as the filler in a polysaccharide matrix (Eliasson, 1986), doughs from parenchyma cooked for 12 min have more starch granules that retain their rounded shape with slight or no swelling than those cooked for 15 min. These starch granules are rigid fillers that have intergranular interactions, such as entanglement between surface molecules of adjacent granules (Evans and Haisman, 1979).

During heating, at the time of water absorption, material is leached out from the starch granules. In gelatinized starch suspension, amylose has been found outside the granules, forming a network structure around them (Eliasson and Gudmundsson, 1996). Increasing the cooking time of cassava parenchyma from 12 to 15 min and decreasing the temperature during the storage period from -5 to -20ºC led to a more cohesive cassava dough, probably due to the increased amylose content in the continuous phase and the strong interaction between starch granules and the continuous matrix.

CONCLUSIONS

The results of this study showed that the method used to measure the textural characteristics of cassava dough samples was sufficiently sensitive to detect changes related to modifications in the processing conditions. The temperature reached by the samples of cooked cassava parenchyma during the storage period was the main factor affecting the texture of the reconstituted dough samples. Decreasing the temperature from -5 to -20 ºC during the storage period of the cooked parenchyma increased the values of the deformability modulus (E), hardness and cohesiveness of the dough, probably due to the interactions between starch granules, which act as the filler in the matrix, and the elastic network.

Increasing the cooking time of cassava parenchyma from 12 to 15 min decreased the values of E and increased the cohesiveness of the cassava dough samples. The cooking method influenced only the hardness of the samples. Dough from a cooking treatment in boiling water was firmer than that which was steamed. This result can be due to a higher absorption of water in the parenchyma during this cooking treatment. The cassava dough reconstituted with flour prepared from parenchyma cooked for 15 min and left at -20ºC showed suitable textural characteristics. Further research on starch modification in the cassava parenchyma cells during processing would help to understand the effect of operational conditions on the final texture of cassava dough.

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NOMENCLATURE

$\kappa_h/t()$	applied strain	(-)
h_0	initial height of the specimen	m
$h/t($	sample height at any time during the compression test	m
A_0	initial cross-sectional area of the sample	m^2
$A/t()$	sample area at any time during the compression test	m^2
$F/t($	applied force perpendicular to the area of the material at any time during the compression test	N
$\omega/t()$	applied stress	Pa
E	deformability modulus	Pa

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