# State Of Knowledge Report On Fresh Yam And Pounded Yam - WP2

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# 1. Composition and Structure of Raw Material

Yams are climbing monocotyledonous vines with large strong underground tubers (Mozie, 1984). Yam is a generic name for the plants of twining climbers that form tubers in the genus Dioscorea of the monocot family Dioscoreaceae (Zhu, 2015). They are an integral part of food systems, estimated to provide more than 200 dietary calories each day for over 60million people (FAO, 2002).

Yams constitute a nutritious, high carbohydrate and high fibre food source. They are also important in household food security, diet diversification, employment and income generation as well as alleviation of rural poverty. They are of major importance in the diet and economic welfare of people in West Africa (Nigeria, Ghana, Benin and Togo)the Caribbean Islands, Asia and Oceania. West Africa accounts for 91% of yam production in the world, while Nigeria accounts for 68% of the world's annual total production of yams (50 million tonnes) (FAO, 2009). Food yams are members of the genus *Dioscorea*, family Dioscoreaceae, order Dioscoreales. More than 600 species of *Dioscorea* exist (Salda 1999; Lebot 2008) but only six are mostly grown as staple foods in Africa. These are *Dioscorea rotundata Poir* (White yam), *Dioscorea cayenesis Lam*, (Yellow yam), *Dioscorea alata Linn* (Water yam), *Dioscorea dumetorum (*Kunth*) Pax* (Trifoliate yam), *Diosocrea bulbifera Linn.* (Aerial yam) and *Dioscorea esculenta (Lour) Burk* (Chinese yam). Table 1 shows the important food yam species found in different parts of the world.

Yam cultivation is intimately integrated with socio-cultural, economic and religious customs of several West Africa communities (Coursey, 1972, 1976a, and 1976b. It is not surprising that a considerable amount of ritualism is developed around the production and utilization of yams. One of the most important manifestations of this ritualism is the new-yam festival, which is celebrated in various ways in the West African yam zone. It is traditional that yam must not be officially harvested or consumed before this festival. On the day of the festival, the farmer harvests several yams from his farm, uses part of it to prepare a feast, which he will use to pay homage to elders and friends. Considerable religious activity and social merry making often accompany this festival. The expression "yam civilization" came into being for these reasons (Coursey, 1972,1976a, 1976b). In Nigeria, yam is usually part of the bride price at marriage ceremonies and "pounded yam" is the traditional form in which yam is popularly eaten. It is a high status food that is given to an honoured guest. It is also used in important ceremonies such as chieftaincy or coronation (Ugwu, 1990). In South-eastern Nigeria, yam is a totem of masculinity and a calendar crop around which the Ibo farming season and annual festivals revolve.

**Table 1: Major food yam species**

| | AFRICA | ASIA | AMERICAS |
|---|---|---|---|
| Major economic Species | *D. rotundata*<br>*D. cayenensis*<br>*D. alata*<br>*D. esculenta*<br>*D. bulbifera*<br>*D. dumetorum* | *D. alata*<br>*D. esculenta*<br><br><br>*D. bulbifera*<br>*D. opposita* | *D. trifida*<br>*D. rotundata*<br>*D. cayenensis*<br>*D. alata*<br>*D. bulbifera*<br>*D. convolvulacea* |
| Secondary species | *D. praehensilis*<br>*D. preussii*<br>*D. sansibarensis* | *D. hispida*<br>*D. nummularia*<br>*D. japonica*<br>*D. pentaphylla* | *D. esculenta* |

Source: Muzac-Tucker et. al., (1993)

## 1.1. Composition

The tuber is the main economically utilised part of the yam plant. The chemical composition of the tuber varies with species and cultivars (Interspecific) and within species (intraspecific). Climate, cultural and edaphic factors of the environment under which they are cultivated, maturity at harvest and storage method can also cause variations between same cultivars (Asiedu, 1986). Yam as a multi-species crop shows variation in its properties across species and varieties. Genotypic diversity of yams is wide, There have been reports on variability in chemical and physicochemical composition of yams from different countries ; Cameroon (Egbe and Treche 1984), Jamaica (Muzac-Tucker et al.1993), Cote d'ivoire (Amani et al. 2004), Vanuatu (Lebot et al., 2006), Ethiopia (Tamiru et al. 2008), Indian (Shantakumari et al. 2008), Sri Lankan (Senanayake et al.2012), Ghana (Baah et al. 2009 ; Afoakwa et al. 2013), Indonesian yams (Aparianta et al. 2014) and Nigeria (Otegbayo et al. 2017). Table 2 shows the Chemical composition and antinutritional of forty-three varieties of yam from *D. rotundata (TDr; 27), D. alata (TDa;9), D. bulbifera (TDb; 5), D. cayenensis (TDc; 2), and D. dumetorum (TDd; 2),* collected from two major yam growing ecological zones in Nigeria. Generally, in terms of chemical composition amongst the yam species studied, *D. bulbifera* specie had the highest protein, sugar, ash and non-starchy carbohydrates. Protein content decreased along the species as follows: TDb (6.02%) > TDc (5.85%)> TDr (4.76%) > TDa (4.32%) though there were significant variations among the cultivars in each species (Table 2). TDr had the highest mean value for starch, while TDb had the lowest (60.97%).

Basically the methods used to determine the chemical composition of yam tubers by these authors are procedures such as ; the Kjeldahl analysis for protein determination, Soxhlet extraction for fats (AOAC, 2016) Atomic Absorption Spectrophotometry (AAS) andinductively coupled plasma spectrometry (Zarcinas et al. (1987), Near-InfraRed Spectroscopy (NIRS) (Lebot and Malapa, 2013).

