# MECHANICAL AND VISCOELASTIC PROPERTIES OF YAM

# *(Dioscorea alata)*

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## ABSTRACT

*The main mechanical properties and viscoelastic characteristics of two different cultivars of yam has been measured in this work. Using an Instron machine, some different tests has been applied: puncture, uniaxial compression and bending in order to calculate the parameters: maximum stress of penetration, stress and strain at fracture, deformability modulus and the constants "a" and "b" from the Peleg model. It is concluded that the Pico de Botella cultivar has a fracture stress higher (0.57 MPa) than the Diamante 22 cultivar (0.31 MPa) and also the degree of deformation at fracture is higher (32 % versus 21 %). In relation with the constants from the Peleg viscoelasticity model, there are no differences between cultivars, both having the same value of the asintotic stress (a = 0.43) and very similar for the relaxation stress rates (Pico de Botella, b = 0.03 and Diamante 22, b = 0.02).*

**KEYWORDS**

Yam, mechanical properties, viscoelasticity.

## INTRODUCTION

Among the main agricultural products of the Atlantic Coast of Colombia, yam is the most inexpensive and profitable product which is cultivated with corn, cassava or alone. Yam contains better nutritional value (proteins, essential amino acids and minerals) than other roots and tubers such as cassava and potato (Coursey and Ayensu 1972), and literature concerning production and processing is not commonly available (Morales 1992). World-wide production of yam has grown 4.7% annually for the last twenty six years from 1.34 million to 4.42 million Ha. The four major producers of yam are Nigeria, Ghana, Benin and Togo. Colombia is the fifth producer but its expansion was the highest (18.6% annual average) (Corporación PBA 2004).

The high moisture content of yam could be the cause of vulnerability to mechanical damages during processing, handling and storage. Nwandikom (1990) has carried out an extensive work with some cultivars of yam in Nigeria, by using different mechanical techniques: impact load resistance, tissue fracture and compression of tuber tissue. This author concluded that mechanical damage to yam tubers is the major limiting factor of the automatization of its production and increased productivity. Also that mechanical properties (penetration, flexibility, viscoelasticity and uniaxial compression) play a major role in predicting physical damage to tubers and that tubers with more than 70% moisture content must be placed singly. On the other hand, Aluko and Koya (2006), have pointed out that adequate knowledge of their engineering properties is an essential prerequisite for the scientific design and development of equipment for planting and handling yams setts mechanically.

Calzada and Peleg (1978), have interpreted the relationship stress/deformation during the compression of solid foods (potato) and they explained that two antagonistic mechanisms which regulate the levels of stress exist: the internal fractures, that diminish the mechanical strength and the compactation that has the tendency to increase it. A simple model that only contains two constants (a and b) has been of great applicability to compare the form of the relaxation curves for different materials such as potatoes, apple, pear, etc., (Peleg 1979).

Currently, there are not data in the literature of this type of measures in yam; for this reason, in the present work a study to characterize the main mechanical properties of two varieties of fresh yam cultivated in the Atlantic Region of Colombia has been carried out.

## MATERIALS AND METHODS

### Samples

Two varieties of yam *(Dioscorea alata)*: Diamante 22 and Pico de Botella were selected presenting the best characteristics in reduced sugar content to be used in the deep fat frying process (Alvis and Vélez 2006). These samples were acquired in the germoplasm bank of the University of Cordoba (Colombia) and were stored during 90 days to 28ºC until its posterior analysis.

### Mechanical determinations

The *"maximum penetration stress"* ($\sigma_{max}$) of the whole tuber with peel on, and of 3 cm thick slices was measured with two Magness-Taylor probes (7.9 and 4.6 mm diameter) mounted in an Instron machine.

The *"fracture stress"* (σ) was measured by a three-point bending test according to Bruns and Bourne (1975). The sample was cut into bars 0.8 x 0.8 x 40 mm long. The bars were placed on a bridge with the supports 20 mm apart and a descending bar in the center descended until the bar fractured. The fracture stress "σ" for a symmetrical beam of rectangular cross-section is:

$$\sigma = \frac{3FL}{2bh^2} \qquad (1)$$

Where $b$ and $h$ are the dimension of the cross-section and $L$ the length.

The uniaxial compression test compressed 20 mm cubes of yam until fracture and the deformability modulus, and stress and strain at fracture calculated.

In all the previous cases, the tests were made at a deformation speed of 5 cm/min, at room temperature (25ºC) and taking 5 replicates (different batches of yam) of each experiment.

The relaxation test was performed by compressing 20 mm cubes of yam by 20% and holding that degree of compression for 8 minutes while measuring the decay in force (see figure 1).

