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Determination of Design-Related Properties of Selected Irish Potatoes Varieties

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ABSTRACT
The aim of this study was to determine some design-related properties of Irish potatoes commonly grown in Nigeria that may be useful in designing, handling and processing equipment of the product. Two varieties were selected: *Nicola* and *Diamant*. The measured properties were length, width, thickness, bulk density, solid density and angle of repose. Other parameters were arithmetic mean, geometric mean, surface area, volume, porosity and kernel weight. The mean length, width and thickness obtained for Nicola variety were 66.5, 37.3 and 32.4 mm respectively; while 57.4, 35.2, and 31.7 mm were obtained for *Diaman*t, respectively. The mean angle of repose of *Nicola* and *Diamant* varieties were 27.20 and 26.40°, respectively. Mean roundness of *Nicola* and *Diaman*t varieties were also obtained as 0.6 and 0.7 respectively. The mean surface area and volume of *Nicola* variety was determined to be 58.55 cm^2 and 42.61 cm^3 while that of D*iama*nt variety was 50.31 cm^2 and 34.08 cm^3, respectively. Moisture contents of Nicola and Diamant varieties used were obtained as 76.3 and 85.9%, respectively. Mean hardness of *Nicola* and *Diamant* varieties was 1.52 and 1.7 HV, respectively; indicating that *Diamant* is a harder variety than *Nicola*. These properties may be useful and serve as a guide on major engineering design of handling and processing equipment.
Keywords: Potatoes, Variety, Design factors, Properties

INTRODUCTION
Irish potato (*Solanum tuberosum* L.) originated in the high plains of Peru where it is largely cultivated as food. It was introduced in Nigeria in 1920 by Europeans involved in tin mining on the Jos Plateau. Production was then limited to small gardens until the Second World War when the British Colonial Government encouraged its cultivation so as to provide food for the service men in West Africa (Okonkwo and Okoye, 1995; Ugonna *et al.,* 2013). Kudi *et al.* (2008) observed that Irish potato has the highest yield per unit area among roots and tuber crops in Nigeria thereby bringing more income to farmers than other roots and tuber crops. Potato production in Nigeria in the year 2011 stood at 14 million tones cultivated on 14,680 hectars with an estimated yield of 7.8 t/ha (Ugonna *et al.,* 2013). Nigeria has been identified as the 4th biggest potato producer in Sub-Saharan Africa.

Potatoes in Nigeria are cultivated mainly by small rural farmers in marginal areas. The most important area of potato production in Nigeria is the Jos Plateau, which accounts for 85% of production in Nigeria. Obudu Hills, Biu and Nambila plateaus are other areas where potato can be grown both in the dry and rainy seasons. In the northern states of Kebbi, Kano, Kaduna, Borno, Sokoto and Adamawa, potato is produced between November - February when temperatures are sufficiently low (Okonkwo and Okoye, 1995).

Potato is one of the world's prime sources of human nutrition. The protein: carbohydrate ratio is higher than for most cereals and even higher than those of other tuber and root crops (Okonkwo and Okoye, 1995). Potato usage in conventional ways as food stuff and industrial processing has become increasingly prominent in industrialized societies. In the food sector, potatoes are processed into deep-frogmen chips and mashed potato. By-products such as potato starch, glucose and dextrose are used in the brewing industry, confectionary and in the distillation of alcohol. In the non-food sector, by-products such as potato starch and dextrin are used in processes for the manufacture of cardboard, glues, textiles and paints and as ironing sprays in the laundry. Thus, the importance of Irish potato in daily life cannot be overemphasized. The objective of this study, therefore, was to determine some physical and engineering properties of two Irish potato varieties (*Diaman*t and *Nicola*) necessary for the design of its various related processing equipment.

MATERIALS AND METHODS
Selection of Irish Potato Varieties for the Experiment
The *Diamant* and *Nicola* potato varieties (Figure 1) were procured from a renowned grower in Jos – Nigeria. Their selection was based on their variations in size, average yield and their wide adoption in most potato producing states of Nigeria.