**Table 2: *Chemical composition of yam germplasm (%)**

| *****TDb*** | **MC** | **Prot** | **Ash** | **Sug** | **Starc** | **NDF** | **ADF** | **Lig** | **Cellu** | **H.Ce** |
|---|---|---|---|---|---|---|---|---|---|---|
| **TDb 3079** | 10.58$^{e}$ | 5.69$^{c}$ | 3.91 | 0.77 | 52.17 | 6.70$^{c}$ | 3.24$^{c}$ | 1.10$^{b}$ | 3.36$^{c}$ | 2.15$^{c}$ |
| **TDb 3084** | 12.68$^{a}$ | 5.89$^{b}$ | 5.29 | 1.56 | 69.98 | 7.14$^{a}$ | 3.42$^{a}$ | 1.20$^{a}$ | 3.72$^{a}$ | 2.23$^{a}$ |
| **TDb 3072** | 11.68$_{d}$ | 5.23$^{d}$ | 3.65 | 3.86 | 54.34 | 5.66$^{d}$ | 2.97$^{c}$ | 1.05$^{bc}$ | 2.69$^{d}$ | 1.92$^{e}$ |
| **TDb 3086** | 12.21$^{c}$ | 4.60$^{e}$ | 4.31 | 2.66 | 70.64 | 6.88$^{d}$ | 3.36$^{b}$ | 1.15$^{a}$ | 3.52$^{b}$ | 2.21$^{b}$ |
| **TDb 3069** | 12.42$^{b}$ | 8.71$^{a}$ | 4.43 | 3.15 | 57.78 | 5.62$^{d}$ | 3.04$^{d}$ | 1.04$^{c}$ | 2.59$^{e}$ | 2.00$^{d}$ |
| ***mean*** | **11.91** | **6.02$^{b}$** | **4.32** | **2.40** | **60.97** | **6.40$^{b}$** | **3.20$^{b}$** | **1.11$^{b}$** | **3.19$^{b}$** | **2.10$^{b}$** |
| ******TDr*** | | | | | | | | | | |
| **Gbongi** | 11.12$^{g}$ | 5.58$^{a}$ | 3.22 | 1.18$^{l}$ | 86.73 | 6.22$^{a}$ | 2.95$^{b}$ | 1.54$^{a}$ | 3.27$^{a}$ | 1.42$^{c}$ |
| **Mumuyi** | 10.42$^{n}$ | 5.27$^{b}$ | 3.38 | 1.66 | 65.06 | 3.28$^{e}$ | 1.33$^{ijk}$ | 0.48$^{ghi}$ | 1.97$^{de}$ | 0.85$^{l}$ |
| **Suba** | 10.62$^{l}$ | 4.64$^{ij}$ | 3.50 | 1.64 | 62.60 | 2.67$^{ij}$ | 1.34$^{ij}$ | 0.00$^{o}$ | 1.33$^{jkl}$ | 1.34$^{d}$ |
| **Kangan** | 10.88$^{ij}$ | 4.40$^{k}$ | 3.60 | 2.46 | 78.20 | 3.72$^{d}$ | 1.69$^{gh}$ | 0.63$^{e}$ | 2.04$^{de}$ | 1.06$^{j}$ |
| **Danachabja** | 10.89$^{ij}$ | 4.41$^{k}$ | 3.60 | 1.33$^{j}$ | 60.94 | 3.73$^{d}$ | 1.78$^{fg}$ | 0.43$^{ljk}$ | 1.96$^{de}$ | 1.35$^{d}$ |
| **Adaka** | 11.70$^{c}$ | 4.32$^{k}$ | 2.37$^{j}$ | 2.94 | 66.38 | 2.06$^{l}$ | 1.03$^{o}$ | 0.00$^{o}$ | 1.23$^{kl}$ | 1.03$^{j}$ |
| **Gwari** | 10.66$^{k}$ | 4.85$^{g}$ | 2.64 | 1.44$^{ij}$ | 64.98 | 2.52$^{j}$ | 1.39$^{i}$ | 0.26$^{mn}$ | 1.13$^{m}$ | 1.13$^{h}$ |
| **Godiya** | 10.62$^{k}$ | 4.85$^{g}$ | 2.80 | 1.0$^{1}$ | 64.90 | 6.31$^{a}$ | 3.10$^{a}$ | 1.04$^{bc}$ | 3.21$^{a}$ | 2.06$^{a}$ |
| **Meccakw** | 11.88$^{c}$ | 5.54$^{a}$ | 2.29 | 1.32$^{j}$ | 66.74 | 3.23$^{e}$ | 1.21$^{kl}$ | 0.58$^{efg}$ | 2.02$^{de}$ | 0.63$^{o}$ |
| **Akwuki** | 11.57$^{d}$ | 5.19$^{c}$ | 3.20 | 2.01$^{f}$ | 77.56 | 2.41$^{j}$ | 1.17$^{lm}$ | 0.27$^{m}$ | 1.24$^{kl}$ | 0.90$^{l}$ |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Gbinra** | $11.33^{e}$ | $4.60^{a}$ | 2.82 | 3.17 | 63.94 | $4.17^{c}$ | $1.88^{f}$ | $1.05^{bc}$ | $2.29^{c}$ | 0.83 |
| **Mailemu** | $12.82^{a}$ | 3.96 | $2.44^{i}$ | 1.73 | 63.68 | $5.27^{b}$ | $2.52^{c}$ | $0.96^{cd}$ | $2.75^{b}$ | $1.56^{b}$ |
| **Orin** | $11.35^{e}$ | $5.20^{c}$ | 2.60 | 2.59 | 72.89 | $4.15^{c}$ | $2.48^{c}$ | $0.88^{d}$ | $1.68^{gh}$ | $1.60^{b}$ |
| **Yangbede** | $10.26^{p}$ | $4.22^{l}$ | 2.94 | 0.97 | 72.42 | $3.61^{d}$ | $1.64^{h}$ | $0.60^{ef}$ | $1.97^{de}$ | $1.05^{j}$ |
| **Ameh** | $11.01^{h}$ | $5.13^{d}$ | 3.02 | 1.99 | 71.89 | $2.96^{g}$ | $1.37^{ij}$ | $0.17^{n}$ | $1.59^{hi}$ | $1.20^{e}$ |
| **Jibo** | $11.10^{g}$ | $4.55^{j}$ | $2.50^{i}$ | 3.07 | 73.07 | $3.17^{f}$ | $1.25^{jkl}$ | $0.50^{fgh}$ | $1.92^{def}$ | $0.75^{n}$ |
| **Amula** | $11.19^{f}$ | 4.07 | 3.21 | 1.89 | 78.12 | $5.40^{b}$ | $2.27^{d}$ | $0.94^{d}$ | $3.13^{a}$ | $1.33^{d}$ |
| **Lagos** | $10.36^{o}$ | 4.07 | 3.17 | 2.48 | 67.78 | $3.46^{d}$ | $1.57^{h}$ | $0.33^{lm}$ | $1.90^{ef}$ | $1.24^{e}$ |
| **Omi efun** | $9.96^{r}$ | $5.03^{e}$ | $2.47^{i}$ | 2.51 | 66.60 | $3.70^{d}$ | $1.69^{gh}$ | $0.54^{efg}$ | $2.02^{de}$ | $1.15^{g}$ |
| **Pepa** | 10.57 | $5.38^{a}$ | $2.50^{i}$ | $1.37^{j}$ | 69.73 | $4.17^{c}$ | $2.09^{e}$ | 0.88d | $2.08^{d}$ | $1.21^{e}$ |
| **Ehorbia** | $10.39^{n}$ | $4.82^{h}$ | 2.73 | 1.75 | 70.70 | $2.06^{e}$ | $1.10^{b}$ | $2.28^{c}$ | $0.96^{k}$ | $0.96^{k}$ |
| **Coach** | $12.51^{b}$ | $4.69^{i}$ | 3.02 | $1.3^{kl}$ | 59.14 | $1.08^{no}$ | $0.00^{o}$ | $1.21^{lm}$ | $1.08^{w}$ | $1.08^{w}$ |
| **Olotan** | $10.00^{q}$ | $4.30^{k}$ | $2.49^{i}$ | 2.89 | 56.67 | $1.10^{mn}$ | $0.37^{kl}$ | $1.77^{fg}$ | $0.73^{n}$ | $0.73^{n}$ |
| **Oginni** | $10.04^{q}$ | $4.23^{l}$ | 2.58 | 3.31 | 70.72 | $1.30^{ijk}$ | $0.00^{o}$ | $1.27^{jkl}$ | $1.30^{d}$ | $1.30^{d}$ |
| **Danacha** | $11.48^{d}$ | $4.27^{l}$ | 2.89 | 3.26 | 75.01 | $3.10^{a}$ | $1.08^{b}$ | 3.18a | $2.02^{a}$ | $2.02^{a}$ |
| **Boki** | $11.39^{e}$ | 4.96f | 3.43 | 2.66 | 61.69 | $1.57^{h}$ | $0.40^{jkl}$ | $1.39^{jk}$ | $1.17^{g}$ | $1.17^{gh}$ |
| **Ameh abj** | $10.76^{j}$ | $5.00^{f}$ | 3.01 | 4.61 | 74.05 | $1.64^{h}$ | $0.48^{hij}$ | $1.43^{ij}$ | $1.18^{e}$ | $1.18^{efgh}$ |
| ***mean*** | **$11.00^{a}$** | **4.76** | **2.91** | **2.17** | **68.97** | **$3.73^{a}$** | **$1.76^{a}$** | **$0.57^{a}$** | **$1.97^{a}$** | **1.18** |
| ***TDa*** | | | | | | | | | | |
| **Kesofunf** | $12.81^{c}$ | 4.01 | 4.62 | 3.14 | 65.11 | $3.78^{c}$ | $2.10^{c}$ | $0.87^{c}$ | $1.68^{d}$ | $1.34^{c}$ |
| **Sharmab** | $12.47^{c}$ | $3.21^{f}$ | 4.04 | 2.10 | 73.36 | $2.40^{h}$ | $1.54^{f}$ | $1.04^{a}$ | **$0.86^{u}$** | $0.72^{g}$ |
| **TDa 291** | $12.63^{b}$ | $3.82^{d}$ | 4.37 | 3.54 | 49.58 | $2.67^{c}$ | $2.30^{b}$ | $0.70^{f}$ | $1.37^{f}$ | $1.43^{b}$ |
| **Boko** | $12.72^{b}$ | $6.73^{a}$ | 4.32 | $1.02^{f}$ | 60.80 | $4.74^{a}$ | $2.85^{a}$ | $0.96^{b}$ | $1.89^{c}$ | $1.81^{a}$ |
| **Ogunawa** | $12.33^{c}$ | $5.11^{b}$ | 4.29 | 2.11 | 63.38 | $3.47^{f}$ | $1.93^{d}$ | $0.00^{h}$ | $1.54^{e}$ | $1.23^{d}$ |
| **Olesunle** | $12.16^{c}$ | $4.96^{b}$ | 6.69 | 2.85 | 70.97 | $3.66^{e}$ | $2.14^{c}$ | $0.64^{g}$ | $1.53^{e}$ | $1.18^{e}$ |
| **TDa 93-36** | $12.29^{a}$ | $3.32^{f}$ | 4.30 | 4.14 | 67.70 | $2.46^{g}$ | $1.33^{g}$ | $0.85^{cd}$ | $1.15^{g}$ | $1.31^{c}$ |
| **SharmaG** | $13.14^{a}$ | $3.38^{e}$ | 4.26 | 1.52 | 66.87 | $3.74^{d}$ | $1.73^{c}$ | $1.44^{a}$ | $2.01^{b}$ | $1.09^{f}$ |
| **TDa 92-2** | $12.28^{c}$ | $4.35^{c}$ | 3.81 | 4.12 | 66.91 | $4.25^{b}$ | $1.93^{d}$ | $0.55^{b}$ | $2.32^{g}$ | $1.09^{f}$ |
| ***mean*** | **12.58** | **4.32** | **4.41** | **2.72** | **64.96** | **3.57** | **$1.98^{a}$** | **$0.74^{a}$** | **$1.59^{a}$** | **1.24** |
| ***TDc*** | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Igangan** | 11.67$^{a}$ | 7.15$^{a}$ | 2.64 | 4.40 | 61.20 | 4.40 | 2.48 | 1.02 | 1.92 | 1.46 |
| **TDC 25-4** | 10.82$^{b}$ | 4.55$^{b}$ | 2.70 | 1.96 | 72.11 | 1.96 | 0.92 | 0.00 | 1.04 | 0.92 |
| **mean** | **11.24** | **5.85$^{b}$** | **2.67** | **2.15** | **66.65** | **3.18$^{a}$** | **1.70$^{a}$** | **0.51$^{a}$** | **1.48$^{a}$** | **1.19$^{a}$** |

Source Otegbayo et al. (2017)

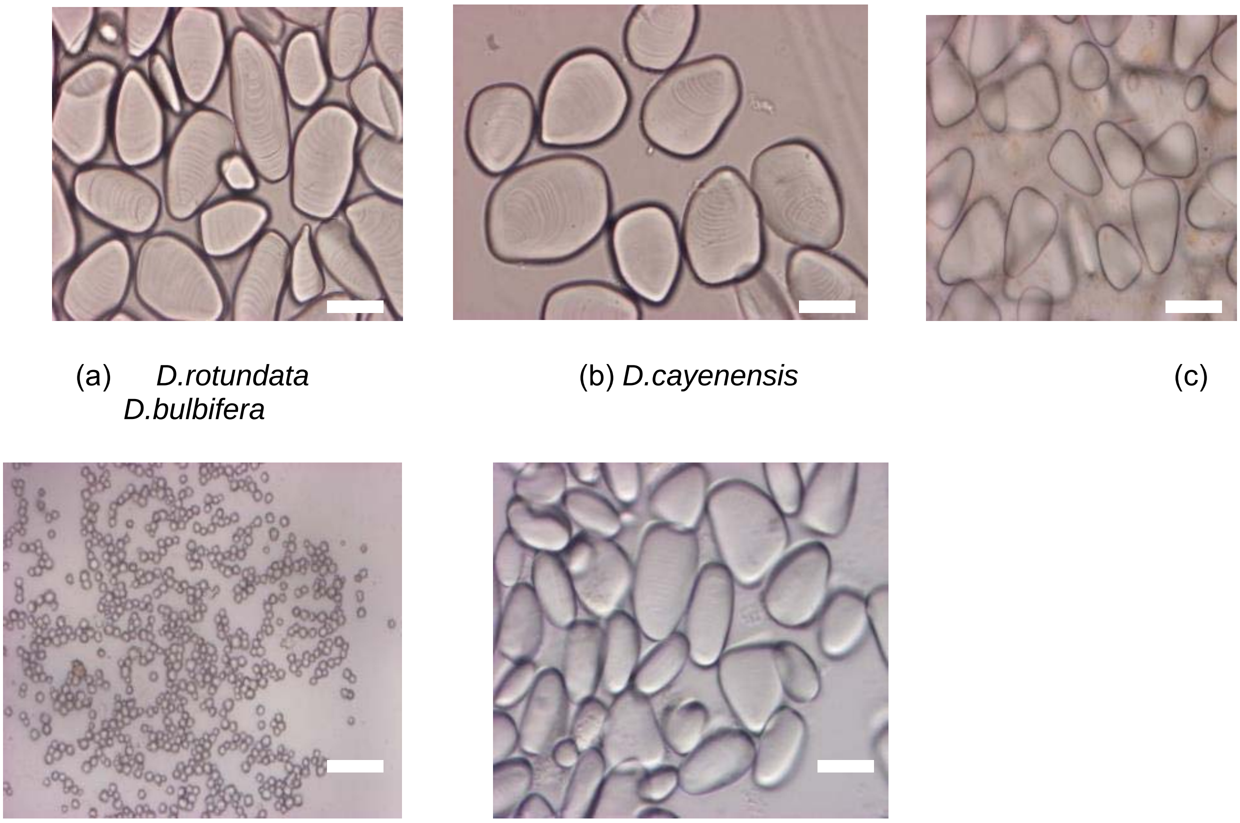
All analyses on dry weight basis (DWB)

