Some physical properties of *Tawain* (*Hexalobus crispiflorus* A. Rich.) fruit

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Abstract: Some engineering properties of *Tawain* (*Hexalobus crispiflorus* A. Rich.), a rare wild fruit in the thick rain forest riverine zones of tropical region were investigated. The fruits are only available and used during the harvesting period hence the properties were determined at three harvesting periods of two-week intervals corresponding to three moisture levels using standard methods. Moisture content decreased from 58.95% to 55.93% over the period. Mean dimensions ranged from 77.68 to 96.98 mm in length; 47.15 to 54.32 mm in width; 50.93 to 59.03 mm in thickness; sphericity of 0.70 to 0.75 and aspect ratio of 0.57 to 0.62 in aspect ratio suggesting an ellipsoid shape. Porosity, true and bulk density decreased with increasing harvest date. Coefficient of static friction on galvanized steel, wood and glass decreased with delayed harvest. The data generated are useful in the design of systems for handling and processing of *Tawain* fruits.

Keywords: physical properties, *Tawain*, rare wild fruit, handling and processing, harvesting

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1 Introduction

The edible fruits of the tropics are many in number, varied in form, and irregular in distribution. These fruits are outstanding in one or more of the following: size, beauty, flavor, and nutritional value. Some excellent fruits which rival the largely commercialized fruits are still relatively unknown in most parts of the tropics and should be promoted. *Hexalobus crispiflorus*, one of these rare fruits is classified in the *Annonaceae* family and belongs to the genus *hexalobus* which comprises five species. Other rare crops that still remain wild and not grown on commercial basis have been reported by Akaaimo and Raji (2006) and Raji and Ahemen (2008). These crops, despite their importance and various local usages for medicinal purposes and food condiments are still yet to be explored for large scale production (Marina, 2012; Macha, 2015; Shukla and Mehta, 2015). *H. crispiflorus* occurs from Guinea Bissau east to southern Sudan, south of Gabon and DR Congo (Okhale et al., 2016) and in Nigeria, it is native to the South, the thick rain forest zone but most common in the South-South geo-political zone of the country all in Africa. *H. crispiflorus* is a multipurpose tree with local importance for people living in or close to the forest and is considered as one of the useful plants of West Tropical Africa (Burkill, 1985) and as one of the under-exploited leguminous crops (Akoja and Amoo, 2011). Some of the native names in Nigeria for *H. crispiflorus* fruit are *tawain* (*Izon*), *ojiogoda* (*Igbo*) and *apárá joke* (*Yoruba*) (Burkill, 1985; Okhale et al., 2016). Artificial propagation of *H. crispiflorus* is only done by seeding and planting distance is about 6 m × 6 m (Djagbletey, 2011).

The tree yields edible fruits and products used in traditional medicine. The ripe fruit has a brown outer pulp which is peeled off and the inner part eaten fresh (Figure 1). The outer part of the pulp is firm and has a slightly tart taste; the inner part surrounding the seeds is jelly-like and

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sweet and is slightly scented (Danforth and Noren, 1997). Abbiw (1990) stated that bark decoctions are used in a bath to treat fever and skin diseases and a bark macerate is also taken to treat venereal diseases, while the pulped bark is applied to wounds, furuncles and swollen glands. A decoction of the twig bark is drunk as emetic and purgative.

Figure 1 *Tawain* Fruits (a) Unpeeled and (b) peeled

Agricultural and food products have several unique characteristics that set them apart from engineering materials (Muskovics et al., 2006). According to Mohsenin (1980) the knowledge of engineering properties is useful for both engineers and food scientists; plant and animal breeders and it is also important in the design of machines, structures, processes and controls; and in determining the efficiency of a machine or an operation. Awady et al. (2004), El Sayed et al. (2009) and Yehia et al. (2009) corroborated that the knowledge of the physical and mechanical characteristics of agricultural products is important in the design of agricultural machines and equipment. Many studies have been reported on the engineering properties of various agricultural crops (Akar and Aydin, 2005; Topuz et al., 2005; Abou Elmagdet et al., 2002). However, there is a 2.1dearth of information on the physical properties of *H. crispiflorus* fruits and their dependence on processing parameters that would be useful for the design of processing machines. Hence, this work was carried out to determine some physical properties of *H. crispiflorus* fruits with a view to obtaining a database of parameter useful in the design and management of harvesting, handling and storage systems for the fruit. Its processing and handling are still done manually hence the need for machanisation. Also, since the fruit is still harvested when needed, it is necessary to consider the effect of harvest date after maturity on the physical properties.

