TEXTURE AND MICROSTRUCTURE CHARACTERIZATION OF PASTES RECONSTITUTED FROM DRUM-DRIED FLAKES OF YAM (*DIOSCOREA* SPP.)

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Abstract
　　Drum-dried flakes were processed from two popular varieties of the tropical tuber crop yam species *D. cayenensis-rotundata* and reconstituted to dough like pastes, the most consumed form in Côte d'Ivoire. Pastes from flakes were compared to that prepared by a standardized laboratory procedure. The structure and texture of the pastes was characterized by instrumental and sensory analysis as well as microscopy. Large differences were found between the yam pastes from the two varieties in terms of changes in textural properties and structure upon the drum-drying processing. Reconstituted paste from the variety Assawa was perceived by the sensory panel as more springy and chewy whereas that of Kponan was less extensible and sticky. Although, no significant difference was found in mechanical properties, in terms of firmness, elasticity and adhesion of pastes. Light micrographs revealed that the variety Kponan was less susceptible to cell rupturing.

Keywords: Yam, drum-dried flakes, pastes, textural properties, structure

Introduction:

Yam (*Dioscorea* spp.) based foods are an important source of calories for many people in West Africa, particularly in Côte d'Ivoire where about 3 million tons per year are produced. Consumption of this tuber crop is important and is estimated to 120 kg per capita (Sylla, 2003). The two economically important species are *D. cayenensis-rotundata* and *D. alata* (Doumbia, 1998). These species are mainly consumed in form of dough-like paste called "foutou" (Konan *et al.*, 2003). This dish is obtained by cooking peeled slices of the tubers in water and pounding in a wooden mortar until a thick paste is formed. Small balls are manually rolled from the dough and eaten with traditional sauces of meat, fish or vegetable.

Yam is a starchy crop which is considered as a potential for feeding people in African urban areas where increasing urbanization opens the market for instant food products such as dry flakes. However, supply of yam tubers in these areas is affected by storage losses which can fluctuate between 25 and 60% (Girardin, 1998), transportation losses and cost. Furthermore, the preparation of the yam paste is done in the traditional way which is tedious (pounding with hands) and time consuming which is critical for urban households (Bricas and Attaie, 1998). Drum dried flakes processing was proposed by some authors as an attempt to reduce the post-harvest losses of yam and also provide convenience food in ease of preparation (Rodríguez-Sosa and González, 1972; Rodríguez-Sosa *et al*. 1972; Onayemi and Potter, 1974, Hsu *et al*., 2003).

Texture of yam pastes is the most important sensory criterion of quality for the product and consumer acceptance (Akissoe *et al*., 2001; Egesi *et al*., 2003; Konan *et al*., 2003; Otegbayo *et al*., 2005). Preferred texture attributes are smoothness, stickiness, firmness, elasticity and extensibility (Konan *et al*., 2003; Otegbayo *et al*., 2005). During the preparation of the paste, the mechanical energy involved by pounding, leads to a strong disintegration of the cells which, in turn, contributes to the release of swollen starch granules and the formation of a continuous starch phase that governs the cohesion of the paste (Brunnschweiler *et al*., 2006). The latter authors have shown that the high firmness is explained by moderate cell disintegration, and the adhesion of yam pastes is a property that is strongly related to conformational properties of amylose rather than to the disintegration state of cells.

However, there is a lack of literature on the effect of the drum-drying process on texture and structure of yam paste. Preliminary information can be drawn from previous research on instant mashed potato. It has been shown for this product that mechanical and thermal stress during processing lead to cell disruption and extracellular starch, and the product flow properties are determined by the integrity and the volume fraction of plant

cells as much as the amount of extracellular starch in the continuous fluid phase (Lamberti *et al.*, 2004).

The objective of the present work was to investigate the textural and the structural properties of yam paste reconstituted from drum-dried flakes and the comparison with freshly prepared pastes obtained by a standardized laboratory procedure (Brunnschweiler *et al.*, 2006). The textural properties of the pastes were measured by sensory and instrumental profile tests, and their microstructures were assessed by light microscopy.

1. Materials and methods
1.1. Experimental materials

Two yam varieties of *D. cayenensis-rotundata* (cv. Assawa and Kponan) were bought at the local market in Abidjan (Côte d'Ivoire) and shipped to Switzerland. Tubers were stored for two weeks at 17°C and 65% relative humidity until used (within two to three weeks). These two yam varieties are much preferred by consumers (Konan *et al.*, 2003) but have short time of storage. Production of flakes from these varieties is way to reduce post-harvest waste.

