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DETERMINATION OF SOME ENGINEERING PROPERTIES OF SWEET POTATO (*Ipomoea batatas*)

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ABSTRACT

This work presents the determination of some engineering properties of sweet potato, (shape, size, colour, volume, particle density, sphericity, weight, surface area and compressive strength) was determined at moisture contents of 81.2%. Under approved standard laboratory conditions and using standard methods and instruments, experiments were conducted and results were obtained. The highest value of compressive strength for sweet potato when placed in the horizontally and vertically are 7.07 kN and 5.62 kN respectively. In bagging and sorting of sweet potato special care should be taken in placing the sweet potato in a horizontal position due to the compression of the weight of the sweet potatoes when bagged, the maximum values of the Major, Intermediate and Minor Diameter are 70.92mm, 63.01mm and 44.73mm respectively, the minimum values were calculated to be 56.0mm, 29.0mm and 38.77mm respectively, and mean to be 74.33mm, 41.04mm and 38.77mm respectively. These values were used for sorting, grading and construction of sieve to separate the values below the mean obtain. The coefficient of variation of the major, minor and intermediate was gotten to be 20.6%, 15.8% and 16.6% respectively. These results are important for maximum efficiency in designing equipment required for further processing of sweet potato and the reduction of mechanical damage to agricultural produce during postharvest handling and processing.

Keywords: Engineering properties, sweet potato, sphericity, compressive strength

INTRODUCTION

The sweet potato (*Ipomoea batatas*) is a dicotyledonous plant that belongs to the family Convolvulaceae. Its large, starchy, sweet tasting tuberous roots are an important root vegetable (Purseglove, 1991; Woolfe, 1992). The young leaves and shoots are sometimes eaten as greens. Of the approximately 50 genera and more than 1,000 species of Convolvulaceae, I. batatas is the only crop plant of major importance – some others are used locally, but many are actually poisonous.

The ever increasing importance of agricultural produce such as sweet potato (*ipomoea batatas*) together with the complexity of modern technology for their production, processing and storage need a better knowledge of engineering properties of these products. It therefore became very necessary to understand the physical principle guiding the response of these agricultural produce so that processes, handling and machine operations can be designed for maximum efficiency and the quality of the final products. The develop nations of the world practice the modern agriculture, which is the use, handling and processing of plants and animal materials by various

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methods like the mechanical, thermal, electrical optical etc. With this increasing application, little information is available on the basic engineering properties of these materials, particularly in developing country like Nigeria (Mohsenin, 1970).

Most agricultural products have over the years been underexploited in the regions of which they are produced especially in the developing countries like Nigeria. This numerous use of sweet potato makes it a necessity to determine the engineering properties of this valuable agricultural produce so that more extensive study can be conducted in order to determine and locate more areas of sweet potato importance and it's relevant.

The importance of food materials tends to increase greatly with the complexity of new technology for the handling, production, processing, storage and preservation. Evaluation of quality, distribution and marketing and uses of these products depends on the knowledge of engineering properties of these materials. The handling operations can be designed to produce optimum efficiency and the maximum quality of food or end products. For instance, the application of physical properties such as shape is an importance parameter for stress distribution in materials under load is important in developing of sizing and grading machines and for analytical predictions of its drying behavior. Density, size, and drag coefficients are important in calculation of terminal velocity of an object in fluid (Esref and Halil, 2007).

Kachru *et al*. (1994) reported that it is essential to determine the physical properties of biomaterials (such as sweet potato) for proper design of equipment for handling, conveying, separation, drying, aeration and mechanical expression of sweet potato. It has been established that moisture content affects the physical properties of biomaterials appreciably (Desphande *et al.*, 1993; Singh and Goswami, 1996). Knowledge of mechanical properties (these are properties that deals with the behaviour of agricultural products under applied forces) such as stress, strain, hardness and compressive strength is vital to engineers handling agricultural products. The determination of engineering properties of biomaterials under static or dynamic loading is aimed at textural measurement of unprocessed and processed food materials; the reduction of mechanical damage to agricultural produce during postharvest handling, processing and storage; and the determination of design parameter for harvesting and postharvest systems, (Anazodo, 1983). Therefore, the knowledge of engineering properties of biomaterials is important in the design of agricultural machinery, equipment and facilities. The top 5 producers of sweet potatoes in West Africa are Nigeria – 27,000 tonnes, Cameroon – 20,000 tonnes, Ghana – 19,000 tonnes, Cote d'ivore – 15,500 tonnes and Liberia – 14,900 tonnes.