2 Materials and methods

Tawain fruits used in this study were harvested in three groups at two-week intervals during the harvesting period in the raining season from Agudama Ekpetiama village in Yenagoa Local Government Area of Bayelsa State, Nigeria. About 50 fruits were harvested for each group. Fractured and damaged fruits were discarded by handpicking before the samples were used for the experiments. Sample selection was randomized all through the tests and all the physical properties considered were evaluated. The physical properties that were considered in this study are moisture content, size and shape, true density, bulk density, porosity, static coefficient of friction on material surfaces and angle of repose of the fruits.

2.1 Determination of moisture content

The moisture content of the samples was determined using the ASABE Standard (2006) method by drying the fruits samples of 100 g in an electric oven (Uniscope SM9032 Laboratory Oven, England) at a temperature of 103°C±2°C until the mass of the fruit was constant. The moisture content of the sample was calculated on wet basis using Equation (1):

$$MC_{(wb)}(\%)=w_i-w_f/w_i\times 100 \quad (1)$$

where, $MC_{(wb)}$ is the moisture content in percent wet basis; w_i the initial weight before oven drying and w_f the final weight of fruits after oven drying.

2.2 Size and shape

The three perpendicular dimensions of 50 randomly selected unpeeled fruits were measured i.e. length (L), width (B) and thickness (T) using a digital Vernier caliper (Kanon Instrument, Japan) reading to 0.01 mm. The geometric mean diameter (D_m) and the corresponding sphericity (ψ) were determined from the following:

$$D_m=(LBT)^{1/3} \quad (2)$$

$$\psi=\frac{(LBT)^{1/3}}{L} \quad (3)$$

where, as shown in Figure 2; L is the longest intercept (length, m); B is the longest intercept normal to L (width, m) and T is the longest intercept normal to 'L' and 'B' (thickness, m).

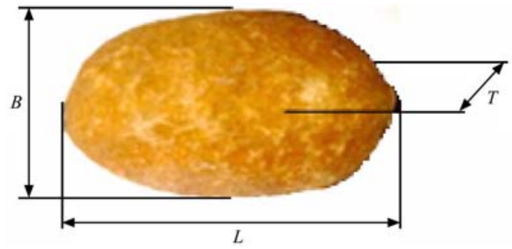


Figure 2 Major (L), Intermediate (B) and Minor (T) Diameters of *Tawain* Fruit

2.3 True and bulk densities

The true density ρ_t was determined by obtaining the individual mass (W_t, kg) of the fruit using a digital weigh balance (AND Ek-6100i) reading to 0.1 g, while its volume (V_t, m^3) was determined by water displacement method and using Equation (4).

$$\rho_t = W_t / V_t \quad (4)$$

The bulk density was determined using the method described by Raji and Ahemen (2008). A wooden box, 200×200×200 mm^3, was constructed and filled with some fruits and the bulk weight (W_b, kg) of the fill measured using an electronic balance. This was replicated 10 times and the bulk density was calculated using Equation (5).

$$\rho_b = W_b / V_b \quad (5)$$

where, (V_b, m^3) is the bulk volume. The porosity (ε) of the fruit was calculated from the bulk and true densities using the relationship given by Moshenin (1986) as:

$$\varepsilon = (1-(\rho_b/\rho_t)) \times 100 \quad (6)$$

2.4 Angle of repose

The angle of repose was determined in this study using a specially constructed topless and bottomless box made of plywood, with a removable front panel (Olaoye, 2000). The box was filled with the fruits, and the front panel was then carefully removed allowing the fruits to slide down and assume natural slope forming an inclined edge. The angle of repose (φ) was calculated as the angle of inclination of the edge from the measurement of the height (H) and base length (D) using the following relationship (Bamgboye and Adejumo, 2009, Akaaimo and Raji, 2005):

$$\varphi = tan^{-1}(H/D) \quad (7)$$

This was replicated ten times and the average value taken as the angle of repose of the *tawain* fruit.

2.5 Coefficient of friction on some material surfaces

The static coefficient of friction of the fruits against three surfaces: Galvanized steel, glass and plywood were determined as described by Ozguven et al. (2005) and Ogunsina et al. (2009). This was done using a tilting table on which each surface to be tested was fixed. The table was gently raised through a lifting mechanism until the fruit just began to slide. The angle of inclination at which the sample started sliding was read off a protractor mounted against the edge of the tilting table (Mohsenin, 1986; Dutta et al., 1988; Akaaimo and Raji, 2006).The mean of the tangent of the angles for ten replications was reported as the coefficient of friction.

2.6 Compressive strength of *Tawain* fruits

Hardness though is a mechanical property also doubles as a physical property as it can be felt. Therefore, the hardness of the fruit was determined with a view to knowing the force required to break the fruit under compression. The uniaxial compression test is the most common means of deriving force-deformation properties of fruit and vegetables in which a force is used to compress the sample (Owolarafe et al., 2006). The procedure used in this study involved loading the sample on desired section at recommended speed of loading and then applying force until the fruit was fractured. A Universal Testing Machine (Instron "Series 3369") was used for the test. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation. The individual fruit was loaded between two parallel plates of the machine with the load applied along the longitudinal and transverse axes at a constant rate of 10 mm min^{-1}. The strength property of interest was that at break point. The stress, force, deformation and energy at break point were recorded.