*MC- Moisture content, DF-dietary fiber, NDF- Neutral detergent fiber, Lig- lignin, Cellu- Cellulose, H.Cell- Hemicellulose. ** TDb- Tropical *dioscorea bulbifera*, TDa – Tropical *dioscorea alata*, TDc – Tropical *dioscorea cayenensis.* ***ND in TDc Iganga and TDc 25-294 means -Not determined.

Yam starch accounts for about 60–80% of the dry matter of yam tuber (on dry weight basis) and has been reported as a dominant factor in determining the physicochemical, rheological and textural characteristics of food products from different yam species (Amani et al, 2004) and RTB crops (Charoenkul et al. 2011). Yam starches consist of two glucose polymers amylose, which is the linear molecule and the highly branched amylopectin. They both occur in the starch granules. Amylose consists of long chains of α D-glucopyranosyl residues linked with α D-(1-4) glycosidic bond. It contains 1000 glucose residues whose average molecular weight ranges between 2x10$^{5}$and 2x10$^{6.}$ Amylopectin is a larger molecule. It contains about 10$^{6}$ glucose units per molecule and joined together by both α- 1-4 glycosidic bonds and α -1-6 glycosidic bond at the branched points (Karim *et al*. 2000). Amylose is a major component of starch and plays an essential role it's a major determinant of the properties, uses of starch and textural quality of yam food products (Srichuwong and Jane 2007). Great variation in the amylose content of diverse genotypes of the same species and between diverse species has been observed (Zhu, 2015). Amylose contents of genotypes from various yam species ranged from 1.4% (Perez et al. 2011) to 50% (Rolland-Sabate et al. (2003). Otegbayo et al. (2014) reported a range of 15.1% to 27.1 for 43 genotypes in 5 yam species (*D. rotundata, D. alata, D. cayenensis, D. dumetorum* and *D. bulbifera)*. Zhu (2015) reported that *D. dumetorum* and *D. esculenta* species have lower amounts of amylose (< 20%) compared to *D.alata*, *D.rotundata* and *D.cayenensis-rotundata*, but these latter 3 species have quite similar amylose content (Amani et al., 2004; Otegbayo et al., 2014).

### *Shape and size of yam starch granules*:

Light microscopy showed that yam starch granules appeared smooth without any fissures (Otegbayo et al. 2011) (Fig. 1). The shapes of *D. alata* starch granules were mostly ovoid, oblong elliptical and round (Fig.2a) while *D. rotundata* had oval oblong, elliptical triangular and irregular shapes (Fig. 2b). Granule shapes of *D. rotundata, D. alata,* and *D. cayenensis* were similar, while those of *D. dumetorum* and *D. bulbifera* were different. *D. bulbifera* starch granules were triangular while those of *D. dumetorum* were hexagonal or polyhedral in shape (Otegbayo et al. 2014). Many authors had similar observations on granule shapes of yam starches (Farhat et al. 1999; Moothy et al 2002, Lindenboom et al. 2004) According to classification of starch granule size by Lindeboom et al. (2004) and Rolland Sabate et al (2003), starch granules from *D. rotundata*, *D. alata*, and *D. cayenensis* and *D. bulbifera* can be classified as large starch granules (i.e. >25 µm) while *D. dumetorum* (7–10mm) are classified as small starch granules.



(a) *D.rotundata* (b) *D.cayenensis* (c) *D.bulbifera*

(d) *D.dumetorum* (e) *D. alata*

**Fig 1. Photomicrograph of starch granules from *D. rotundata, D. cayenensis, D. bulbifera, D. dumetorum,* and *D. alata.***

*(a) Scale bar 90µm, (b) scale bar 90 µm, (c) scale bar 90 µm, (d) scale bar 90 µm, (e) scale bar 90 µm.*

## 1.2. Structure

According to FAO (1998), Yam tuber is more or less cylindrical in shape and 3-5 kg in weight. The yam tuber grows from a corm-like structure located at the base of the vine (Figure 2). Occasionally this corm remains attached to the tuber after harvest and sprouts will develop from it. When the corm separates from the tuber sprouting occurs from the tuber near to the point at which the corm was attached. The transverse section of the tuber is composed of four concentric layers:

**Corky periderm**. The outer portion of the yam tuber; it is a thick layer of cork cells, often cracked, but which provides an effective barrier against water loss and invasion by pathogens.

**Cortex**. A layer located immediately beneath the cork, comprising thin-walled cells with very little stored starch.

**Meristematic layer**. Elongated thin-walled cells under the cortex. Sprouts are initiated from this layer.

**Ground tissue**. The central portion of the tuber, composed of thick-walled starchy cells, with vascular bundles ramifying throughout the mass.

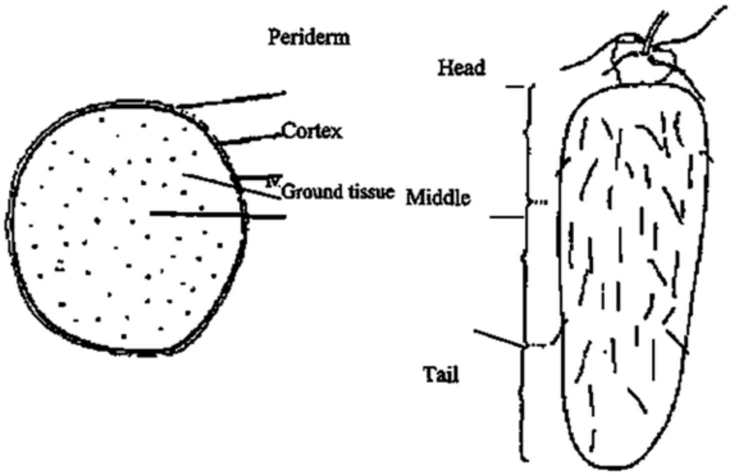
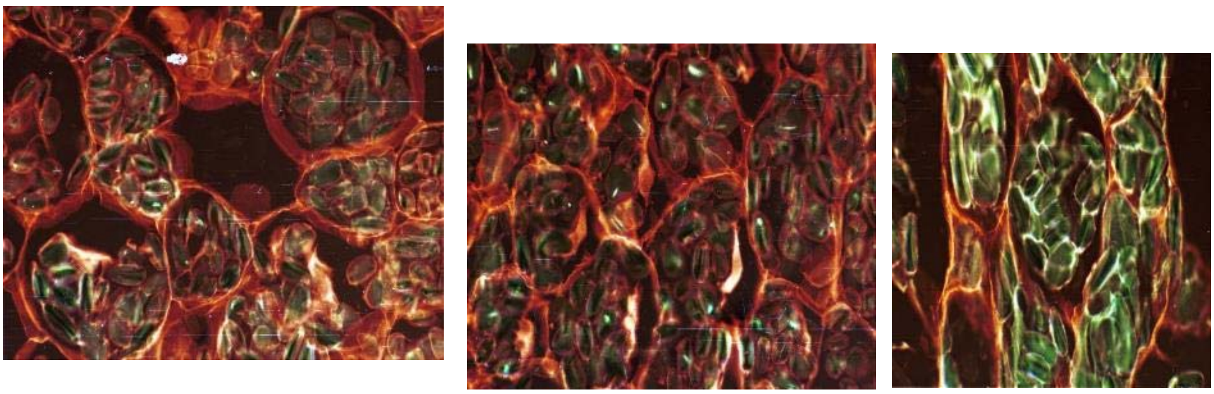



**Figure 2: General Morphology and cross section of yam tuber (Omwueme, 1983)**

The typical shape of parenchyma cells found in the yam tubers is a three dimensional polyhedral type like potato cells (Fig 3 & 4) (Otegbayo et al.,2005; Akissoe et al,2011). Cells from *D. rotundata* varieties showed the prominent three-dimensional polyhedral shape (Fig 3). They were large, thin-walled with big granules and the granules were scattered and loosely bound to each other. Cells from the *D. alata* varieties also had the three- dimensional polyhedral shape, thick walls, but in some varieties the cells were elongated and larger in size than those of *D. rotundata* varieties. Table 3 shows the description of cell structure of ten varieties of yam (5 from *D.rotundata* and 5 from *D.alata* species, respectively.)