Sweet potatoes are an economical and healthful food crop containing high beta-carotene and substantial amounts of ascorbic acid and minerals. Yet, limited sweet potato production is utilized for processing of canned roots, frozen patties, and baby food. Moreover, the quality fresh market sweet potatoes can vary due to cultivar differences, growing conditions, and post-harvest handling practices.

However, this abundant resource is still poorly utilized, in spite of the fact that it is cheaper than other crops. The industrialization of sweet potatoes is mainly based on the starch which can be isolated from this crop and which can be used as ingredients for food products. Noodles are important foods consumed in Asia countries. It is estimated that about 30% - 40% of total wheat flour consumption is as noodle products in most Asian countries, (Zhang *et al.*, 1998). Starch noodle and Japanese white salted noodle are two most popular types, which qualities are mainly affected by starch properties. Starch noodles are made from starch only and the ideal raw material is mung bean starch.

Statement of problem

The shortage of processing and preservative equipments for sweet potato, which may be due to the fact that data on the engineering properties of sweet potato required for the design of these machine are insufficient or not available in some cases. Also, most agricultural produce are visco-elastic, therefore, the determination of the engineering properties of biomaterials are difficult and complicated, since they are apparently affected by temperature, moisture content and the rate of loading (Zoerb and Hall, 1993; Saxena, 1992).

Objectives of the study

The objective of this study is to determine the selected engineering properties of Sweet potato; (shape, size, colour, volume, particle density, Sphericity, weight, surface area, moisture content and compressive strength).

MATERIALS AND METHODS

Selection of material

The agricultural crop used in determining these engineering properties is Sweet Potato (*Ipomoea batatas*) and 30 pieces of the specimen was used during the experiment. The Sweet potato was obtained from Kure Market, Minna, Niger state, within the month of October, 2010. The 30 samples were cleaned to remove foreign matter, dust and dirt. For the experiment the samples were randomly selected and extra care was ensured to select good Sweet potato without any sign of blemish, so as to eliminate getting incorrect results.

Determination of the Engineering Properties

The engineering properties of sweet potato at average moisture content of 81.2% (shape, size, geometric mean diameter, sphericity, colour, seed mass, volume, true density, bulk density, porosity, surface area, angle of repose and compressive strength) were determined according to established standards and procedure (ASAE, 2003; Henderson *et al.*, 1997).

RESULTS AND DISCUSSION

Presentation of result on physical properties

Coefficient of friction: The results of coefficient of sweet potato are presented in Table 3.1.

Table 3.1 Results of Coefficient of Friction

No of Experiment	Types of Surface		
	Wood (°)	Glass (°)	Steel (°)
1	15	12	12
2	14	14	11
3	14	13	12
Average	14	13	11

Moisture content

The result of the experiment are presented in table 4.1 and at predetermined moisture contents for the samples used. The moisture content for the Sweet potato sample is shown in Table 3.2.