1.2. Production of yam flakes

Flakes were produced on pilot-plant scale according to the potato flakes process scheme described by Lamberti *et al.* (2004) with some modifications. Batches of approximately 5 kg of yam tubers were peeled manually with a knife, sliced into 2.5 cm thick pieces and washed. Approximately 3 cm of each tuber was discarded from the tail and head of the tubers before peeling. The pieces were steam-cooked at 100 ± 3°C for 30 min and mashed through 1.25 cm holes (Universal kitchen machine, Romca, Type CEI09P, DE-Kiel) and blended in a mixer for 4 min (Artofex AG, CH-Gränichen). Water was added to the puree at 10% level in order to provide appropriate total solids content facilitating the drying step. Dehydration was performed on a single drum dryer (L.A. Mitchell Ltd., UK-Manchester) at 3.75 bar steam pressure (≈ 140°C) and at a rotating speed of 7-9 rpm. The resulting dried film was broken into flakes in a granulator with a mesh size of 0.5 cm (Frewitt-Granulator, Type MGL.6.A., CH-Freiburg). Flakes were stored in plastic bags and stored in closed boxes until further analysis.

1.3. Preparation of yam pastes
1.3. 1. Reconstitution of flakes

The instant pastes were prepared by adding distilled water heated to 70°C to the flakes at the ratio of 1: 2 (g:g) and mixing gently with a fork within 4-6 min to obtain a dough.

1.3. 2. Preparation of pastes by the standardized laboratory procedure

This standardized procedure is based on small amounts of plant material for the preparation of yam pastes, which served as model system for freshly pounded yam products (Brunnschweiler *et al*., 2006). The yam tubers was peeled and cut into pieces that were boiled for 30 min, and 100-150 g of the boiled pieces were processed in a blade mixer (Robot Moulinette S, Moulinex, MX-Mexico) until dough like pastes were received.

1.4. Physicochemical analysis of flakes
1.4. 1. Moisture/dry matter content

Moisture content of flakes and dry matter content of fresh tubers were determined in a vacuum oven (Chopin & Co.). By this, 5 g of material were weighed and dried for 22 h at 70°C and 0.9 bar pressure with a flow rate of dried air (silicagel/zeolite) at 1.5 L/min. Measurements were done in duplicate.

1.4. 2. Bulk density

Two beakers of 1 L were filled with flakes and water, respectively, at the same level and weighed. The bulk density of the flakes is the ratio of the flakes weight to the water weight.

1.4. 3. Soluble amylose content

The soluble amylose content of produced flakes was determined by a method adapted from the blue value index of mashed potato products (Lamberti *et al*., 2004). An extract was prepared in a water quench with 5 g of flakes in 500 mL distilled water at 66 ± 1°C for 5 min. After 1 min, the suspension was centrifuged at 2800 rpm for 10 min. The supernatant (5 mL) were mixed with 1 mL 0.01 M iodine solution (Merck KGaA, DE-Darmstadt) and made up to 100 mL or 200 mL for Kponan and Assawa, respectively. The absorbance was measured at 660 nm with a spectrometer (U-2000, Hitachi Ltd., JP-Tokyo), against a blind value (1 mL 0.01 M iodine solution + 99 or 199 mL for Kponan and Assawa, respectively). The blue value index (BVI) was calculated by the following equation where A_{660} is the obtained absorbance, *w* the sample weight [g] and *dm* the sample dry matter [g/100 g]:

$$BVI = (A_{660}/w) \, (100/dm)$$

In addition, the wavelength maximum (λmax) of iodine stained flakes was determined by the absorbance measurement of between 440 and 800 nm

Measurements were carried out in duplicate.

1.5. Texture profile analysis (TPA) of yam pastes

Freshly prepared and reconstituted pastes samples (diameter 30 mm, height 20 mm) were tested by two compression cycles with a universal testing machine (ZWICK 010, DE-Ulm). Samples were formed using moulds (diameter 30 mm, height 20 mm) and were compressed twice between two parallel stainless steel plates (diameter 78 mm) to 50% of the original height at a speed of 50 mm/min. From the force-deformation curve, firmness, springiness and adhesiveness were determined as described by Bourne (2002). The pastes firmness was evaluated as the force maximum the first compression cycle. The negative area under the force–time curve (at the first compression cycle) was calculated as adhesiveness. Springiness was determined as the ratio between distance from onset of the second compression cycle to the peak force and distance from the onset of the first compression cycle to the peak force. Two replicates were carried out with three measurements per replicate.