Instrumentation
A number of instruments were used in various measurement and determination of the dimensions and properties of the selected potato varieties. These include; a digital vernier caliper with an accuracy of 0.01 mm (RDDC 708 - *RAIDER*®) used for measuring the dimensions (length, width and thickness); Weigh balance (2000 kg capacity with 0.01 mm sensitivity) used to determine the weight of the potatoes; Oven (Heraeus/Hanau) used for oven-drying of potato and for moisture content determination; frame box used for determination of angle of repose; Hardness tester (Brinell Hardness Tester HBE-3000M) for determining the strength of potatoes; and a measuring cylinder (2000 ml capacity) for volume determination.

(a) **(b)**

Figure 1: (a) *Nicola* and (b) *Diamant* Potato Varieties

Design-Related Properties of Selected Irish Potato Varieties Determined

The physical and engineering properties of *Nicola* and *Diaman*t potato varieties were determined at the Processing Laboratory, Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University Zaria. The properties determined include size and shape, weight, surface area, roundness, sphericity, volume and porosity. Other properties determined were: compressive strength, hardness, angle of repose, density, bulk density, coefficient of static friction and moisture content. All potato samples collected were thoroughly cleaned to remove foreign materials like sticky soil. Sample selection was randomized throughout the experiment

Determination of Design-Related Properties of Nicola and Diamant Potato Varieties

One hundred tubers of each variety were randomly selected for the study. This was considered adequate to give a sample mean of the measured physical property that would be close to the population mean. The dimensions of the samples were measured with precision digital vernier calipers. The principal axes (sizes) considered were: the length, major width and thickness of the potatoes tubers as previously reported (Kaveri and Thirupathi, 2015; Mohsenin, 2010; Firouzi *et al.,* 2009). These parameters were used to determine some essential properties of the potatoes such as arithmetic mean diameter, geometric mean diameter, sphericity, surface area, volume. Other parameters measured were unit weight, angle of repose, thousand kernel weight, solid density, bulk density and porosity.

Determination of Arithmetic Mean Diameter

The arithmetic mean diameter of the potato was determined using the dimensions of the potatoes as given in equation (1) as stated by Kaveri and Thirupathi, (2015); Mohsenin, (2010); Bahnasawy (2007):

$$D_a = \frac{L+W+T}{3} \qquad (1)$$

Where L = length or longest side of the potato (mm)
W = width or minor axis of the potato (mm)
T = thickness of the potato (mm)
D_a = arithmetic mean diameter (mm)

Determination of Geometric Mean Diameter

The geometric mean diameter of the potato was determined from the measured dimensions of the potatoas given in equation (2) as previously described (Bahnasawy, 2007; Mohsenin, 2010; Maninder *et al.,* 2017).

$$D_g = \sqrt[3]{L \times W \times T} \qquad (2)$$

Where L = length or longest side of the potato (mm)
W = width or minor axis of the potato (mm)
T = thickness of the potato (mm)
D_g = geometric mean diameter (mm)

Sphericity Determination

Sphericity of the potato was determined from the potato dimensions that were earlier determined. It was calculated from equation (3):

$$\Phi = \frac{d_i}{d_c} \qquad (3)$$

Φ = Sphericity of the object
d_i = diameter of the largest inscribed circle
d_c = diameter of the smallest circumscribed circle (Mohsenin; 2010; Loghavi *et al.*, 2011).

Surface Area Determination

The surface area was found using the potato geometric dimensions using equation (4) as suggested by Mohsenin (2010):

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

where:
A_s = surface area (mm^2)
D_g = geometric mean diameter (mm)

Volume Determination
Because of the irregular shape of the potatoes, its volume was determined by taking the three different dimensions; length, width and thickness, then the volume was estimated by using the following relationship as describe by Mohsenin, (2010):

$$V = \frac{\pi . L . W . H}{6} \quad \text{……………………(5)}$$

where:

V = volume, mm^3
L = length of potato, mm
W = width of potato, mm
H = thickness, mm