Table 3.2 Moisture Contents for 30 Sweet potato Samples

S/No	Weight of Sample (Before Drying) W_i (g)	Weight of Sample (After Drying) W_f (g)	Weight Of Water removed W(g) = $W_i - W_f$	Moisture Content % $\frac{W_i - W_f}{W_i} \times 100$
1	281.40	49.23	232.17	83
2	281.38	48.89	232.49	83
3	281.36	49.35	232.01	82
4	281.35	48.48	232.87	83
5	272.06	44.85	227.21	84
6	281.20	47.86	233.34	83
7	210.40	46.65	163.75	78
8	281.37	49.55	231.82	82
9	226.03	55.72	170.31	75
10	233.43	54.85	178.58	77
11	225.87	55.86	170.01	75
12	281.16	49.50	231.66	82
13	281.23	48.75	232.48	83
14	281.19	49.15	232.04	83
15	281.46	48.08	233.38	83
16	281.26	49.02	232.24	83
17	158.76	29.65	129.11	81
18	169.48	32.08	136.44	81
19	281.22	49.25	231.97	83
20	177.44	35.25	141.99	80
21	281.42	49.02	232.40	83
22	186.22	38.04	148.18	80
23	224.41	42.48	181.93	81
24	281.29	47.82	233.47	83
25	232.42	44.35	188.07	81
26	281.04	49.35	231.69	82
27	209.28	40.86	168.42	81
28	219.28	39.45	179.83	82
29	281.17	48.86	232.31	83
30	179.04	43.85	135.19	76

The average of the Sweet potato samples gives us the moisture content which is 81.2%. This information is of importance to processing engineers and food scientist to assist them in processing stages such as drying, bagging, and storage.

Shape and Colour

The traced boundary outlines of the samples were compared with charted standard. The shape of some of the sweet potato samples was found to be irregular. The colour of the sweet potato sample used is yellowish at the surface and whitish inside.

The means, standard deviations and coefficient of variation of the measured values of major diameter D_1, Intermediate diameter D_2, minor diameter D_3, of 30 sweet potato samples are presented in the Tables 3.3 to 3.5.

Table 3.3. Mass, Major Diameter, Minor Diameter, Intermediate Diameter of measured parameters of 30 Sweet potato sample

Specimen	Mass (g)	Major Diameter (mm)	Minor Diameter (mm)	Intermediate Diameter (mm)
1.	281.40	67.10	50.16	65.05
2.	281.38	73.30	60.06	66.04
3.	281.36	68.82	51.09	60.80
4.	281.35	68.10	50.16	63.10
5.	272.06	74.39	29.28	62.12
6.	281.20	83.50	41.12	62.32
7.	210.40	56.24	43.28	53.60
8.	281.37	83.48	44.38	73.40
9.	226.03	58.20	30.36	55.30
10.	233.43	62.50	50.36	60.50
11.	225.87	57.10	36.24	55.36
12.	281.16	80.16	47.42	76.24
13.	281.23	77.50	42.52	59.18
14.	281.19	89.38	54.70	82.52
15.	281.46	77.32	53.40	69.38
16.	281.26	78.40	59.38	72.32
17.	158.76	54.08	28.20	42.32
18.	169.48	59.18	41.60	55.86
19.	281.22	80.38	49.18	69.28
20.	177.24	70.56	45.46	61.52
21.	281.42	72.05	52.16	65.25
22.	186.22	69.85	51.65	62.82
23.	224.41	55.16	25.10	42.30
24.	281.29	64.48	36.28	58.24
25.	232.42	82.18	48.10	77.26
26.	281.04	68.32	36.82	54.23
27.	209.28	59.74	32.44	54.32
28.	219.28	78.38	52.42	68.28
29.	281.17	88.28	55.42	82.64
30.	179.04	69.32	42.38	58.44

Table 3.4 Lengths, volumes, and Mass of measured parameters of 30 Sweet potato sample