1.6. Sensory evaluation of yam pastes

The panel was composed of eight people, students and office staff from the Institute of Food Science and Nutrition (ETH Zurich, Switzerland). These panelists were familiar with sensory evaluation of yam pastes, mashed potato and bread dough. They were trained during three sessions for profiling the pastes. The attributes used (Table 1) were taken from previous studies performed in Côte d'Ivoire (Konan *et al.,* 2003). Freshly prepared and reconstituted pastes were tested with two replicates in a sensory room equipped with booths. The panelists received coded samples of pastes in a randomized monadic order. Intensities were rated on a 100 mm line scale with anchors from "not at all" to "much".

1.7. Light microscopy

Cubes (5x5x5 mm) of pastes were cut with a razor blade and frozen in Isopentan (Fluka Chemie GmbH, CH-Buchs) that was cooled with liquid nitrogen. The frozen cubes were stored in liquid nitrogen until cryosections of 10 µm thickness were performed with a cryostat (Jung CM 300, Leica, AU-Vienna). Dry sections were stained for 8 seconds with lugol solution (Fluka Chemie GmbH, CH-Buchs) that was 1:1 diluted with deionised water. The resulting samples were observed in a light-optical microscope (Axioskop 2 mot, Zeiss, CH-Feldbach) in the bright field mode. Micrographs were recorded with a camera (3CCD-Camera, C5810/11, Hamamatsu Photonics Deutschland GmbH, DE-Herrsching am Ammersee).

Table 1: Definition and mode of sensory testing of the textural attributes of the yam pastes

Attribute	Definition	Mode of testing	
		French	English
Springiness	Degree to which the initial shape is recovered after deformation	Presser avec l'index et le majeur	Press with index and middle finger
Firmness	Force required to achieve compression	Presser avec l'index et le majeur jusqu'à effectuer une légère dépression	Press with index and thumb until small depression
Extensibility		Prendre entre les doigts et tirer jusqu'à coupure	Take between fingers and pull until cutting
	Degree to which the sample can be stretched		
Stickiness		Prendre une portion entre les doigts puis les ouvrir	Take sample between fingers and open them
	Degree to which the sample stick to hand		
Lumpiness		Ecraser entre les doigts	
	Presence of lumps		Squeeze between fingers
Chewiness		Mâcher jusqu'à un stade prêt à avaler	Masticate until ready for swallowing
	Mastications required to have a state ready for swallowing		

1.8. Data analysis

Recorded data were examined with the statistical software SPSS V12. 0.1 for windows. Comparison of the means of intensities of sensory and TPA parameters between reconstituted and freshly prepared pastes was analyzed with paired t-test. A two-tailed Pearson correlation was used to calculate the linear correlation between sensory data and TPA measurements. All analyses were done at a significance level $p < 0.05$.

2. Results and discussion
2.1. Tubers and flakes characteristics

The dry matter content of tubers, moisture content and bulk density of the drum dried flakes are presented in Table 2. The dry matter content of yam tubers used for the production of flakes was 35-37%. The moisture content of flakes ranged from 4.50 to 5.88 g/100 g. These values are in agreement with the range shown to be necessary for good storage stability (Onayemi and Potter, 1974). The bulk density of flakes from Kponan is two fold higher than that of Assawa. These results indicate that the density of flakes at the end of the drum-drying process depends on each yam variety. This may be due to differences in starch fraction properties of the two varieties. According to Akambi *et al*. (1996), differences in the density could be explained by the extent of starch solubility and leaching of water soluble substances during the cooking of yam pieces in water.

Table 2: Dry matter content of yam tubers, moisture content and bulk density of yam flakes.

Variety	Tuber dry matter (N = 4)		Flakes moisture content (N = 2)		Flakes bulk density (N = 2)
	$\overline{x}$ [g/100]	SD	$\overline{x}$ [g/100]	R	$\overline{x}$ [kg/m³]
Assawa	34.2	2.3	5.9	0.2	49.7
Kponan	36.9	1.9	4.5	0.1	98.8

Data are indicated as means ($\overline{x}$) of four measurements (N) of tubers dry matter per yam variety, and as two measurements (N) per yam variety for moisture content and bulk density of flakes.