The viscoelastic properties of solid foods frequently have been demonstrated by relaxation curves (Peleg 1979). An ideal mathematical representation of a physical phenomenon is based on the following:

a. The constants and the equations components, carry meaningful physical information; and

b. The equation is sensitive to physical changes in the system but insensitive to arbitrary parameters.

To apply these conditions to relaxation curves a convenient mathematical procedure has been tested.

a) The relaxation curves have been normalized, i.e. the decaying parameter Y(t) was calculated as follows:

$$Y_{(t)} = \frac{F_0 - F_t}{F_0} \qquad (2)$$

Where $F_t$ is the force recorded after 1 min at relaxation.

b) The typical shape of the function $Y_t$ versus t suggests the simplified mathematical form of Mickley *et al*. (1957):

$$Y_{(t)} = \frac{abt}{1+bt} \qquad (3)$$

Where a and b are constants.

If a = 0 the stress does not relax at all (i.e. in an ideal elastic solid) and if a = 1.0 the stress level eventually reaches zero (e.g. in liquids). For 0<a<1, a represents the asymptotic residual values of $Y_{(\infty)}$. The constant b is the representative of the "rate" at which the stress relaxes (1/b is the time necessary to reach the level of a/2).

One of the mathematical characteristics of equation (4) is that it gives a straight line when plotted in the form:

$$\frac{t}{Y_{(t)}} = \frac{1}{ab} + \frac{t}{a} \qquad (4)$$

**Statistical**

A t-student test was used to detect significant differences of the data. The constants "a" and "b" were calculated by using an electronic Excel page (Microsoft office Excel 2003 program).

## RESULTS AND DISCUSSION

1. Puncture test. Sliced samples showed a decrease in the $\sigma_{max}$ values in comparison with those of whole tuber samples. With the probe of 7.9mm, the $\sigma_{max}$ values were lower for both cultivars (Table 1).

As it is shown from the results of the t–student test, the values of $\sigma_{max}$ for the whole yam with peel, are not significantly differences ($p \leq 0.05$) when using both probe, however when the puncture test is carried out on the tissues, the value of $\sigma_{max}$ is different among varieties, being higher for Pico de Botella, due to that its peel is harder and has less sugar content (0.16) in comparison to Diamante 22 (0.46). These differences could be due to the structure and to the composition of the product or both (Mohsenin 1965).

2. Flexure. The Diamante cultivar has a lower fracture force (9.9 N) and lower deformability (5.5 mm) than the Pico de Botella cultivar (16.0 N and 6.1 mm ). See Table 2. This indicates that the Pico de Botella cultivar fractures to much more stress than Diamante 22 and the latter is also something more flexible because it reaches higher values of deformation up to the fracture moment.

3. Uniaxial compression

These results (Table 2) confirm that the cultivar Pico de Botella is much more resistant to the applied forces to deform the product and therefore, less susceptible to mechanical damages occurring during the crop, manipulation, storage and processing, in agreement with the results reported by Nwandikom (1990). For the variety Pico de Botella, the fracture takes place at higher values of the stress and it allows that the same one can be compressed to higher deformations, while the variety Diamante 22 fractures at degree of compression around 20%. Diehl and Hamann (1979), for fresh potatoes, have reported results close to 30%.

4. Relaxation

Figure 1 shows the experimental curves obtained when the function force (t/Y) (s) versus time (t) is plotted.

The fixed normalized and linealized Peleg equation offers the following results:

Diamante 22: $t/Y = 2.34t + 110.68$ $R^2 = 0.996$ (5)

Pico de Botella: $t/Y = 2.308t + 65.78$ $R^2 = 0.998$ (6)

The coefficient of determination is highly significant (p>0.001) for both cases. Right similar (Peleg 1979) has also obtained for fruits such as apple and pear as well as some tubers like potato.

The Peleg "a" and "b" constants show hardly any differences between the two cultivars (See table 2).

In agreement with the interpretation of these constants and the value of a = 0.6 reported by Peleg (1979) for potato, it can be said that both yam cultivars are closer to a Hookean solid than potato, that which belongs together with the relative little moisture that presents the yam (70%) and their high content of starch (28%) with regard to the potato. Potato is very moisture (75.5%), therefore, viscoelastic, less solid and less starches (22%) that are degraded into sugar.

It seems to be that definitively the mechanical properties of yam and their texture, are mainly governed by the composition of the product which it is in agreement with the conclusions pointed out by (Onayemi *et al*. 1987; Afoakwa and Sefa-Dedeh 2001).