Specimen	Mass (g)	Length (mm)	Initial Volume (ml)	Final Volume (ml)	Volume (ml)
1.	281.40	119.10	155	255	100
2.	281.38	150.10	139	240	101
3.	281.36	147.62	142	246	104
4.	281.35	145.26	145	245	100
5.	272.06	109.30	140	240	100
6.	281.20	123.20	130	235	105
7.	210.40	110.40	128	230	102
8.	281.37	108.46	125	215	90
9.	226.03	130.66	115	206	91
10.	233.43	106.44	100	182	60
11.	225.87	150.16	110	160	50
12.	281.16	147.10	115	197	82
13.	281.23	154.26	100	186	86
14.	281.19	105.06	122	185	63
15.	281.46	129.42	125	193	68
16.	281.26	112.12	130	190	60
17.	158.76	100.56	135	195	60
18.	169.48	91.74	120	192	72
19.	281.22	129.38	140	198	58
20.	177.24	92.52	150	205	55
21.	281.42	128.35	140	196	56
22.	186.22	132.24	140	190	50
23.	224.41	89.76	130	190	60
24.	281.29	107.42	135	170	35
25.	232.42	146.12	135	175	40
26.	281.04	117.24	135	178	43
27.	209.28	152.26	130	160	30
28.	219.28	129.44	130	164	34
29.	281..17	103.28	130	165	35
30.	179.04	102.36	130	158	28

Table 3.5. Means, standard deviation and coefficients of variation of measured parameters of Sweet potato samples

S/No	Measured Parameters	Unit	Maximum Value	Minimum Value	Mean	Standard Deviation	Coefficient of Variation (%)
1.	Major Diameter	Mm	132.6	65.0	74.33	14.10	20.6
2.	Intermediate Diameter	Mm	48.2	29.0	41.04	6.09	16.6
3.	Minor Diameter	Mm	46.0	26.0	38.77	5.99	15.8
4.	Mass	G	108.03	34.60	84.24	34.69	38.4
5.	Volume	Ml	100	26	75.15	28.36	42.22

Table 3.6 Means, standard deviation and coefficients of variation of some physical properties (calculated) of Sweet potato

S/No	Calculated Parameters	Unit	Maximum Value	Minimum Value	Mean	Standard Deviation	Coefficient Of Variation (%)
1.	Arithmetic Mean Diameter	mm	58.92	39.02	53.48	9.79	18.4
2.	Geometric Mean Diameter	mm	58.90	44.62	54.09	8.87	17.3
3.	Square Mean Diameter	mm	75.22	38.75	54.07	9.30	16.8
4.	Equivalent Diameter	mm	60.95	37.86	54.18	8.90	17.8
5.	Sphericity	dec	0.68	0.72	0.64	0.58	0.85
6.	Aspect Ratio	dec	0.48	0.56	0.58	0.46	0.76
7.	Particle Density	g/cm^3	1.09	1.03	1.34	1.08	1.04
8	Weight	N	1.04	0.28	0.67	0.26	0.36
9	Surface Area	mm^2	12635.38	3708.97	7670.62	221.32	846.59

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Discussion of result on physical properties

It was observed from table 3.3 to 3.5 that the length (D_1), width (D_2) and thickness (D_3) for the sweet potato have mean values of 70.92, 63.01, and 44.73 respectively. With known axial dimensions, the product can be effectively graded. In the design of machine for processing, the knowledge of different dimensions is important so as to minimize wastage or breakage while grading, peeling and cleaning.

The mean values of the weight and the volume are 247.48 and 58 respectively. The weights of agricultural products are exploited in the design of cleaning equipment using aerodynamic forces, also practical application of mass is in the design of cleaning equipment for separation, conveying and elevating unit operations. The weight and mass of the sweet potato is a useful index in measuring the relative amount of dockage or foreign material in a given lot of material.

The data in Table 3.6 gives the means, standard deviation and coefficient of variation of calculated values of calculated parameters of the sweet potato. AMD has a mean of 53.48 mm, GMD has a mean of 54.09 mm, SMD has a mean 54.07 mm and ED has a mean of 54.18 mm. The arithmetic mean and geometric mean can therefore be used to determine the average diameter of sweet potato. This is useful in determining the diameter of sieve hole.

Sphericity and aspect ratio ranged from 0.68 to 0.72 and 0.48 to 0.56 and mean values of 0.68 and 0.58 respectively. Sphericity values of most agricultural produce have been reported to range between 0.32 and 1.00 and the more regular an object is, the lower the sphericity (Mohsenin, 1970). This is important information for hopper, separation and conveying equipment design.