SD refers to the standard deviation of the four measurements of dry matter content of tubers per yam variety.

R refers to the range of the two measurements of moisture content and bulk density of flakes per yam variety.

The free soluble starch of flakes determined by colorimetry measurement of the iodine complexation recorded as the blue value index is indicated in Table 3. This value also related to the amount of amylose in the extracts, is higher for Assawa than Kponan. Lamberti *et al*. (2004) reported that the blue value index for the mashed potato is influenced by the release of starch after cell disruption during the grinding step. Thus, the highest value of flakes from Assawa can be related to more cell disruption and extracellular starch in this variety compared to Kponan during the drum-drying process. Difference in the extent of cells disintegration of yam varieties was also found by Brunnschweiler *et al.* (2006) in pastes prepared with the traditional and a small scale blade mixer method.

Furthermore, the high wavelength maximum of iodine stained flakes (λmax > 530 nm) indicates that the free extractable starch consists mainly of amylose (Lamberti *et al*., 2004; Brunnschweiler *et al*., 2006).

Table 3: Soluble amylose content of flakes extracts measured by quantification of the iodine complexation (N = 2).

Variety	Absorbance at 660 nm [per g of flakes, dry base]	R	Max. Absorbance [nm]	R
Assawa	0.360	0.001	636.5	1.0
Kponan	0.223	0.000	638.0	0.0

Data are indicated as means of the two measurements (N) of soluble amylose content of flakes per yam variety.

R refers to the range of the two values of soluble amylose content of flakes per yam variety.

2.2. Textural properties of pastes

Table 4 shows the comparison between texture parameters (elasticity, firmness and adhesion) of freshly prepared and reconstituted yam pastes assessed by the TPA. For the three parameters, no significant difference was found between the two pastes from each variety. The drum-drying process did not affect these mechanical properties of yam pastes.

Table 5 presents the comparison of sensory attributes between freshly prepared and reconstituted yam pastes. It is expected that due to the processing conditions the sensory properties of the freshly yam pastes are perceived differently compared to reconstituted drum-dried yam flakes where no pounding was done. For the variety Assawa, a significant difference was shown between the two pastes for the attributes springiness, lumpiness and chewiness. The reconstituted paste was found to be more springy and chewy but less lumpy than the freshly prepared. It must be mentioned that the freshly prepared yam samples are lumpier due to the blade mixer procedure which involves cutting the yam parenchyma in a high-speed cutter. This would not be the case for traditionally pounded yam, involving uniaxial compressions. For the variety Kponan, the two types of pastes were significantly different for their extensibility and stickiness. The reconstituted paste showed the lowest intensities for these attributes. As the blade mixer is the model system for pounded yam products, it could be concluded that the drum-drying of flakes of yam influences the textural properties of the yam pastes and the affected attributes are different between the two tested varieties. According to Brunnschweiler (2004), it is recognized that the textural properties are influenced by the structure elements such as tissue integrity, cell wall composition and properties of parenchyma tissue and starch properties (flow and swelling behaviour, solubility etc.). Therefore, the results may be explained by the extent of the changes of the above factors upon the drum-drying process of flakes.

Table 4: Mean values of instrumentally measured texture attributes with texture profile analysis of freshly prepared and reconstituted pastes from yam varieties Assawa and Kponan (N = 6).

Pastes	Firmness [N]	Elasticity [-]	Adhesion [N.s]
		Assawa	
Reconstitued	18.2 (1.6)	0.37 (0.03)	5.8 (2.0)
Freshly prepared	22.2 (4.0)	0.6 (0.07)	18.8 (9.4)
		Kponan	
Reconstituted	19.2 (1.1)	0.18 (0.01)	2.2 (0.6)
Freshly prepared	15.6 (3.2)	0.41 (0.09)	8.2 (3.6)

Mean values were not significantly different between the two pastes for each variety (P>0.05)

N refers to the number of determinations per yam paste.

Standard deviation in parentheses.

Table 5: Mean values of sensory profiling of freshly prepared and reconstituted pastes from yam varieties Assawa and Kponan (N = 8).

