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Comparison of Selected Engineering Properties of Two Species of Cocoyam Essential for Handling of the Tubers

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A B S T R A C T

Production of cocoyam is mainly carried out manually. Adequate knowledge of their engineering properties is a prerequisite for the development of machinery for harvesting and processing of cocoyam. Some engineering properties of cocoyam from two species of cocoyams, namely Colocasia exculenta (taro) and Xanthosoma saggittifoluim (tannia) were compared. The properties investigated include tuber length, width, volume, angle of repose, density, static coefficient of friction, force–deformation behaviour during compression, stiffness moduli and tuber toughness. Xanthosoma sagittifolium was found to have length of 9.66 ± 4.65 cm, width of 4.24 ± 0.55 cm, and thickness of 4.20 ± 0.73 cm; while Colacassia esculenta have length of 8.5 ± 3.30 cm, width 3.52 ± 0.33 cm and thickness of 3.51 ± 0.34 cm. Xanthosoma sagittifolium and Colacassia esculenta was found to have an average moisture content of 57.65 % and 58.91 % (wet basis)respectively. The average mass, volume and density of Xanthosoma sagittifolium are 126.28 g, 123.75 cm^3 and 1.02 g/cm^3 respectively while the mass, volume and density of Colacassia esculenta are 76.21 g, 75.42 cm^3 and 1.01 g/cm^3 respectively. The mean values of coefficient of static friction was 0.31and 0.21 on wood, 0.31and 0.21 on glass, 0.22 and 0.20 on stainless and 0.25 and 0.21 on galvanized iron surfaces for Xanthosoma sagittifolium and Colacassia esculenta respectively. The average values of angle of repose of Xanthosoma sagittifolium and Colacassia esculenta were 14.05 and 11.99; compressive force was 1628.68 N and 1121.08 N; toughness of 11.02 Nm and 6.89 Nm; Young Modulus of 2365.0 N/mm^2 and 11.98 N/mm^2 respectively.

1. Introduction

Cocoyam is a monocotyledonous plant belonging to the *Araceae* family (the aroids) and they are mainly cultivated in the tropic where rainfall is very high (over 2500 mm) per annum. All Cocoyam produces starchy tubers and vegetables which are highly appreciated in the local populations. Cocoyam is a promising food crop which can be produced on large scale in Nigeria (Nwokocha *et al.,* 2008). Cocoyam tolerates shade and therefore can be grown together with cocoa or coffee trees. They are good first crops after forest clearance and their broad leaves protect the field from soil erosion (Mayhew and Anne, 1988). The part of the cocoyam below the ground is referred to as the "corm". There are two main edible types of cocoyam in Nigeria viz *Colocasia exculenta* (taro) and *Xanthosoma saggittifoluim* (tannia). Taro (colocasia spp) is for its edible corms, cornels and leaves as well as for its traditional ceremonial uses. Originated from India and other parts of South East Asia. It is an herb of about 1 – 2 m tall with a cylindrical corm which bears a whorl of large shield shaped leaves on erect petioles. The plant grows best in well drained light textured soils with pH values ranging from 5.5 to 6.5. Cocoyam can tolerate saline soils better than any other crop.

Cocoyam can tolerate flooded and waterlogged areas. The harvesting, handling or processing of the tubers are mostly done manually.In order to develop appropriate technologies for processing agricultural products, it is pertinent to have the full knowledge of the engineering properties of the biomaterial (Davies, 2010). Basic information on size, density and compressive strength are required for the development of grading system for barriers for pulpers (Gosh, 1969). The physical and mechanical properties such as size, friction angle, angle of repose, compressive strength and bulk density are important in the design of handling system and grading (Bahnasawy et al., 2003; Chandrasekar and Viswananthan, 1999). The objective of this study is to determine some physical and the mechanical properties of two varieties of cocoyam viz: Colocasia esculenta and Xanthosoma spp. When rainfall is low, corm is reduced. Among the Taros, the Eddoe type can tolerate drier conditions than the dasheen types (Onwueme, 1978).