3 Results and discussion

3.1 Moisture content

The results showed that the moisture content of the fruit decreased from 58.95% to 55.93% over the period. The moisture contents of *tawain* fruits at the three harvest periods were obtained to be 58.95%, 57.41% and 55.93% w.b. for the first (MC1), second (MC2) and third (MC3) harvests respectively. Results showed that moisture content decreased with delayed harvest date after maturity. The fruit, from the moisture contents obtained showed that it was a succulent one with more moisture than the fibrous material. A similar decrease in moisture content with increasing harvest maturity was reported by Raji and Ahemen (2008) for *Tacca involucrata* tuber which has a similar shape, size and texture though a tuber.

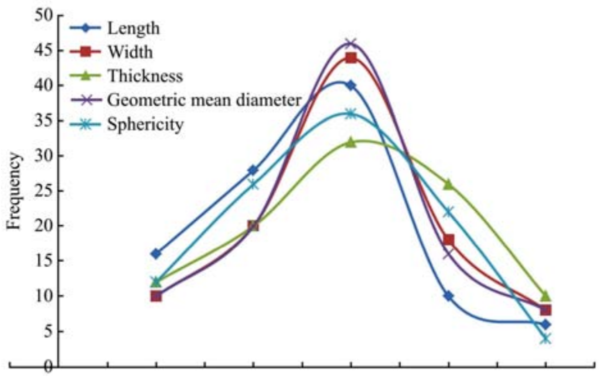
3.2 Size and shape

A summary of the axial dimension which was the means of 50 replicates with the standard deviation (S.D.) are presented in Table 1, while the frequency distributions for the dimensions are presented in Figure 3. The mean dimensions were 77.68(13.24), 96.98(17.88) and 87.86(11.73) mm in length; 47.15(5.06), 53.8(4.57) and 54.32(5.21) mm in width; 50.93(5.97), 57.61(5.64) and 59.03(5.73) mm in thickness. The overall mean length, width and thickness for the three harvest dates were 87.51(9.65), 51.78(4.01) and 55.86(4.33) and were taken as the representative dimensions of *tawain* fruit.

Table 1 Summary of axial dimensions of *tawain* fruits at three moisture levels

Period of Harvest (with Moisture content %)		*L* (mm)	*B* (mm)	*T* (mm)	*Dm* (mm)	Sp	Ra
First Harvest (58.95)	Min	52.84	35.28	38.73	41.64	0.60	0.46
	Max	112.60	59.33	62.91	73.87	0.91	0.86
	Mean	77.68	47.15	50.93	56.99	0.74	0.62
	S. D	13.24	5.06	5.97	6.88	0.06	0.08
	Skewness	0.39	0.00	7.14	0.10	0.05	0.39
	Kurtosis	0.14	0.09	–0.42	0.31	0.22	0.64
Second Harvest (57.41)	Min	60.09	41.77	41.03	46.88	0.57	0.41
	Max	138.5	61.58	68.76	80.64	0.89	0.83
	Mean	96.98	53.8	57.61	66.84	0.70	0.57
	S. D	17.88	4.57	5.64	7.43	0.07	0.08
	Skewness	0.17	–0.63	–0.74	–0.58	0.23	0.53
	Kurtosis	0.47	0.31	0.75	0.50	0.30	0.86
Third Harvest (55.93)	Min	67.00	41.50	48.72	54.96	0.59	0.41
	Max	108.00	66.40	71.80	79.79	0.86	0.79
	Mean	87.86	54.32	59.03	65.44	0.75	0.62
	S. D	11.73	5.21	5.73	6.42	0.05	0.07
	Skewness	0.12	0.43	0.36	0.57	0.18	0.39
	Kurtosis	–1.11	0.08	–0.59	–0.59	–0.73	–0.40

The means of the geometric diameters over the harvest dates were respectively 56.99(6.88), 66.84(7.43) and 65.44(6.42) mm; sphericity of 0.74(0.06), 0.70(0.07) and 0.75(0.05) and aspect ratio of 0.62(0.08), 0.57(0.08) and 0.62(0.07). The overall means of geometric mean diameter, sphericity and aspect ratio were 63.09(5.32) mm, 0.73(0.03) and 0.6(0.08) respectively. The sphericity fall within the range of 0.32 and 1.00 reported for most agricultural produce (Mohsenin, 1986; Irtwange and Igbeka, 2002). The closer the sphericity to 1.0, the higher the tendency of the fruit to roll about any of the three axes and the closer the ratio of thickness to width to 1.0, the higher the tendency to rotate about the major axis (Aremu and Fadele, 2011). The sphericity obtained indicates the possibility of *tawain* fruits to roll relatively well while the aspect ratio indicated that the fruit is of ellipsoid shape hence will roll easily about the longitudinal dimension.