Pastes	Springiness [mm]	Firmness [mm]	Extensibility [mm]	Stickiness [mm]	Lumpiness [mm]	Chewiness [mm]
			Assawa			
Reconstituted	84 [a] (19)	71 [a] (28)	37 [a] (22)	30 [a] (19)	6 [b] (12)	52 [a] (23)
Freshly prepared	65 [b] (35)	55 [a] (33)	28 [a] (26)	23 [a] (22)	22 [a] (26)	42 [b] (34)
			Kponan			
Reconstituted	49 [a] (33)	62 [a] (33)	3 [b] (6)	4 [b] (8)	11 [a] (24)	22 [a] (22)
Fresh	51 [a] (28)	39 [a] (26)	18 [a] (20)	18 [a] (15)	6 [a] (16)	33 [a] (24)

Data are indicated as means of intensities of each attribute rated by eight panelists in two test sessions, with standard deviation in parentheses.
a,b, Means with different superscripts in the same column are significantly different (P<0.05).
N refers to the number of panelists.

Pearson correlations between the three TPA parameters and sensory attributes mean scores were shown in Table 6. A high positive significant correlation (r = 0.932, p < 0.05) was shown between adhesion and the sensory attribute stickiness on the one hand and with extensibility (r = 0.908, p < 0.05) on the other hand. No significant correlation was perceived between the measurements of the attributes of elasticity and firmness by the two methods. These mechanical properties are supposed to correlate with the sensory properties springiness and firmness, respectively. Therefore, the results must be confirmed further.

Table 6: Two-tailed Pearson correlation coefficients between sensory attributes and texture profile analyses (TPA) parameters.

Parameter	Springiness	Firmness_s	Extensibility	Stickiness	Lumpiness	Chewiness	Elasticity	Firmness_i
Sensory								
Firmness_s	0,657							
Extensibility	0,190	-0,419						
Stickiness	0,096	-0,491	**0,995**					
Lumpiness	0,063	0,271	-0,411	-0,451				
Chewiness	0,290	-0,331	**0,995**	**0,980**	-0,400			
TPA								
Elasticity	0,063	-0,589	0,832	0,825	0,043	0,809		
Firmness_i	0,343	0,608	-0,450	-0,515	**0,927**	-0,405	-0,145	
Adhesion	-0,189	-0,632	**0,908**	**0,932**	-0,252	0,865	0,860	-0,414

Significant correlations are in boldface ((P<0.05)

_i = instrumental, _s = sensory

2.3. Microstructure of pastes

Light micrographs of cryostat-sections of reconstituted and fresh pastes prepared with the blade mixer are presented in Figure 1. For yam

variety Assawa, reconstituted pastes showed partly disrupted or totally destroyed cells with leaching starch into the extracellular space (Figure 1a, b) whereas pastes prepared by the standardized blade mixer method presented most intact cells. Although, for the variety Kponan, almost intact cells were found in pastes prepared with the two methods, in the case of the reconstituted product, cells were not round-off but elongated (Figure 1c, d). Intact tissue patches, mainly around vascular bundles could be observed for pastes prepared by the blade mixer method.   The results confirm that the variety Kponan is less susceptible to cells disintegration upon the drum-drying process of flakes than the variety Assawa. The same result was found by Brunnschweiler *et al*. (2006) for pastes prepared with the standardized blade mixer process. Baah (2009) also observed difference in cells disruption between yam varieties from *D. alata* and related the less cells disruptions to a more rigidity in their cell walls and higher total dietary fibers content. The mechanical and thermal treatments as well as a high drying rate applied during the drum-drying of flakes are expected to cause a greater effect on cell separation, cell and starch granule rupturing than the blade mixer procedure. In contrast, the results showed that the extent of cell disintegration upon drum-drying seems to depend on the variety. However, intact tissue parts observed only in the blade mixer paste indicate that the drum-drying process causes the greatest tissues disintegration.