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2. Materials and Methods

2.1. Source of Cocoyam

The two varieties of cocoyam namely: *Colocassia esculentum* (Taro) and *Xanthosoma sagittifolium* (Tannia) which are the two most popular varieties were gotten from a farm in Uhe quarters of Igueben Local Government Area of Edo State, Nigeria, where it was kept in a cool place covered with leaves. The two varieties were washed in water, drained, marked and numbered for easy identification.

2.2 Determination of weight

Both the initial and final weight were measured to 0.001 g accuracy using an electronic balance.

2.3 Determination of moisture content

The moisture content of the cocoyam samples were determined by gravimetric method. The initial weight (W_1) of the cocoyam tubers were taken and recorded and the tubers were oven dried at 105 °C for 24 h after which the final weight (W_2) of the tubers were taken. The moisture content was determined on wet basis by using the following equation

Moisture content wet basis =

$$(W_1 - W_2)/W_1 \qquad (1)$$

Where W_1 = Initial weight of material (wet weight)

W_2 = Final weight of material (oven dry weight)

2.4 Determination of geometrical properties

Size:

The dimensions of each tuber were measured in three mutually perpendicular axes using a pair of vernier caliper. For each tuber, the measured dimensions consisted of the length, and three diameters of the transverse section.

Geometric mean diameter, *Dg* of the tubers was calculated by using the following relationship given by (Mohsenin, 1978; Sreenarayanan, 1985; Sharma, 2005) as:

$$D_g = (WTL)^{1/3} \qquad (2)$$

Sphericity:

According to [1], the degree of sphericity, Ø is expressed as follows:

$$Ø = [(WTL)^{1/3}]/L \qquad (3)$$

Also, the surface area, S is given by

$$S = \pi D_g^2 \qquad (4)$$

2.5 Volume and Density

Water displacement method as described by Dutta *et al*.(1988) and Shepherd and Bhardwaj (1986). Water is poured in a measuring cylinder to a certain level and each of the cocoyam tuber is then immersed. The change in the water level is read directly from the measuring cylinder and recorded. The volume of water displaced is equal to volume of the material.

2.6 Determination of angle of repose and frictional properties

The Coefficient of static friction is the ratio of the force required to slide the bulb over a surface divided by the normal force pressing the tuber against the surface. The static coefficient of friction of both species of cocoyam was determined on four structural surface materials, namely: wood, glass, galvanized steel and stainless steel, which are commonly used as materials of construction for crop planting and handling equipment. This was accomplished using the inclined plane method, earlier described by Zoerb, (1967) and widely adopted in the literature [Oje and Ugbor,1991; Ajav,1998; Olajide and Ade-Omowaye 1999). The material surface was placed to tilting table. The table was tilted slowly manually until movement of the whole tuber mass was initiated. The coefficient of friction was the tangent of the slope angle of the table measured with a protractor.

2.7 Measurement of angle of repose

The method of Kaleemullah and Gunansekar (2002) was adopted to determine the angle of repose. The tuber was placed at the center of a galvanized sheet. The tuber was raised slowly so that a natural heap was formed. The angle of repose of tuber was calculated from the height of an inclined plane. There are numerous methods for measuring angle of repose and each produces slightly different results. Results are also sensitive to the exact methodology of the experimenter. As a result, data from different labs are not always comparable. One method is the triaxial shear test, another is the direct shear test. If the coefficient of static friction is known of a material, then a good approximation of the angle of repose can be made with the following function in Equation 5.

$$\tan(\theta) = \mu_s \qquad (5)$$

Where: μ_s is the coefficient of static friction *and* θ is the angle of repose.

3. Results and Discussion

A summary of the results for all the measured parameters for *Xanthosoma sagittifollium* at average moisture content 57.65 % wet basis and *colocassia esculentum* at average moisture content of 58.91 % wet basis are shown in Tables 1 and 2 respectively.