(a)TDr 99-9 (b) TDr 99-12 (c) TDa 85/00250

**Fig 3: Photomicrograph showing cells from sections of raw yam of *D. rotundata* and *D. alata* (a: *D. rotundata, b: D. rotundata, c, D. alata*) (Otegbayo et al. 2005)**

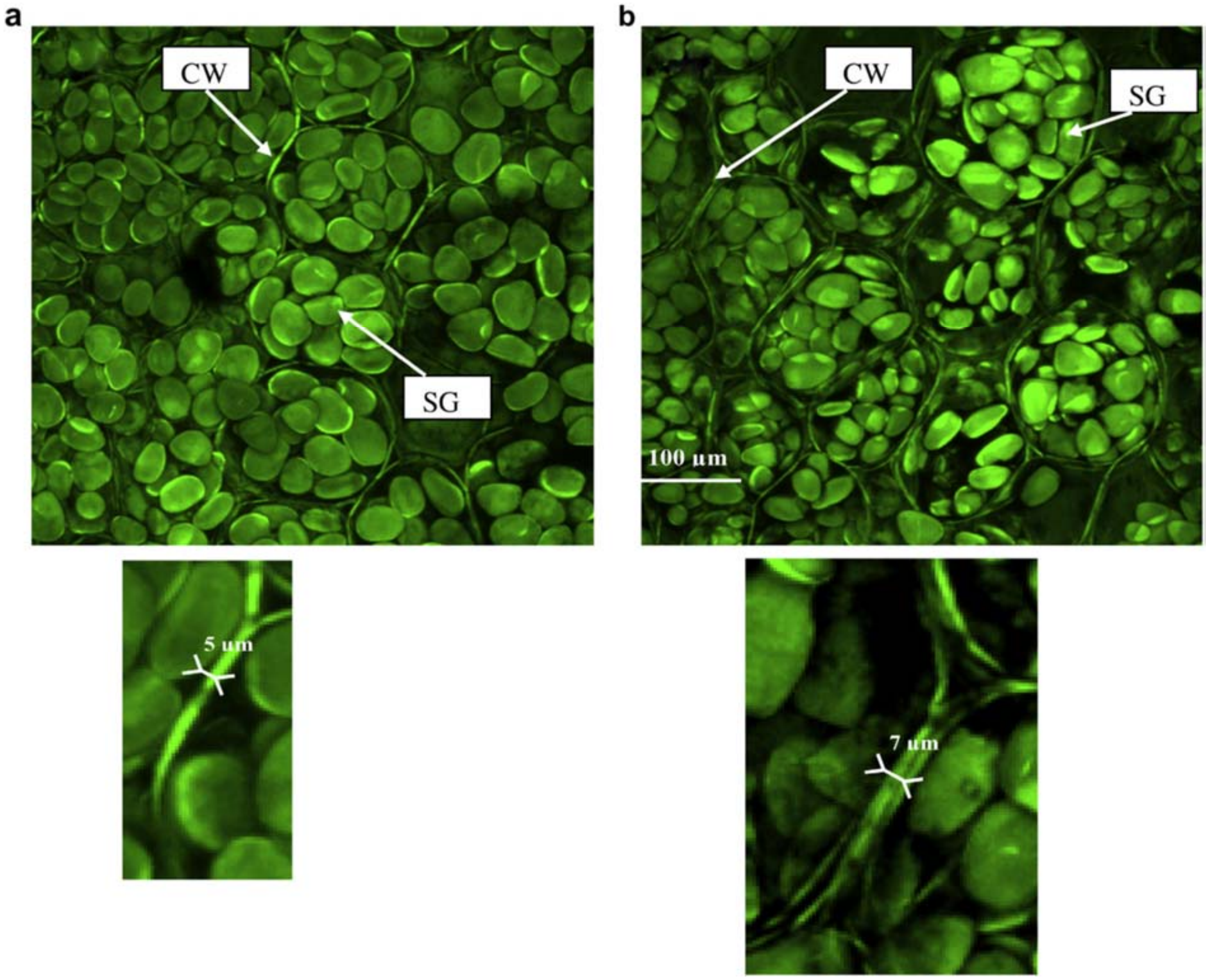



**Fig 4:**
**Fracture of raw yam tubers of Laboco (a) and Florido (b) cultivars observed by Confocal Laser Scanning Microscopy; cell walls (CW) and starch grains (SG) (Akissoe et al. 2011)**

**Table 3: Characteristics of cells from fresh yam tubers (Otegbayo et al. 2004)**

| Yam species / variety | Mean cell size (μm) | Cell description |
|---|---|---|
| *D. rotundata* | | |
| TDr 93-31 | 88.10 | Cell polyhedral in shape, granules loosely bounded to each other, thin middle lamellae visible, presence of inter-amylar crystals of varying shapes and raphide bundles. |
| TDr 93-79 | 66.96 | Cell polyhedral in shape, granules loosely bounded to each other, middle lamellae visible, presence of inter-amylar crystals of varying shapes and raphide bundles. |
| TDr 99-12 | 103.68 | Cell polyhedral in shape, big granules loosely bounded to each other and scattered, middle lamellae visible, presence of inter-amylar crystals of varying shapes and raphide bundles. |
| TDr 99-9 | 81 | Cell polyhedral and round shaped big cells interspersed with small cells, granules big and loosely bounded to each other, middle lamellae visible, presence of inter-amylar crystals of varying shapes and raphide bundles. |
| TDr 96/02229 | 87.23 | Cell polyhedral in shape, granules closely bounded to each other but not as dense as *D. alata* granules, middle lamellae visible, presence of inter-amylar crystals of varying shapes and raphide bundles. |
| TDr 131 | 72 | Cell polyhedral in shape, small granules closely bound to each other, middle lamellae visible, and presence of inter-amylar crystals, which look like crystal sands. |
| Specie mean | 83.2 | |
| *D. alata* | | |
| 291 | 56.52 | Cell polyhedral in shape, granules loosely bounded to each other, middle lamellae visible, inter-amylar crystals on very few granules. Granule arrangement very similar to *D. rotundata* starch granules |
| TDa 95/00328 | 117.56 | Big and elongated polyhedral cells, granules closely and densely packed together with small intercellular space between them. Middle lamellae visible, interamylar crystals and raphide bundles very prominent. |
| TDa 297 | 63.54 | Small polyhedral and round shaped cells, granules closely packed together but not as close as in other *D. alata* yams (95/00328). |
| TDa 92-2 | 56.69 | Small polyhedral and round shaped cells, granules loosely bound together and scattered as in *D. rotundata* starch granules. |
| TDa 93-36 | 55.56 | Small polyhedral and round shaped cells, granules densely packed together but not as close as in other D*. alata* yams. |
| TDa 85/00250 | 111.96 | Big and elongated polyhedral cells, granules closely and densely packed together with small intercellular space between them. Middle lamellae not too visible, inter-amylar crystals in only very few granules. |
| Specie mean | 77.0 | |

n=10

# 2. PROCESSING CONDITION

Pounded yam is a glutinous dough processed traditionally by cooking pounding and kneading of boiled yam (Figs 4 & 5). Traditionally, the cooking time of the boiled yam is usually between 15 and 20 minutes depending on the variety of yam and the complete pounding process could take about 20 minutes. The boiled yam pieces are pounded, then kneaded to get a glutinous dough. On getting a glutinous dough cold water is usually sprinkled on it, pounded again before adding hot water to soften it to desired consisitency. They add hot water based on the preference of consumers. The pounding step is a very important step in determining the textural quality of the dough; it can affect the smoothness and stretchability of the dough. Kneading step is next in importance to pounding, the kneading can determine the cohesiveness and stretchability of the dough. It is done at intervals, for about one minute, this can be done several times before the completion of the pounding process and it also depend on the pounder since it involves a lot of mechanical energy input and the preference of the consumer. If water is added before a dough is formed, it is believed that the dough will not be stretchable and the traditional processors of pounded yam believe that such pounded yam will retrograde faster.

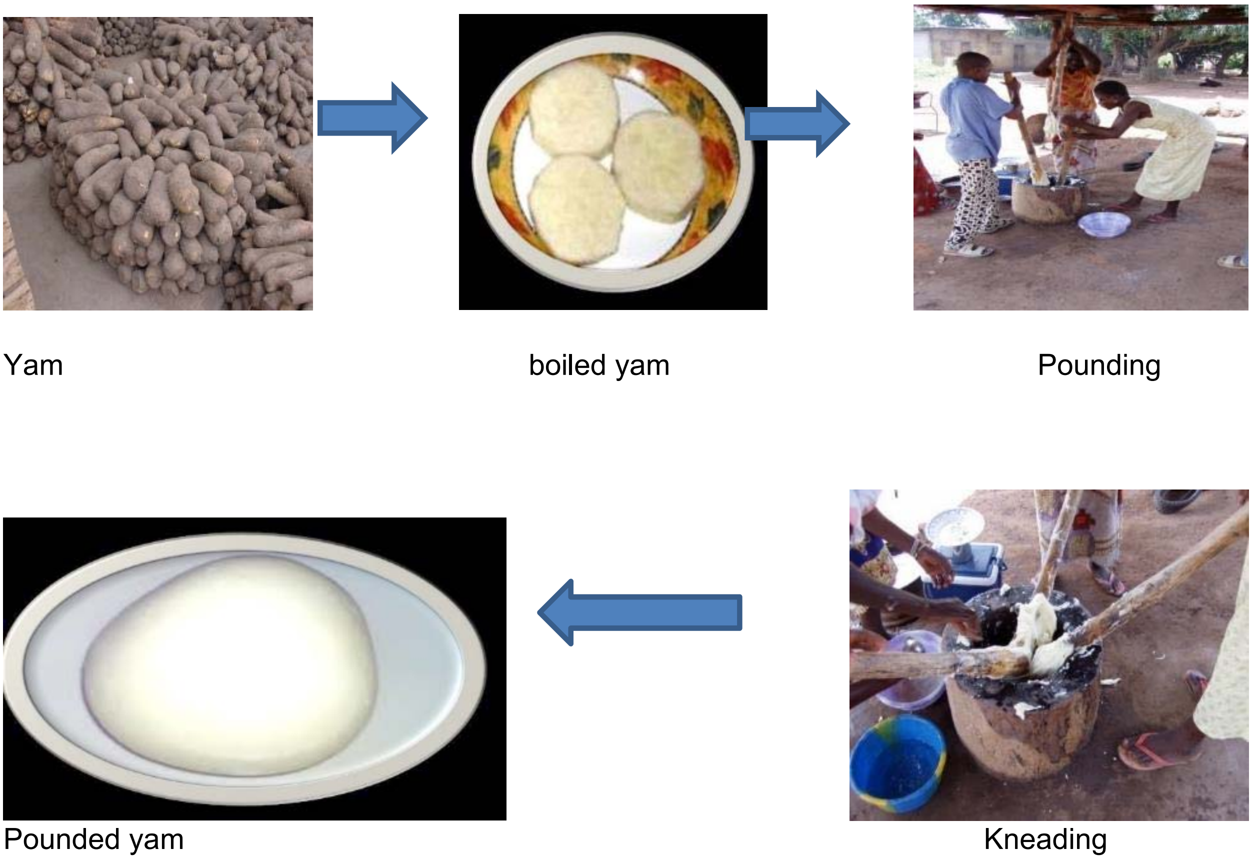



Fig 4: Pictures adapted from Akissoe (2017) presentation on preferred consumer traits, Paris, 2017)