The examination of structure-texture relationships shows the influence of the extent of cell disintegration on texture of yam pastes. The differences in the extent of cell disintegration observed on micrographs from Assawa led to a significant difference in chewiness and springiness of pastes, as assessed by the sensory panel. Baah (2009) noticed good sensory scores for yam varieties with higher degree of cells disintegration. The present result indicates that the targeted textural properties are related to the integrity of cells and it can be stated that a high degree of cell disintegration promotes a springy and chewy product. The present study have shown in agreement with previous reports (Lamberti *et al*., 2004; Brunnschweiler *et al*., 2006) that the free starch leached in the extracellular after cell disruption consists on amylose. To this regards, the springiness and chewiness of yam pastes could be attributed to the amount of free (or soluble) amylose in the flakes. The role of soluble amylose on the textural properties of yam paste is reported in the literature (Onayemi and Potter, 1974; Brunnschweiler *et al*., 2006). The later stated that the adhesive properties of yam pastes are primarily influenced by the aggregation state of amylose.
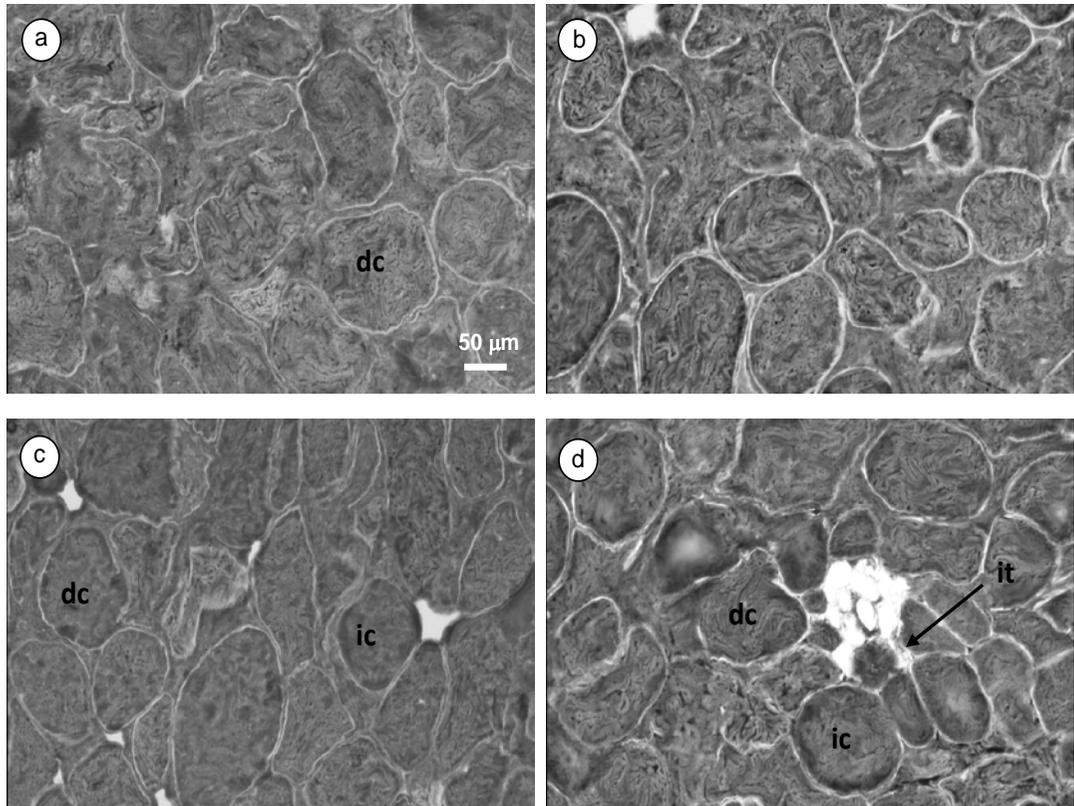
Figure 1: Light micrographs of cryostat-sections (10 µm) of reconstituted pastes from flakes
and freshly prepared pastes with blade mixer method, stained with iodine.
Yam pastes of a) Assawa reconstituted, b) Assawa freshly prepared,
c)   Kponan reconstituted, and d) Kponan freshly prepared
ic = intact cells, dc = disrupted cells, it = intact tissue patch).

Conclusion

Sensory and TPA measurements have shown that the drum drying
flaking causes changes on the textural properties of yam paste (foutou),
particularly springiness, chewiness, extensibility and stickiness. The
influence on these attributes was different in the two yam varieties Kponan
and Assawa of the species *D. cayenensis-rotundata*. In contrast to the
expectation, the effect of the drum-drying process on yam tissue cell
disintegration was not more severe than the blade mixer procedure but
depends on the cell integrity of yam varieties. The chewiness and springiness
of pastes was found to be related to the extent of cell disintegration and the
soluble amylose fraction. However, extensibility and stickiness seemed to be
influenced by the amylose structure or its rheological properties and by other
parenchyma component (cell wall polysaccharides and mucilage substances).
Further investigations on other polymeric components of the tuber

parenchyma and the organization of the cellular structure are necessary to provide a proper knowledge and understanding of changes in textural properties upon the drum-drying process of yam flakes.

Acknowledgement

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