3.1 Physical Properties

Size dimensions:

The mean dimension of about twelve tubers were measured for two varieties of cocoyam: *Colacassia esculenta* and *Xanthosoma sagittifolium*. Tables 1 and 2 shows the mean, minimum, maximum and standard deviation values of each. *Xanthosoma sagittifolium* was found to have length of 9.66 ± 4.65 cm, width of 4.24 ±0.55 cm, and thickness of 4.20 ± 0.73 cm. Also, the dimensions of *Colacassia esculenta* are: length 8.5 ± 3.30 cm, width 3.52 ± 0.33 cm and thickness of 3.51 ± 0.34 cm. *Xanthosoma sagittifolium* is seen to have a higher mean length of 9.66 cm and higher maximum length of 19.5 cm than *Colacassia esculenta* which has a mean length of 8.50 cm and a maximum length of 17.50 cm. This agrees with the observation of Onwueme (1978) that *Xanthosoma sagittifolium* can be distinguished by a larger tuber size. Little difference is also noticed in the width and thickness as mean width and thickness of *Xanthosoma sagittifolium* are 4.24 cm and 4.20 cm respectively while that of *Colacassia esculenta* are 3.52 cm and 3.51 cm respectively.

Table 1: Physical properties of *Colocassia esculentum*

Properties	Mean	Min	Max	SD
Length (cm)	9.66	4.7	19.5	4.65
Width(cm)	4.24	3.25	5.24	0.55
Thickness(cm)	4.2	3.24	6.07	0.73
Geometric mean	5.46	3.88	8.51	1.30
Sphericity	0.63	0.42	0.98	0.16
Mass	126.28	36.29	361.08	93
Volume	123.75	35	340	87.7
Density	1.02	0.68	1.34	0.15
Moisture Content	57.65	38.89	69.01	9.00
Angle of repose	14.05	9.87	21.8	3.47
Coefficient of Friction				
Wood	0.31	0.14	0.47	0.12
Glass	0.32	0.17	0.49	0.12
Stainless	0.22	0.11	0.38	0.09
Galvanized iron	0.25	0.17	0.4	0.06
Compressive Force	1628.68	492.8	2742	694.04

Table 2: Physical properties of *Xanthosoma sagittifolium*

Properties	Mean	Min	Max	SD
Length	8.50	4.56	17.50	3.30
Width	3.52	2.71	3.91	0.33
Thickness	3.51	2.78	4.03	0.34
Geometric mean	4.65	3.68	6.18	0.67
Sphericity	0.59	0.35	0.87	0.13
Mass	76.61	28.92	167.48	37.13
Volume	75.42	40.00	170.00	35.83
Density	1.01	0.72	1.23	0.12
Angle of repose	11.99	7.22	29.05	6.44
Moisture Content	58.91	41.61	84.51	12.86
Coefficient of friction				
Wood	0.21	0.11	0.56	0.12
Glass	0.21	0.10	0.58	0.14
Stainless	0.20	0.08	0.46	0.11
galvanized iron	0.21	0.10	0.56	0.13
Compressive Force	1121.08	295.80	2076.20	575.13

SD= Standard Deviation

Mass, volume and density:

The average mass and volume of *Xanthosoma sagittifolium* are 126.28 g and 123.75 cm^3 respectively while the mass and volume of *Colacassia esculenta* are 76.21 g and 75.42 cm^3 respectively. This shows a large gap in their masses and volume repectively. Hence *Xanthosoma sagittifolium* are larger in tuber sizes and weightier than Colacassia esculenta. This again agrees with assertion by Mayhew and Anne (1988). The densities of the various tubers were derived from ratio of mass to volume. The two varieties showed a close range of values for density: 1.02 g/cm^3 and 1.01 g/cm^3 for *Xanthosoma sagittifolium* and *Colacassia esculenta* respectively. This is closely related to those gotten from yam sets in Aluko and Koya (2006) and constitutes an important consideration for material selection, machine frame development, and hopper capacity design in developing a cocoyam planter.