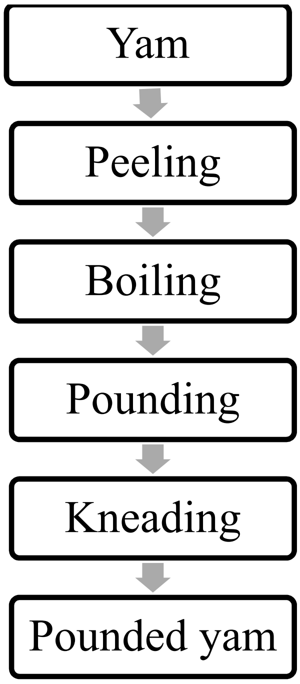



**Fig 5: Flow diagram of Pounded yam processing**

# 3. SENSORY ANALYSIS AND CONSUMER PREFERENCE

Pounded yam is a glutinous dough made by peeling, boiling, pounding and kneading yam tubers. It is a very popular food product in the yam production zone of West Africa, and it is the dish of choice served to honored guests during festivals, weddings and various traditional ceremonies. A consumer of pounded yam will normally want to feel the food to find out if the feel or touch is acceptable before considering the taste or aroma of the product. Hahn et al. (1987) reported that in pounded yam, hand feel is more important than mouthfeel and Ayernor (1976) also explained that a defect in the perceived texture of the food would have an extremely negative impact on the consumer's hedonic responses to the product. Wilkinson et al. (2001), stated that texture determines the identity of the food product and is often cited as a reason for liking or not liking a food and an indicator of food quality. The difference between a slice of boiled yam and pounded yam is the texture. The pounded yam texture is achieved by taking the boiled yam through further processing steps, which are pounding and kneading. This extra step determines whether it will be acceptable or unacceptable to different consumers. The perception of texture is a response to different kinds of physical and physicochemical stimuli that may or may not be related and this can be affected by psychological and cultural factors as well (Peleg, 1983). Texture perception therefore appears to be a procedure of monitoring the entire breakdown process during chewing and the addition of saliva to the food to reach a state that is ready for swallowing (Lillford, 1991).

According to many authors ( Bokanga , 2003, Konan et al, 2003, Otegbayo et al. 2005b, 2007 ; Nindjin et al. 2007 ; Akissoe et al. 2009) textural quality is the most important food quality attribute preferred by consumers of pounded yam. Textural quality a group of physical characteristics that arise from the structural elements of the food, sensed by the feelings of touch, related to deformation, disintegration and flow under a force and are measured objectively by force distance and time" (Bourne, 2002). This definition points closely to the fact that texture is a set of complex sensory properties referred to as textural attributes. Textural attributes important for pounded yam by consumers are: stretchability, smoothness. adhesiveness (stickiness), cohesiveness (mouldability) (Egesi et al. 2003, Otegbayo et al. 2005b, 2007 Nindjin et al. 2007 ; Akissoe et al. 2009). The textural attributes and their definition are presented in Table 4. In Nigeria, Taste as food attribute does not apply to pounded yam in Nigeria because it is eaten with soup and this masks off the taste. Taste can only be important an important food quality attribute in boiled yam.

The authors Onayemi (1985), Konan et al. (2003), Egesi et al. 2003, Otegbayo et al. 2005b, 2007 Nindjin et al. 2007 ; Akissoe et al. 2009) were unanimous in their description of pounded yam with good textural quality which they described as moderately soft, cohesive, stretchable, smooth and with a reasonable degree of adhesiveness. However, amongst the textural attributes identified in pounded yam, stretchability of the pounded yam ranked as the most important textural attribute (Otegbayo et al. 2010, Key informant (KII), Market interview (MI) and Focus group discussion (FGD) conducted for WP1). Nindjin et al. 2007, Otegbayo et al (2011) and Akissoe et al, (2009) studied changes in biochemical composition of yam during storage.

Table 4 : Textural attributes preferred in pounded yam by consumers

| | | |
|---|---|---|
| **Mechanical properties** | Textural Attribute | Definition |
| | Hardness | Force required to compress a sample |
| | Adhesiveness | Degree to which particles the pounded yam stick to the hand |
| | Stretchability | Distance to which the deformed material can be stretched |
| | Cohesiveness | The ease of molding the pounded yam, or how moldable the pounded yam is |
| **Geometric properties** | | |
| | Smoothness | Absence of lumps |
| | Fibrousness | Presence of fibre strands |
| | | |

Source : Otegbayo et al. 2005b

They reported an increase in dry matter, but did not evidenced any variation in protein, amylose and fat contents of the yam varieties. Pounded yam made from stored yam tubers were much more preferred than those made from fresh yam tubers. Pounded yam samples from fresh *D. rotundata* (the yam species that is preferred for making pounded yam (Dansi, 2001 ; Hounhouigan et al.2003, Akissoe et al.2011, Brunschweiler et al. 2006) were described as cohesive, moderately hard but stiff (rigid), stretchable, less deformable and smooth, while those from stored tubers could be described as smooth, cohesive, moderately soft but firm, deformable and more stretchable and less sticky than those from fresh tubers. However all these authors (Onayem et al (1987), Nindjin et al, (2003), Akissoe et al. (2008) Akissoe et al. 2011, Brunschweiller et al. 2006, Otegbayo et al., 2011) reported that pounded yam produced from *D.rotundata* tubers were firm, cohesive, doughy, and stretchable than those made from D. *alata* tubers. Otegbayo et al. (2010, 2011) however reported variability in textural qualities among yam varieties within both *D. rotundata* and *D. alata* species.

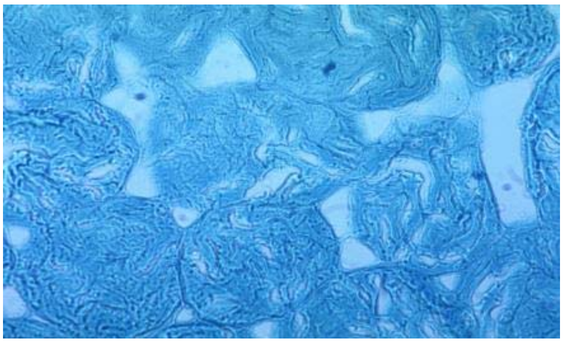
# 4. PRODUCT CHARACTERIZATION AND RELATIONSHIP WITH SENSORY EVALUATION

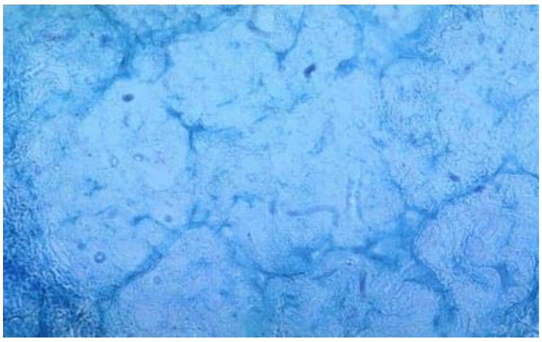
## 4.1. Evolution of composition and structure with processing

When plant foods are cooked there is initial loss of firmness due to membrane disruption and loss of turgor (Greve et al., 1994). This result in changes in the cell walls particularly the middle lamella. In the case of starchy material, gelatinisation of starch occurs in parallel. The final texture is therefore dependent on the relative importance of each factor contributing to the texture and the degree to which each has been changed by the processing method used.

***Boiled yam***: Otegbayo et al. (2005a) and Brunscheweiller et al. (2006) studied the microstucture and histology of boiled yam and pounded yam and its relationship with the textural quality of these products. They based their observation and result on the effect of processing on the structure-texture relationship in cooked potatoes studied by microstructure (Reeve, 1977 ; Burton, 1989 ; Lamberti et al. 2004). The microstructure of the boiled yam samples in both yam species showed the characteristic loss of structural integrity with cellular disorganization. Otegbayo et al. (2005a) and Akissoe et al. (2011) reported that the microstructure of boiled yam samples that were mealy showed clear loss of the typical reticular microscopic structure (Fig. 6a,b). There was cell wall distension and complete cell separation at the middle lamella. The cells became "rounded off" and turgid. The starch granules became packed into a mass of dense amorphous matter and looked like a soft solid comprising clusters of usually single and intact cells. In the waxy varieties, the microstructure showed no cell separation, and some cells were still partly attached to each other instead of separating while some tended to round off towards spherical shapes but remained partly attached to each other (Fig. 6a,b). This may be as a result of the only partial dissolution of wall polymers, many of which are involved in cell adhesion and cell wall distension due to swelling of the gelatinized starch as a result of water uptake during cooking (Otegbayo et al. (2005a) and Akissoe et al. (2011) Burton (1989) and Brett and Waldron (1996) reported that by this time, the polyuronides of the cell walls and the middle lamellae had broken down sufficiently so that they could no longer provide tissue cohesion. This is similar to what was reported in potatoes by previous authors on mealy and waxy potatoes. Hence they concluded that the differences observed in the microstucture of these boiled yam samples can be used as an indicator of their textural quality.

***Pounded yam :*** Brunschweiler et al (2006), stated that the basic difference between the microstructure of boiled yam and pounded yam lies in the arrangement and integrity of the parenchyma cells in connectivity with the starch phase. These authors further stated that during the pounding of the yam, the mechanical energy imputed leads to strong disintegration of the cells ; this contributes to the release of swollen granules and formation of continuous phase that governs the cohesion of pastes (fig 7 a-h).





(a) (b

**Fig 6 (a) Photomicrograph of boiled yam with good textural quality (mealy) (b) Photomicrograph of boiled yam with unacceptable textural quality (waxy) (Otegbayo et al. (2005a)**

It was reported that the microstructure of pounded yam made from D. *rotundata* varieties revealed that cells were less extensively disintegrated compared to pounded yam from D. *alata* varieties in which the cells were extensively disintegrated ( Fig7a-c). Similarly, Otegbayo (2004) observed that the cells of *D. rotundata* varieties which gave pounded yam with acceptable textural quality were less disintingrated compared to *D.alata* varieties or other D.rotundata varieties that gave pounded yam of less acceptable textural quality where the cells were extensively disintegrated (fig8c) which produced good textural quality pounded yam.