The particle density ranged from 1.03 g/cm^3 to 1.09 g/cm^3 with a mean value of 1.34 g/cm^3. The particle density of agricultural products have been reported to play significant importance in the design of silos and storage bins, maturity and quality evaluation of products which are essential to sweet potato and tubers marketing.

The values obtain when compared to the standard charted values on other tubers (Mohsenin, 1986) shows that sweet potato are relatively small in size compared to the rest, and also weigh lesser and less denser to other tubers, it also spoil easily when exposed to sunlight, humidity and other climatic condition, and breaks easily when exposed to much cold, since it is not completely spherical like other tubers more consideration is put in designing its hopper and conveying equipment. From the surface area obtain from the experiment and compared to the standard charted of tubers, it shows that the surface area of sweet potato is smaller which makes it easier to peel, which should be taken into consideration when designing the peelers for sweet potato and any other processing equipment.

Presentation of results on Mechanical properties

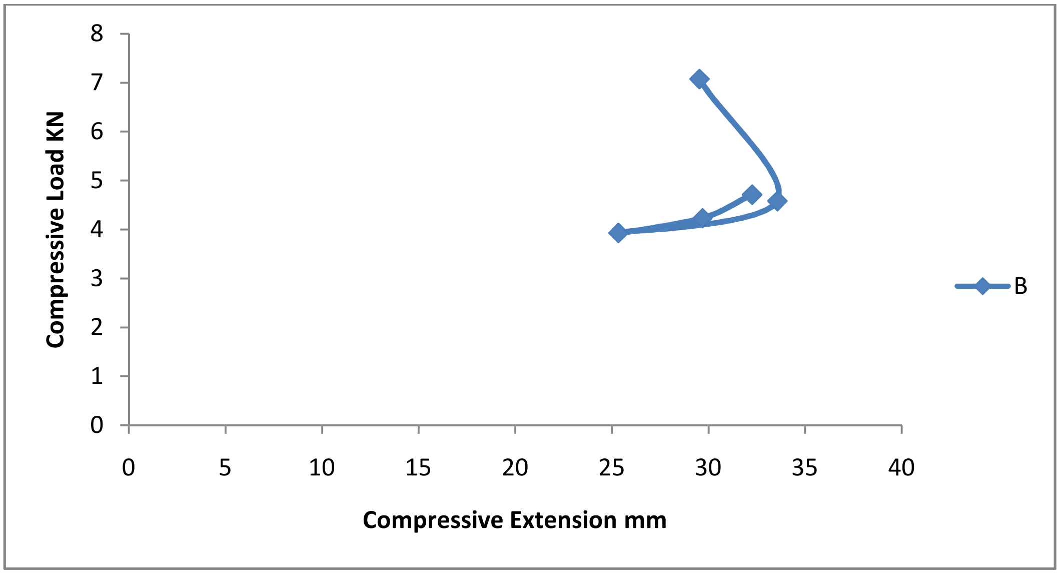

Fig. 3.1: Compressive Load against Compression Extension of Sweet potato (Horizontal)