Coefficient of friction and angle of repose:

For *Xanthosoma sagittifolium* , the mean values of coefficient of static friction was 0.31 on wood, 0.31 on glass, 0.22 on stainless and 0.25 on galvanized iron surfaces. Similarly *Colacassia esculenta* showed values of 0.21 on wood, 0.21 on glass, 0.20 on stainless and 021 on galvanized iron sheet. Although Aluko and Koya (2006) reported average coefficient of static friction of yam set as 0.42 on galvanized steel, 0.38 on wood and Formica, we cannot really make any meaningful comparism because the yam set where cut in pieces, it has also been air dried for at least four days and they were used to check the drying characteristics. The surfaces used also were different. The use of stainless is very important in food processing especially in the production of cocoyam flour and starch. The stainless material does not rust easily, good machinability and prevents contamination of food products. They are therefore now increasingly used for many processing equipment though they are more expensive.

The average values of angle of repose of *Xanthosoma sagittifolium* and *Colacassia esculenta* were 14.05^o and 11.99^o respectively.

3.2 Mechanical Properties

Values of the mechanical properties of *Xanthosoma sagittifolium* and *Colacassia esculenta* are shown in the Tables 3 and 4. The measured parameters were the force at peak (Rupture force), deformation at peak, energy at peak and the corresponding young modulus.

Compressive force:

The compressive force is needed to cause the crop to rupture. It was observed that in the axial position, the compressive force was about 1967.16 N and 1480.42 N for *Xanthosoma sagittifolium* and *Colacassia esculenta* respectively. Similarly, in the lateral position, the force required to rupture the cocoyam tuber was about 976.36 N and 864.40 N for *Xanthosoma sagittifolium* and *Colacassia esculenta* respectively. This shows that the average compressive force both in the lateral and axial position of *Xanthosoma sagittifolium* is higher than that of *Colacassia esculenta*. This is in contradiction with Mayhew and Anne (1988) which observed that *Colacassia esculenta* especially the *colocasia Antiquorium* is very hard. However, the hardness value of the two varieties may be as a result of their respective moisture content during the time the test was performed.

Toughness (Strain Energy):

Toughness or strain energy is defined as the energy absorbed by the tubers prior to tuber rupture per unit volume (Burubai, 2008). Results showed toughness of 7.99 Nm and 6.25 Nm for *Colacassia esculenta* in the axial and lateral loading positions respectively. Similarly, toughness of 11.87 Nm and 8.81 Nm for *Xanthosoma sagittifolium* in the axial and lateral positions were observed. This indicates a higher value of toughness in the axial position than in the lateral for both specimens.

Young Modulus:

This is a measure of the stiffness and rigidity of the specimen. In other words, its shows how easily the tuber surface can be deformed. Experimental results showed values of 94.26 N/mm^2 and 11.32 N/mm^2 for *Xanthosoma sagittifolium* and *Colacassia esculenta* respectively in the axial position. In the lateral position value of 5515.38 N/mm^2 and 7.66 N/mm^2 were obtained for *Xanthosoma sagittifolium* and *Colacassia esculenta* respectively. This shows that during crushing or peeling of the tuber, *Colacassia esculenta* will yield faster to deformation than *Xanthosoma sagittifolium* especially in the lateral position. The values are shown in Table 3 and 4.

Table 3: Mechanical properties of *Xanthosoma sagittifolium*

Sample number	Force (N)	Def (mm)	Toughness (Nm)	Young Modulous (N/mm2)
1	1891.9	14.14	9.77	1.14
2	1162.9	25.11	11.97	14194
3	492.8	23.48	6.37	20.03
4	1212.8	20.48	11.26	57.77
5	1753	12.69	9.74	107.11
6	1624.5	13.64	10.12	121.05
7	2042.4	14.53	12.06	106.48
8	1418.8	18.89	12.29	71.12
9	594.5	10.18	2.15	13234
10	2524	16.15	17.67	135.54
11	2742	15.25	16.13	180.74
12	2084.6	12.91	12.72	151.07
Mean	1628.68	16.45	11.02	2365.00
Sd	694.04	4.58	4.06	5305.31
Min	492.8	10.18	2.15	1.14
Max	2742	25.11	17.67	14194