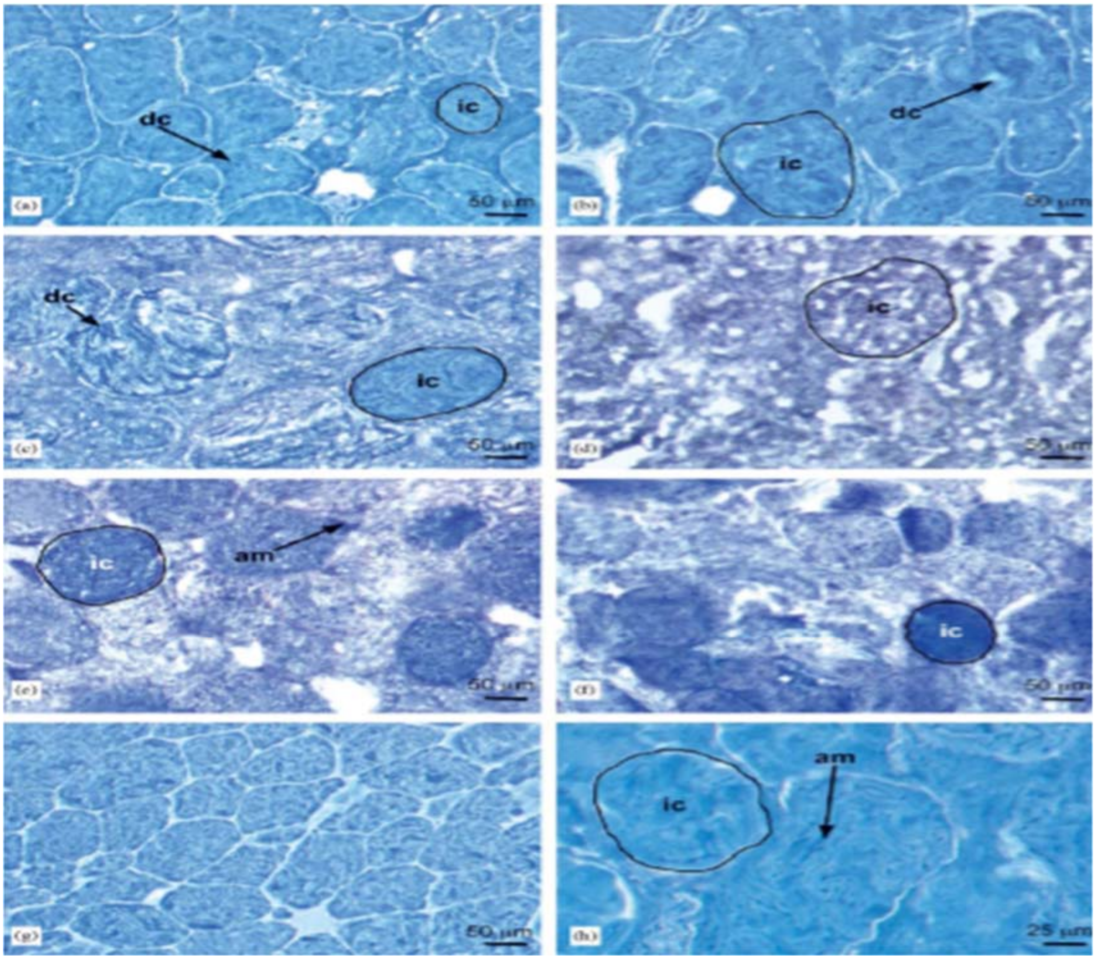
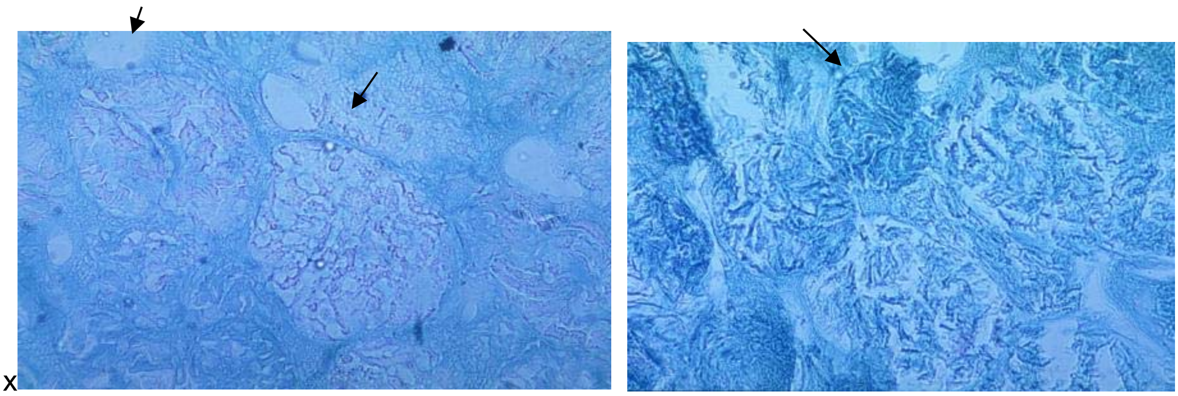



**Fig. 7. Light micrographs of cryostat-sections (10mm) of yam pastes prepared with the blade mixer method and stained with iodine of the varieties: (a) Kponan, (b) Krengle` , (c) 156 of D. cayenensis-rotundata, and of (d) A5 and (e) Betebete` of D. alata. In (f) a traditionally prepared yam paste from Betebete`` is shown. On micrograph (g) a non-disintegrated tissue structure and on (h) an amplified image with pronounced phase separation of amylose and amylopectin in a paste of variety Krengle` is shown (amylose rich zones, ic intact cells, dc disrupted cells)**

Source: Brunschweiller et al. (2006)

x



(a) (b)

**Fig 8 (a) Microstructure of pounded yam made from TDr 99-9 *(D. rotundata*) with acceptable textural quality (arrow shows cells with less disintegration) (b) : Microstructure of pounded yam made from TDr 131(*D. rotundata*) with unacceptable textural quality (arrow shows extensive cell disintegration)**

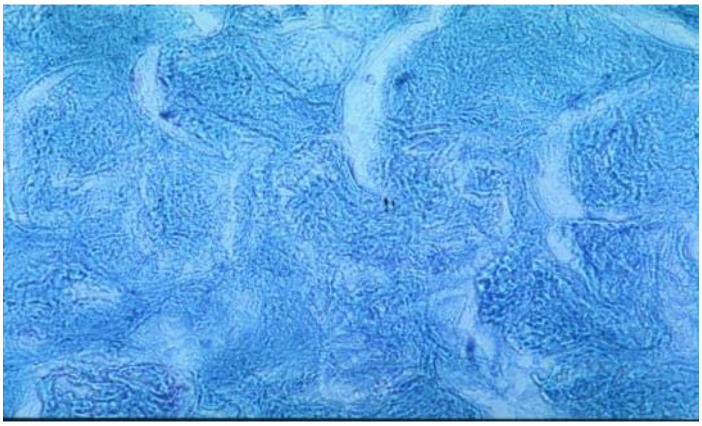


**Fig 8c: Microstructure of pounded yam made from TDa 85/00250 (*D. alata*) with unacceptable textural quality.**

## 4.2. Instrumental Texture assessment and relationship with sensory evaluation

Although texture is primarily a sensory attribute, both sensory and objective (instrumental) methods are used for quantifying it in foods. The sensory method is the only direct method of measuring texture, however instrumental methods have some advantages of reducing variations among measurements due to human factors, are more precise and can provide a common language among researchers (Bourne, 1982). Akissoe et al. (2011) and Otegbayo et al. (2007) evaluated the textural quality of pounded yam by both instrumental and sensory evaluation methods. The authors both used the TA. XT2*i* texturometer. The TA. XT2*i* texturometer/ texture Analyzer measures texture by simulating the masticating action of the human jaw, which follows a sine-wave speed pattern (Bourne, 1978; Bourne, 1990). The curve generated by the texturometer is a plot of force as a function of time hence it was called texture profile. Akissoe et al. (2011) used the texturometer to measure the springiness and stickiness of the pounded yam, while they evaluated firmness of pounded yam samples through an extrusion test with an Instron Universal testing machine (Canton, USA). Brunschweiler et al. (2007) also used the Universal testing machine (ZwickZolio, Zwick, GmbH, DE-Ulm) equipped with 100N load cell to measure the firmness of pounded yam samples. Otegbayo et al. (2007) used the instrumental texture profile analysis method using the TA. XT2*i* texture analyzer/texturometer. TPA parameters (cohesiveness, hardness, springiness, stringiness, adhesiveness, modulus of deformability) were calculated using the computer software Texture Expert Exceed version (Stable Micro Systems), which allows capturing, storage and analysis of real-time data generated from the experimental runs with the texture analyzer. The spherical balls of pounded yam were flattened to 20–25-mm wide and 30-mm thick before evaluation of textural quality. Consistent thickness and diameter was necessary in order to get consistent results because compression tests are usually geometry and dimension sensitive (Bourne 2002). Each sample was placed on a stationary horizontal plate loaded and unloaded by moving a flat plate (HDP/90 heavy-duty platform base). A flat-ended 300-mm high and 75-mm diameter aluminium cylinder plunger (probe) was used to make contact with the food sample. The plunger height was 45 cm, and the speed was 1.0 mm/s. A two-bite cycle was employed. The time between the two strokes was 1.5 s, and the stress that developed in the food sample was measured as the sample was compressed. The force was measured as compression. After this "first bite," the load was removed from the sample and allowed to relax somewhat. As the plunger pulled away from the surface of the sample, any tension due to stickiness was recorded. The second bite then compressed the sample again before allowing it to relax. The resistance during deformation of the food was monitored throughout this two-bite cycle. Fifteen replicates were analyzed per sample.

In their study on instrumental texture profile analysis on Pounded yam, Otegbayo et al (2007) extracted five parameters (cohesiveness, hardness, springiness, stringiness, adhesiveness, modulus of deformability) from the TPA force-time curve. They defined these parameters as follows:

*Cohesiveness*: The ratio of the positive force areas during the second compression to that during the first compression (2/1) or how well a product withstands a second deformation relative to how it behaved under the first deformation.