Solid density
Solid density which is another way of describing density was determined from the relationship between mass, volume and density. In this determination the unit mass of the potato alongside volume of each potato were determined. The solid density was then determined using equation (6) as given by Kaveri and Thirupathi, (2015); Mohsenin, (2010).

$$\rho_s = \frac{Mass\ of\ sample}{volume\ of\ sample} \quad (6)$$

ρ_s = solid density in kg/m^3

Bulk Density Determination
The following expression was used to determine the bulk density as described by Jarolmasjed *et al*. (2012):

$$\rho_b = \frac{weigth\ of\ packed\ material}{known\ volume} \quad \text{……(7)}$$

ρ_b Is the bulk density in kg/m^3

Porosity
Porosity as a very important physical characteristic was determined using the solid density and bulk density parameters as cited in equation (8) and described by Kaveri and Thirupathi, (2015); Mohsenin, (2010).

$$porosity\ (\varepsilon) = \left[1 - \frac{\rho_b}{\rho_s}\right] \times 100 \quad \text{….(8)}$$

Unit Weight Determination
The weight of a single potato tuber was determined by the use of an electronic mettle balance with a sensitivity of 0.001g (Gonchen, 2012).

Angle of Repose Determination
The angle of repose was determined using the method described by Mohsenin, (2010). In this method, a frame box was mounted on a flat wooden surface and then gently tilted until the materials just began to slide was measured as the angle of repose for the potatoes.

Determination of Moisture Content
The moisture content of the selected potato varieties was determined by oven dry method following the ASAE, (1983) approach. Samples of the potato varieties were dried in an oven (Heraeus/Hanau) at 60°C for 12 h to a constant weight and their respective moisture contents were determined using equation (9) as suggested by Shiva *et al.* (2018); AOAC, (1995):

$$MC_{wb} = \frac{W_i - W_d}{W_i} \times 100 \quad (9)$$

where:

MC_{wb} = moisture content, % w.b.
W_i = initial mass of sample, kg.
W_d = dried mass of sample, kg.

Statistical Analysis
The statistical tools used in computation, comparison and analyzing the data obtained are mean, standard deviation (SD) and coefficient of variation (CV) using Microsoft Excel 2013 to compare differences between the two varieties of Irish potatoes.

RESULTS AND DISCUSSION

Design-Related Properties
The mean, standard deviation and coefficient of variation of the measured properties of the selected Irish potatoes are presented in Tables 1 and 2. Results obtained showed that the mean length, width and thickness obtained were 66.5, 37.3 and 32.4 mm for *Nicola* variety; whereas, 57.4, 35.2 and 31.7 mm were obtained as the mean length, width and thickness for *Diamant variety,* respectively. From this result, it can be seen that the length, width and thickness of *Nicola* is greater than that of *Diamant* variety, indicating that *Nicola* variety is larger in size than *Diamant* variety.

These dimensions are applied while determining sieve apertures, hopper sizes, peeling machines in the design of potato processing machines (Heidarbeigi *et al.,* 2009; Mohsenin, 2010; Kaveri and Thirupathi, 2015). The mean sphericity for both varieties was found to be 0.7. Their mean roundness, however, differs slightly as *Nicola* has 0.6 while 0.7 was obtained for *Diamant* variety. Roundness and sphericity are properties that relate to material shape and are needed for analytical prediction of the drying behaviour of agricultural materials as observed by Maninder *et al.* (2017); Kaveri and Thirupathi, (2015).

Table 1: Design-related properties of *Nicola* potato variety

VARIABLE	UNITS	N	MEAN	SD	CV (%)
Length	mm	100	66.5	10.2	15.3
Width	mm	100	37.3	3.3	8.9
Thickness	mm	100	32.4	3.8	11.7
Arithmetic mean diameter	mm	100	45.4	4.4	9.7
Geometric mean diameter	mm	100	43.0	3.8	8.8
Sphericity	Ø	100	0.7	0.1	14.3
Roundness		100	0.6	0.1	16.7
Surface area	mm^2	100	5854.8	1022.5	17.5
Volume	mm^3	100	42606.8	11204.4	26.3
Bulk density	kg/m^3	3	0.51	0.02	3.9
Solid density	kg/m^3	3	1.0	0.12	12
Porosity	%	3	48.8	4.8	9.8
Thousand kernel weight	G	5	55872.02	1746.075	3.13
Moisture content	%	3	76.3	8.5	11.14
Hardness	HV	5	1.52	0.11	7.2
Angle of repose	°	3	27.2	1.72	6.3
Coefficient of friction	μ	5	0.27	0.02	7.4