Sd= Standard Deviation, Def.= Deformation

Deformation:

Deformation was also observed to be greater in the lateral position than the axial for both species. *Xanthosoma sagittifolium* showed deformation of 14.23 mm and 19.63 mm at axial and lateral positions respectively while *Colacassia esculenta* gave deformation of 12.23 mm and 14.20 mm in the axial and lateral positions respectively. This indicates that more deformation is observed in the lateral position meaning that the product damage is eminent in this position.

From the results obtained the minimum and maximum values of the coefficient of static friction on wood are 0.14 cm and 0.47 cm respectively while the minimum and maximum values of the coefficient of static friction on glass are 0.17 cm and 0.49 cm respectively for *Xanthosoma sagittifolium*. Similarly, the minimum and maximum values of the coefficient of static friction on wood are 0.56 cm and 0.11 cm respectively while the minimum and maximum values of the coefficient of static friction on glass are 0.10 cm and 0.58 cm respectively for *Colocassia Esculenta*. The toughness showed minimum and maximum values of 2.15 Nm and 17.67 Nm respectively for *Xanthosoma sagittifolium* while *Colocassia Esculenta* showed minimum and maximum values of 1.47 Nm and 15.42 Nmrespectively.

Table 4: Mechanical properties of *Colacassia Esculentas*

Sample number	Force (N)	Def (mm)	Toughness (Nm)	Young Modulus (N/mm2)
1	999.5	10.7	4.72	9.64
2	1893.4	18.43	15.42	7.4
3	1563	14.31	8.84	9.18
4	1652	10.63	7.09	14.72
5	2076.2	15.94	13.54	11.34
6	747.7	16.66	5.44	0.43
7	1111.4	9.57	4.76	11.74
8	621.7	13.54	4.91	0.6
9	494	12.18	2.86	0.38
10	295.8	8.63	1.47	43.28
11	729.9	11.93	3.78	0.78
12	1268.3	18.01	9.84	0.72
Mean	1121.08	13.38	6.89	9.18
Sd	575.13	3.31	4.26	11.98
Min	295.8	8.63	1.47	0.38
Max	2076.2	18.43	15.42	43.28

Sd= Standard Deviation, Def. = Deformation

4. Conclusion

The Engineering properties of cocoyam were investigated for two species of cocoyam viz: *Xanthosoma Saggittifolium* and *colocassia esculenta*. The engineering properties determined in this study constitute an important baseline data for the scientific design and development of various machines and equipment for the planting, harvesting and post- harvesting operations of cocoyam. Based on the results obtained from this study, it is can be concluded that:

1. The two varieties showed a close range of values for density: 1.02 g/cm^3 and 1.01g/cm^3 for *Xanthosoma sagittifolium* and *Colacassia esculenta* respectively.
2. *Colocassia esculenta* showed a higher mean moisture content of 58.91 % wet basis than *Xanthosoma sagittifolium* with mean moisture content of 57.65 % wet basis.
3. It was observed that wood showed the highest coefficient of friction while stainless steel showed the lowest for both varieties of cocoyam.
4. In the axial position, the compressive force was about 1967.16 N and 1480.42 N for Xanthosoma sagittifolium and Colacassia esculenta respectively. Similarly, in the lateral position, the force required to rupture the cocoyam tuber was about 976.36 N and 864.40 N for *Xanthosoma sagittifolium* and *Colocassia esculenta* respectively.

References

Abano, K. K. and K. K. Amoah. 2011. Effect of moisture content on the physical Properties of Tiger nut (cyperus esculentus). *Asia journal of Agricultural Research*.; ISSN 1819-1894/DOI:10.3923/ajar.2011.