*Adhesiveness*: Adhesiveness is defined in ITPA as the negative force area of the first bite (Bourne 1978). It represents the force necessary to pull the plunger (finger in sensory evaluation) away from the sample.

*Hardness*: The peak force during the first compression of the product is the hardness.

*Springiness*: The distance that the food recovered in its height during the time that elapsed between the end of the first bite and the start of the second bite is defined as springiness (Bourne 1978).

*Stringiness*: is the distance a product stretches as the compressing plunger is pulled away at the end of the first bite or the distance the product was extended during decompression before breaking off (Bourne 1978).

*Deformability*: The modulus of deformability ((Mohsenin and Millat 1977; Mohsenin 1986) for the pounded yam made from the yam varieties was calculated as the slope of the force–compression curve at 10% strain. This was used because at this point, the compression on the pounded yam was not great enough to cause a permanent deformation (i.e., break or rupture the pounded yam). This parameter was therefore used to measure the stiffness (rigidity) or firmness of the pounded yam. The steeper the slope, the stiffer or more rigid the product will be, the higher the modulus of deformability (D), and therefore the less deformable the product.

They stated that the textural qualities of pounded yam can be predicted and described by observing the shape of the TPA curve. Fig 10a shows the typical TPA curve of a pounded yam with good textural qualities while fig 10b shows that of pounded yam with poor textural quality. Fig 10a, illustrates a product that is moderately firm, highly deformable (low modulus of deformability) with a reasonable degree of adhesiveness, cohesiveness and stringiness (resilience). Area 2 is almost the same size as area 1 indicating a good degree of cohesiveness. The steepness of the slope denotes its degree of firmness. The steeper the slope, the firmer the pounded yam. Figure 10b, shows a very soft, sticky, less cohesive (difficult to mould) pounded yam and a highly undeformable product. The softness of the pounded yam is denoted by the concave shape of the initial part of the curve.

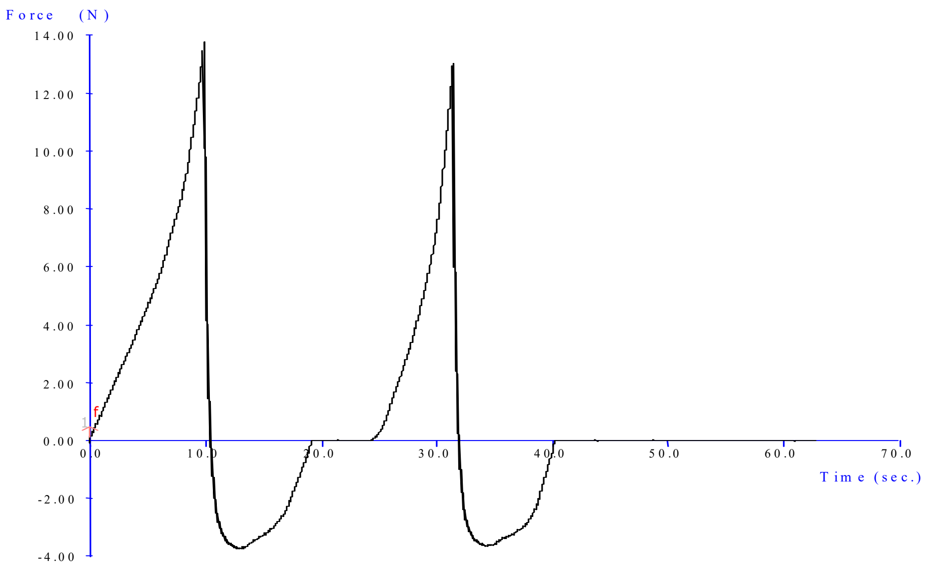



**Fig 10a:TPA curve of pounded yam of good textural quality**

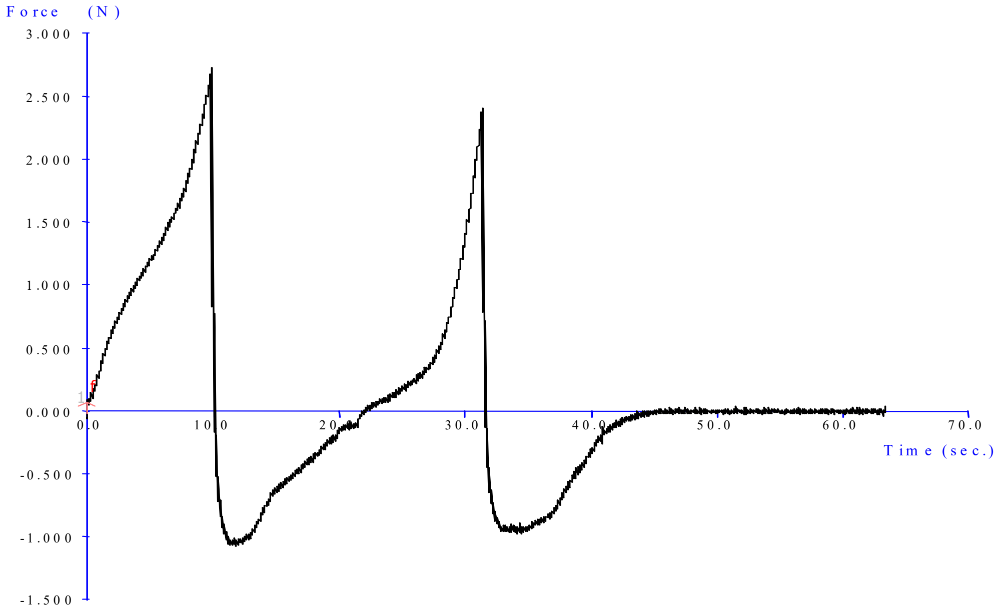



**Fig 10b:TPA curve of pounded yam of poor textural quality**

## 4.3. Correlations between ITPA and STPA

According to Akissoe et al.(2011) there was no correlation between instrumental texture measurement and sensory analysis in pounded yam and made from *D. rotundata* (Laboco, Gnidou, Morokoro and *D.alata* (Florido). Based on information from processors, that yam tubers that will be good for pounded yam will be very mealy, these authors hypothesized that DMA could be used to predict the textural properties of yam tubers; however they concluded that there was no correlation between the textural properties of the pounded yam samples and DMA results. However, Otegbayo et al. (2007) using the Texture profile analysis method reported correlation between instrumental TPA (ITPA) measurement and sensory texture profile analysis (STPA) measurement of pounded yam samples made from fresh and stored tubers of D.rotundata and *D.alata* (Table5a-d). They stated that there were significant positive correlations between the five dominant ITPA parameters (hardness, cohesiveness, springiness, stringiness and adhesiveness) and the sensory parameters (adhesiveness or stickiness, stretchability, cohesiveness and hardness). The modulus of deformability also correlated with the stretchability and sensory hardness. This shows that the harder the pounded yam, the higher the modulus of deformability and the less deformable (stiffer) the pounded yam. It was also observed that the higher the stringiness of the pounded yam (ITPA), the higher its stretchability (STPA). Hence they concluded that both ITPAand STPA can be used interchangeably to measure the textural quality of pounded yam.

**Table 5a: Correlation co-efficients (r) between Sensory and Instrumental textural parameters for pounded yam made from fresh tubers of *D. rotundata*.**

| No | *Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Instrumental | | | | | | | | | | |
| 1 | Hardness | 1.00$^{**}$ | | | | | | | | | |
| 2 | Deformability | 0.95$^{**}$ | 1.00$^{**}$ | | | | | | | | |
| 3 | Cohesiveness | 0.80$^{**}$ | 0.70$^{*}$ | 1.00$^{**}$ | | | | | | | |
| 4 | Adhesiveness | 0.95$^{**}$ | 0.83$^{**}$ | 0.83$^{**}$ | 1.00$^{**}$ | | | | | | |
| 5 | Stringiness | 0.76$^{*}$ | 0.71$^{*}$ | 0.91$^{**}$ | 0.70$^{*}$ | 1.00$^{**}$ | | | | | |
| 6 | Springiness | 0.81$^{**}$ | 0.71$^{*}$ | 0.99$^{**}$ | 0.86$^{**}$ | 0.86$^{**}$ | 1.00$^{**}$ | | | | |
| | Sensory | | | | | | | | | | |
| 7 | Stickiness | 0.79$^{**}$ | 0.78$^{*}$ | 0.72$^{*}$ | 0.65 | 0.89$^{**}$ | 0.69$^{*}$ | 1.00$^{**}$ | | | |
| 8 | Cohesiveness | 0.80$^{**}$ | 0.77$^{*}$ | 0.92$^{**}$ | 0.72$^{*}$ | 0.91$^{**}$ | 0.89$^{**}$ | 0.90$^{**}$ | 1.00$^{**}$ | | |
| 9 | Elasticity | 0.44 | 0.52 | 0.70$^{*}$ | 0.31 | 0.83$^{**}$ | 0.66$^{*}$ | 0.73$^{*}$ | 0.86$^{**}$ | 1.00$^{**}$ | |
| 10 | Hardness | 0.62 | 0.66$^{*}$ | 0.82$^{**}$ | 0.53 | 0.94$^{**}$ | 0.77$^{*}$ | 0.85$^{**}$ | 0.95$^{**}$ | 0.95$^{**}$ | 1.00$^{**}$ |

Level of significance: $^{*}$at 0.05, $^{**}$at 0.01

*Nos 1-10 rep instrumental and sensory texture parameters

**Table 5b:Correlation co-efficient (r) between Sensory and Instrumental textural parameters for pounded yam made from fresh *D.alata* yams**

| No | *Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Instrumental | | | | | | | | | | |
| 1 | Hardness | 1.00$^{**}$ | | | | | | | | | |
| 2 | Deformability | 1.00$^{**}$ | 1.00$^{**}$ | | | | | | | | |
| 3 | Cohesiveness | 0.40 | 0.42 | 1.00$^{**}$ | | | | | | | |
| 4 | Adhesiveness | 0.88 | 0.88$^{**}$ | 0.71$^{*}$ | 1.00$^{**}$ | | | | | | |
| 5 | Stringiness | 0.59 | 0.60 | 0.92$^{**}$ | 0.76$^{*}$ | 1.00$^{**}$ | | | | | |
| 6 | Springiness | 0.47 | 0.49 | 0.99$^{**}$ | 0.73$^{*}$ | 0.93$^{**}$ | 1.00$^{**}$ | | | | |
| | Sensory | | | | | | | | | | |
| 7 | Stickiness | 0.63 | 0.66$^{*}$ | 0.82$^{**}$ | 0.69$^{*}$ | 0.89$^{**}$ | 0.89$^{**}$ | 1.00$^{**}$ | | | |
| 8 | Cohesiveness | 0.43 | 0.48 | 0.74$^{*}$ | 0.49 | 0.92$^{**}$ | 0.81$^{**}$ | 0.96$^{**}$ | 1.00$^{**}$ | | |
| 9 | Elasticity | 0.52 | 0.58 | 0.83$^{**}$ | 0.62 | 0.58 | 0.89$^{**}$ | 0.98$^{**}$ | 0.95$^{**}$ | 1.00$^{**}$ | |
| 10 | Hardness | 0.55 | 0.58 | 0.75$^{*}$ | 0.57 | 0.81$^{**}$ | 0.83$^{**}$ | 0.98$^{**}$ | 0.99$^{**}$ | 0.97$^{**}$ | 1.00$^{**}$ |

Level of significance: $^{*}$at 0.05, $^{**}$at 0.01. *Nos 1-10 rep instrumental and sensory texture profile parameters.