## CONCLUSIONS

The flexion test results are higher for Pico de Botella. Pico de Botella variety is less susceptible of being damaged by effect of manipulation during harvest and storage because it is much more resistant to the applied forces to deform the product and viscoelastic properties of both varieties are next to zero. For this reason, the product tends to behave close to the Hooke solid.

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**Figure captions**

FIGURE 1.

EXPERIMENTAL CURVES FORCE (t/Y) VERSUS TIME (t) ACCORDING TO PELEG MODEL FOR BOTH CULTIVAR

TABLE 1.

RESULTS OF THE MAXIMUM PUNCTURE STRESS ($\sigma_{max}$) EXPRESSED IN MPa. DATA ARE MEAN VALUES (± STANDARD DEVIATION) OF 5 DETERMINATIONS.

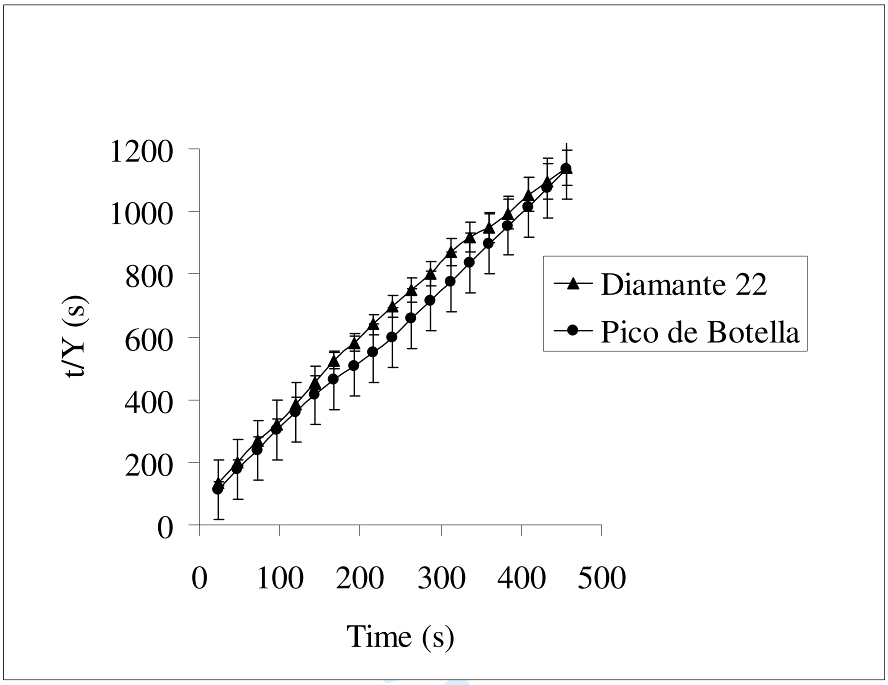
| Cultivar | Whole tuber | | Slice | |
|---|---|---|---|---|
| | Probe Diameter (mm) | | | |
| | 4.6 | 7.9 | 4.6 | 7.9 |
| Diamante 22 | 3.72[a] ± 0.68 | 2.18[a] ± 0.17 | 1.27[a] ± 0.09 | 1.11[a] ± 0.04 |
| Pico de Botella | 3.30[a] ± 0.30 | 2.20[a] ± 0.42 | 1.66[b] ± 0.16 | 1.26[b] ± 0.16 |

Confidence level at p≤0.05; Means followed by different letters in each column were significantly different p≤0.05)

TABLE 2.

MECHANICAL PROPERTIES (FLEXURE, UNIAXIAL COMPRESSION AND RELAXATION) FOR BOTH YAM CULTIVARS. DATA ARE MEAN VALUES (± STANDARD DEVIATION) OF 5 DETERMINATIONS.

| Mechanical Property | Cultivar | |
|---|---|---|
| | Diamante 22 | Pico de Botella |
| FLEXURE | | |
| Fracture force (N) | 9.9 ± 0.7 | 16.0 ± 1.2 |
| Deformability (mm) | 5.5 ± 0.3 | 6.1 ± 0.3 |
| UNIAXIAL COMPRESSION | | |
| Fracture stress (MPa) | 0.31 ± 0.02 | 0.57 ± 0.04 |
| Fracture strain (mm) | 0.21 ± 0.02 | 0.32 ± 0.02 |
| Deformability modulus (MPa) | 1.48 ± 0.13 | 1.78 ± 0.14 |
| RELAXATION | | |
| Peleg "a" | 0.43 ± 0.1 | 0.43 ± 0.1 |
| Peleg "b" | 0.02 ± 0.0 | 0.03 ± 0.0 |


1200
1000
800
600
400
200
0
0
100
200
300
400
500
t/Y (s)
Time (s)
Diamante 22
Pico de Botella