Ajav, E.A. 1998 . Engineering properties of yam set related to mechanization of yam planting. *Journal of Root crops.*; **24**(2), 171- 176.

Aluko, O.B. and G. A. Makanjuola. 2002. Preliminary studies of some agronomic and design factors relevant to the mechanization of yam sett planting on ridges. *Journal of Agricultural Engineering and Technology.*; **10**, 17–27.

Aluko, O. B. and OA Koya. 2006. Some Engineering properties of yam set from two species of yam. *Journal of Food Engineering*.; **76**, 396- 401.

Bahnasawy, A. H., Z.A. El-Haddad, M.Y. El-Ansary and H.M. Sorour. 2003. Physical and mechanical properties of some Egyptian onion cultivars. *Journal of Food Engineering.*; **62**, 255–261

Burubai, W., A.J. Akor, A.H. .Igoni and Y.T. Puyate. 2008. Fracture resistance of african nutmeg (monodora myristica) to compressive loading. American- *Eurasian Journal of Scientific Researches*; **3**(1), 15-18.

Chandrasekar, V. and R Viswananthan. 1999. Physical and thermal properties of coffee. *Journal of Agricultural Engineering Research.*; **73**,227- 234

Davies, R.M. 2010. Engineering properties of three varieties of melon seeds as potentials for the development of melon processing machine. *Advanced Journal of Food science and Technology*; **2**(1),63-66.

Dutta, S.K., V.K. Nema and R.K. Bhardwa. 1988. Physical properties of gram. *J. Agric. Eng. Res*.; **39**, 259-268.

Gosh, B.N. (1969). Physical properties of the different grades of arabica beans. *Trans. ASAE.* 1969; **9**(3), 592–593.

Kaleemullah, S. and J.J. Gunansekar. 2002. Moisture-dependent physical properties of aracanut kernels. *Biosyst Engineering*; **82**,331- 338.

Mayhew, S. and P. Anne. 1988. *Tropical and Sub-Tropical Foods*. 1st edition. Macmilan (London), p. 115.

Mohsenin, N.N. (1978). *Physical properties of plant and animal materials: Structure, physical characteristics and mechanical properties.* 1st Edn., Gordon and Breach Science Publishers, New York, 1978.

Nwokocha, L.M. , N.A. Aviara, C. Senan,and P.A. Williams. 2008. A comparative study of some properties of cassava (Manihot esculenta, Crantz) and cocoyam (Colocasia esculenta, Linn) starches. *Carbohydrate Polymers.* 2008, DOI: 10.1016/j.carbpol.10.034.

Ogunjimi, L.A., N.A. Aviara and O.A. Aregbesola. 2002. Some physical and engineering properties of locust bean seed. *Journal of Food Engineering*; **55**(2), 95-9.

Oje, K. and E.C. Ugbor. 1991. Some physical properties of oil bean seed. *Journal of Agricultural Engineering Research*; **50**, 305–313.

Olajide, J.O. and B.O. Ade-Omowaye.1999 Some physical properties of locust bean seed. *Journal of Agricultural Engineering Research*; **74**, 213–215.

Onwueme, I. C.1978. *The Tropical Tuber Crops*. English and Language book Society, John Wiley and Sons, Chichester, p. 179.

Shepherd, H. and R.K. Bhardwaj. 1986. Moisture dependent physical properties of pigeon pea. *J. Agric. Eng.Res.*; **35,** 227-234.

Sharma, R. K., R.K. Dubey and C.K. Teckchandani.1985. Engineering Properties of Black Gram Soybean and green gram. *Proc. Indian Soc. Agric. Eng*.; **3**,181- 185.

Sreenarayanan, V. V., V. Suubramanian and R. Visvanathan.1985. Physical and Thermal Properties of soybean, prod. *Indian Society of Agricultural Engineering*; **3**,161-169.

Zoerb, G.C. 1967. Instrumentation and measurement techniques for determining physical properties of farm products. *Transactions of the ASAE*, **10**, 100–109.