Similarly, mean surface area and volume of *Nicola* was determined to be 58.55 cm^2 and 42.61 cm^3 while that of *Diamant* variety was 50.31 cm^2 and 34.08 cm^3, respectively. Mass, volume and density of food and agricultural products play an important role in the design of hopper and storage facilities (Jarolmasjed *et al.*, 2012). Surface area is also important in heat and mass transfer process. Mean bulk and solid density of *Nicola* variety were respectively obtained as 0.51 kg/m^3 and 1.0 kg/m^3 while those of *Diamant* variety were 0.55 and 0.99 kg/m^3, respectively. Bulk and solid densities affect the rate of heat and mass transfer of moisture during aeration and drying process (Heidarbeigi *et al.,* 2009; Mohsenin, 2010).

The mean angle of repose of *Nicola* and *Diamant* varieties was also found to be 27.2° and 26.4°. The angle of repose determines the maximum angle of a pile of bio-materials in the horizontal plane and is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but peaked as suggested by Mohsenin (2010). The moisture contents of *Nicola* and *Diamant* varieties were obtained as 76.3 and 85.9% respectively. Moisture content is of great importance to food scientists and processing engineers in the determination of certain adaptation and resistance to processing stages such as drying, bagging, storage, cooking and consumption.

The mean hardness of *Nicola* and *Diamant varieties* were 1.52 HV and 1.7 HV, respectively. These show that *Diamant* was a harder variety than *Nicola*. Knowledge of engineering properties such as hardness is vital to engineers while handling agricultural products. Kaveri and Thirupathi, (2015) opined that hardness under static or dynamic loading is aimed at textural measurement of both processed and unprocessed food material; the reduction of mechanical damage to agricultural produce during handling, processing and storage; and the determination of design parameters for harvest and post-harvest systems. The probability of fracture of a particle under tension depends on the applied macroscopic stress and size of the particles. This property is required for the design of agricultural processing machines to minimize breakage and wastage (Ryder, 1996).

CONCLUSION

Physical and engineering properties of *Nicola and Diamant* Irish potatoes varieties commonly grown in Northern Nigeria that may be useful in designing handling and processing equipment such as planting, harvesting, handling, processing and storage facilities were determined and the results obtained showed marked differences. The *Diamant* variety had more hardness compared to *Nicola* but smaller in size in terms of surface area and volume. These properties could serve as a guide on major engineering design of potato handling and processing equipment.

Table 2: Design-related properties of *Diamant* potato variety

VARIABLE	UNITS	N	MEAN	SD	CV (%)
Length	mm	100	57.4	9.5	16.6
Width	mm	100	35.2	4.8	13.6
Thickness	mm	100	31.7	3.8	11.9
Arithmetic mean diameter	mm	100	41.4	4.5	10.9
Geometric mean diameter	mm	100	39.8	4.1	10.3
Sphericity	Ø	100	0.7	0.1	14.3
Roundness		100	0.7	0.1	14.3
Surface area	mm^2	100	5031.3	1030.5	20.5
Volume	mm^3	100	34081.9	10501.9	30.
Bulk density	kg/m^3	3	0.55	0.03	5.5
Solid density	kg/m^3	3	0.99	0.05	5.1
Porosity	%	3	44.6	5.5	12.3
Thousand kernel weight	G	5	40233.9	1339.5	3.3
Moisture content	%	3	85.9	3.01	3.5
Hardness	HV	5	1.7	0.14	8.2
Angle of repose	O	5	26.4	1.2	4.6
Coefficient of friction	μ	5	0.26	0.012	4.6

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