**Table 5c: Correlation co-efficients (r) between Sensory attributes and Instrumental textural parameters for pounded yam made from stored tubers of *D. rotundata*.**

| No | *Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Instrumental | | | | | | | | | | |
| 1 | Hardness | 1.00** | | | | | | | | | |
| 2 | Deformability | 0.97** | 1.00** | | | | | | | | |
| 3 | Cohesiveness | 0.58 | 0.48 | 1.00** | | | | | | | |
| 4 | Adhesiveness | 0.08 | -0.02 | 0.70** | 1.00** | | | | | | |
| 5 | Stringiness | 0.98 | 0.35 | 0.95** | 0.60 | 1.00** | | | | | |
| 6 | Springiness | 0.46 | 0.36 | 0.99** | 0.78** | 0.95** | 1.00** | | | | |
| | Sensory | | | | | | | | | | |
| 7 | Stickiness | 0.69** | 0.61 | 0.96** | 0.61 | 0.90 | 0.92 | 1.00** | | | |
| 8 | Cohesiveness | 0.58 | 0.48 | 0.96** | 0.65 | 0.87** | 0.92 | 0.97** | 1.00** | | |
| 9 | Elasticity | 0.71** | 0.70* | 0.84** | 0.57 | 0.71** | 0.78** | 0.92** | 0.87** | 1.00** | |
| 10 | Hardness | 0.69* | 0.67 | 0.87** | 0.56 | 0.77** | 0.81** | 0.96** | 0.71** | 0.99** | 1.00** |

Level of significance: *at 0.05, **at 0.01. *Nos 1-10 rep instrumental and sensory texture profile parameters

**Table 5d: Correlation co-efficient (r) between Sensory and Instrumental textural parameters for pounded yam made from stored *D. alata* yams.**

| No | *Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Instrumental | | | | | | | | | | |
| 1 | Hardness | 1.00** | | | | | | | | | |
| 2 | Deformability | 0.95** | 1.00** | | | | | | | | |
| 3 | Cohesiveness | 0.06 | -0.09 | 1.00** | | | | | | | |
| 4 | Adhesiveness | 0.04 | 0.12 | 0.67** | 1.00** | | | | | | |
| 5 | Stringiness | 0.82 | 0.67** | 0.61 | 0.33 | 1.00** | | | | | |
| 6 | Springiness | -0.12 | 0.25 | 0.95** | -0.85** | 0.95** | 1.00** | | | | |
| | Sensory | | | | | | | | | | |
| 7 | Stickiness | 0.32 | 0.31 | 0.83** | 0.87** | 0.69 | 0.76 | 1.00** | | | |
| 8 | Cohesiveness | 0.27 | 0.25 | 0.85** | 0.90** | 0.64 | 0.82** | 0.99** | 1.00** | | |
| 9 | Elasticity | 0.64 | 0.58 | 0.70** | 0.65 | 0.85 | 0.61 | 0.88** | 0.88** | 1.00** | |
| 10 | Hardness | 0.48 | 0.43 | 0.82** | 0.80** | 0.80 | -0.12. | 0.98** | 0.97** | 0.95** | 1.00** |

Level of significance: *at 0.05, **at 0.01

*Nos 1-10 rep instrumental and sensory texture profile parameters.

## 4.4. Relationship between composition and sensory evaluation

There has been reports by various authors on the relationship between the composition of yam tuber and the sensory attributes of pounded yam. The reports are summarized in the table 6.

| **Biophysical characteristic** | **Sensory attribute** | **Relationship** | **Reference** |
|---|---|---|---|
| **1. Microstructure** | Textural quality | | |
| Starch granule size | | *D. rotundata* that have larger starch granules gave paste with higher viscosity and firmer and less sticky pounded yam. | Otegbayo et al. 2011<br><br>Amani et al. 2004 |
| Cell integrity | Textural quality | Cells of yam tubers (*D. rotundata*) that are less susceptible to disintegration during mechanical energy input during pounding produce firmer and less sticky pounded yam | Bruschweiler et al. (2006), Otegbayo, (2004) |
| Rounding "off" of cells during cooking of boiled yam | Textural quality | Cells of yam tubers that produced boiled yam that were mealy were usually rounded off and almost completely separated. In the waxy varieties, they showed no cell separation, and some cells were still partly attached to each other instead of separating | Brunschweiler et al. 2006, Otegbayo et al. 2005a, Akissoe et al, (2011) |
| **2. Physical properties** | Textural quality | | |
| Water binding Capacity (WBC) | Firmness/ stickiness | High water binding capacity of yam starch may imply a soft or less firm pounded yam | Otegbayo et al. (2011) |
| Swelling power | Firmness /viscosity | Starches extracted from *D. rotundata* cultivars have higher swelling power than *D. alata* cultivars which also have higher swelling power than *D. esculenta* starches.<br><br>High swelling power could contribute to increase paste viscosity and firmness of pounded yam, this can also influence the viscosity of the starch which subsequently affects its stretchability | Otegbayo et al. (2011)<br><br>Amani et al. 2004 |
| Pasting characteristics | Textural quality | *D. rotundata* yams that gave paste with high final viscosity, peak viscosity, breakdown and set back viscosity gave pounded yam with good textural quality, of moderate softness, stretchable, cohesive and smoothness, is related to the doughy, firm, stretchability and cohesiveness of pounded yam with good textural quality. | Otegbayo et al. (2006) Salda et al.(1998) |

| 3. **Chemical composition** | Sensory attribute | Relationship | Reference |
|---|---|---|---|
| Dry matter | Textural quality<br><br>Firmness | The higher the dry matter, the firmer the pounded yam | Olorunda et al. (1981), Otegbayo (2004), Brunschweiler et al. (2006) Akissoe et al. (2011), |
| Starch | Firmness | Firmness is negatively correlated with soluble starch | Akissoe et al. (2011) |
| Amylose | Firmness<br><br>Stickiness/ adhesiveness | No correlation between amylose content of raw yam and firmness of pounded yam has been evidenced.<br><br>Pounded yam prepared with high amylose yam may however be less sticky<br><br>In addition, soluble amylose seems positively correlated with sensorial firmness (Akissoé et al., 2011) while other authors did not give evidence of any difference between yam species (Brunschweiler et al. 2006). | Akissoé et al., 2009<br><br>Otegbayo et al. (2011)<br><br>Brunschweiler et al. (2006),<br><br>Akissoé et al., 2011 |
| Pectin | | *D. rotundata* cultivars present a higher level of pectin. High pectin content in the intercellular space would favor separation of sclereid cells that could promote a smooth texture. | Otegbayo et al. (2012)<br><br>Casanas et al. (2002), |
| Crude fiber, Cellulose, ADF, NDF | | Contradictory results about fiber content of the various yam species do not allow to hypothesize about the role of fibers on texture of pounded yam. | Otegbayo et al. (2012)<br><br>Otegbayo et al. (2017) |
| Calcium | smoothness | Higher levels of Calcium are reported for *D. rotundata* compared to *D. alata*.<br><br>It could bind pectin and other soluble dietary fiber in food during cooking and facilitate the presence of solubilizable elements that are important in achieving a smooth texture. | Casanas et al. (2002), Otegbayo et al. (2010) |
| Phosphorus | | The higher phosphorous content of *D. rotundata* varieties might influence the high swelling power and viscosity of the starch resulting in a firm stretchable dough (pounded yam), | Rasper and Coursey, (1967), Otegbayo et al. (2011) |
| 4. Storage of yam tubers (4-6 months) | Textural quality | Changes in biochemical composition of yam tubers occurs during storage such as increase in dry matter, | Onayemi and Idowu (1988) |

| | | | |
|---|---|---|---|
| | | sugar content and non-starchy carbohydrates (Liginin, cellulose, pectin) and decrease in starch, improved the textural quality of pounded yam made from stored tubers. Pounded yam made from stored yam tubers are more preferred by consumers.<br><br>However, changes in biochemical composition of yam tubers during storage is species dependent. | Akissoe et al. 2009, Bruschweiler et al. (2006), Otegbayo et al. (2010) |

# 5. CONCLUSION/SYNTHESIS

Chemical composition of yam has been reported by many authors. In terms of the morphological characteristics of yam starch, from the reports only the granule size can influence the physicochemical and functional properties of the starch which can subsequently affect the textural quality of the final product. The cell integrity of the yam before and after cooking and pounding can be an indicator of textural quality of pounded yam but it is not a rapid or high throughput method. It has been established that dry matter, starch and amylose contents plays a great role in the final texture of yam food products. Non- starchy carbohydrates may also influence the textural quality of pounded yam, pectin was reported to influence smoothness in pounded yam. Various instrumental methods have been used to evaluate textural quality of pounded yam as reported by different authors. The implication of this for RTB food s is that we may need to find out which method correlates with the textural quality that the consumers preferred. From this review it is seen that the perceptions of authors on pounded yam may be different, the traditional eaters of pounded yam regard it as a glutinous dough while some refer to it as a paste, this need to be established. The role of non-starchy carbohydrates and their effect on food quality of pounded yam needs to be investigated. There are a lot of studies still to be done to establish factors that can determine the food quality attributes of pounded yam preferred by consumers.

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