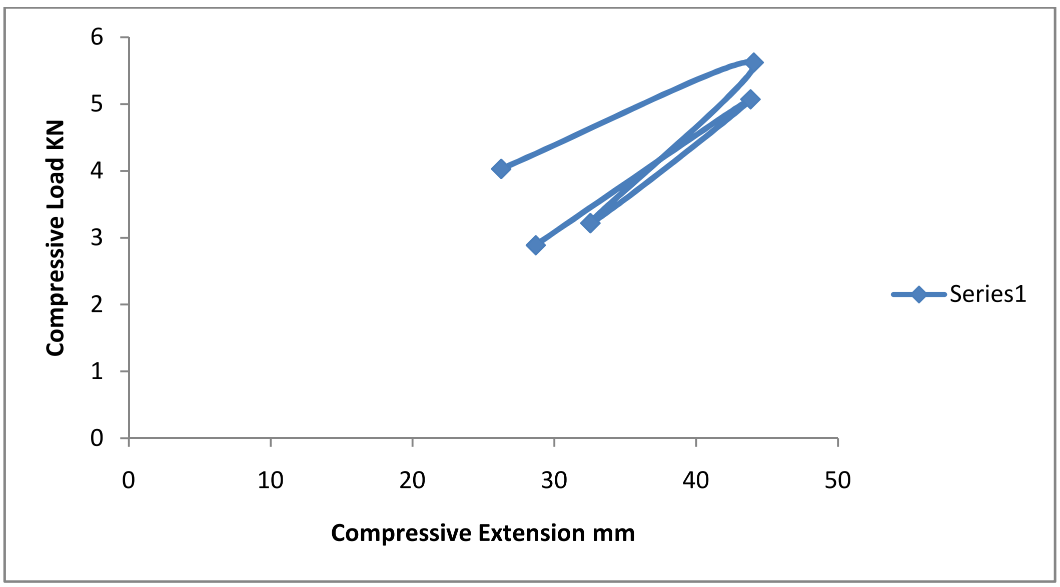

Fig. 3.2: Compressive Load against Compression Extension of Sweet potato (Vertical)

DISCUSSION OF RESULT ON MECHANICAL PROPERTIES

With the anvil height set on the Universal Material Testing Machine. For the 5 sweet potato samples, the compressive load at break is 7.07.KN, 4.58 KN, 3.93 KN, 4.23 KN, and 4.71 KN when the sweet potato was placed in horizontal position and for another 5 sweet potato sample the compressive load at break is 3.32 KN, 5.62 KN, 3.22 KN, 5.07 KN and 2.89 KN when the sweet potato was placed in vertical position. From the graph in Fig 4.1 and Fig 4.2, it shows that as more pressure is placed on the sweet potato samples it begins to extend towards its axis thereby causing a break or crack, which increase as more load is placed on it, thereby giving the upward slope in the graph which represent that increase in load result to the increase in extension of the sweet potato. From the values obtain above it shows that the pressure in cracking the sweet potato in the horizontal position is greater than sweet potato placed in the vertical position, this can be concluded that in case of storage and bagging the sweet potato should be placed at the horizontal position because it takes more force to break or crack the sweet potato in that position compared to the vertical position, with the knowledge of these it could be applied in the design of harvesting equipment and storage devices for sweet potato.

The likelihood of fracture of a particle under tension or compression depends on the applied macroscopic stress and the size of the particle. In case of Sweet potato which are bigger at the center than the top and bottom, which makes it easier to break at the top and bottom, the compressive load, A farm product machine designer needs knowledge of the compressive strength of sweet potato for process design and handling. The compressive load is an important parameter that must be considered for maximum efficiency of the operations.

CONCLUSION

The physical and mechanical properties of sweet potato including shape, size, geometric mean diameter, sphericity, colour, mass, volume, particle density, surface area and compressive strength were determined at 81.2% wet bases moisture content. The relationships derived between the size, surface area, weight, and sphericity all follow a standard pattern which would be useful in the design of machine for processing, sweet potato having a moisture content of 81.2% shows that sweet potato is mainly composed of water, and will spoil easily if not preserved properly, so it is necessary to gather relevant data on the engineering properties of sweet potato so as an accurate measurement in the design and fabrication of equipment for handling and processing of the sweet potato and storage devices. Mass and volume of food materials and agricultural products play an important role in the design or cellars, barns or storage bins; mechanical compressing of ensilages and maturity evaluation. Result showed that sweet potato had an irregular shape and the particle densities of sweet potato had a greater value than their aspect ratio. Densities have been of interest in breakage susceptibility and hardness studies. Also the knowledge of compressive strength is of great importance to engineers handling agricultural products.

These parameters obtained are of importance in designing equipment for handling and processing operations of the product. From the data obtained for the selected physical and mechanical properties of sweet potato, it was established that, they are useful in design of post harvest handling and processing operations.

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