Dimension					
Length (mm)	52.84-64.79	64.79-76.74	76.74-88.69	88.7-100.64	100.6-112.5
Width (mm)	35.28-40.09	40.09-44.90	44.90-49.71	49.71-54.52	54.52-59.33
Thickness (mm)	38.73-43.57	43.57-48.41	48.41-53.25	53.25-58.09	58.09-62.93
Geometric mean diameter (mm).	41.64-48.09	48.09-54.54	54.54-60.99	60.99-67.44	67.44-73.89
Sphericity	0.60-0.66	0.66-0.72	0.72-0.78	0.78-0.84	0.84-0.91

Figure 3 Frequency distribution of axial dimensions of *tawain* fruit at first harvest (MC1)

Analyses of the dimensions as presented in Table 2 showed that moisture content had significant effect (p<0.01) on the length, width, thickness, geometric mean diameter, sphericity and aspect ratio. The results showed that the mean length of *tawain* fruit at MC3 was higher than MC1 but less than that of MC2 and are all significantly different. According to Koo and Reese (1977) a moisture stress of any duration after a fruit is matured reduces the size of the fruit and that the reduction is never entirely regained. The longer length during the second harvest indicated that the hanging nature of the fruit on the tree before harvest resulted in shrinking only at the axial dimensions but not on the longitudinal whose fibres were still under tension. Further drying before the third harvest resulted in shrinking along the longitudinal dimension as the fibres were becoming dryer. The width, thickness, geometric mean diameter, sphericity and aspect ratio were significantly higher (p<0.01) at the third harvest date compared to the first harvest date. However, significant differences (p<0.01) were not observed in the second and third harvest dates except for the longitudinal length (Table 2). The knowledge related to shape and physical dimensions of *tawain* fruit is useful in screening to separate foreign materials and in sorting and sizing of the fruits as well as determining how many fruits can be placed in shipping containers. The major axis finds use in indicating the natural rest position of the fruit while the importance of sphericity and aspect ratio is in determining the shape of the fruit. These dimensions are useful data in designing of machine components.

Table 2 Summary of ANOVA results for the axial dimensions of *tawain* fruits

Moisture content	L (mm)	B (mm)	T (mm)	D_m (mm)	Sp	Ra
MC1	77.675^a	47.152^a	50.926^a	56.999^a	0.699^a	0.569^a
MC2	96.983^c	53.859^b	57.611^b	65.401^b	0.742^b	0.617^b
MC3	88.270^b	54.130^b	58.902^b	66.836^b	0.746^b	0.620^b

Note: Means with same letter(s) across rows (along column) are not significantly different at p<0.01.

The frequency distributions (with skewness and kurtosis) for the dimensions during the first harvest as presented in Table 1 are shown in Figure 3. The curves show a trend towards a normal distribution for all the parameters with the peaks being around the means. The trends obtained for the other two periods of harvest (not shown) are similar. This shows that the axial dimensions are relatively uniform and these are useful information in the design of separation and size reduction systems. Skewness characterizes the degree of symmetry of a distribution around its mean. Positive skewness indicates a distribution with an asymmetric tail extending towards more positive values (skewed to the right) and vice versa for negative. Kurtosis characterizes the relative peakedness or flatness of a distribution compared to the normal distribution.

3.4 True and bulk densities

The true density of *tawain* fruits varied in a decreasing order from 903.90-981.80 kg m^{-3}, 882.90-984.00 kg m^{-3} and 845.70-959.20 kg m^{-3} for MC1, MC2 and MC3 respectively (Table 3). The result shows that the fruit is lighter than water and as such will float in water. This is useful in the design of cleaning and separation machines to remove sinkable materials from the fruit. According to Aviara et al. (2007) true density would be necessary in the determination of the equivalent sphere effective diameter of the fruits. Also, the bulk density ranged from 496.25-499.63 kg m^{-3}, 487.50-502.50 kg m^{-3} and 460.63-499.38 kg m^{-3} respectively. The overall average which was taken as the representative value of the bulk density was 481.98 kg m^{-3}. This value is close to but less than that obtained for *gbafilo* fruits (Davis and Zibokere, 2011) and higher than that for nutmeg (Burubai et al., 2007).

Table 3 Physical properties of *tawain* fruits at the three moisture levels

Moisture content (%)	True density (kg/m^3)	Bulk density (kg/m^3)	Porosity	Angle of repose (^{o})
MC 1	945.0 (34.5) a	499.6 (2.7) a	0.47 (0.02) a	29.1 (2.7) a
MC 2	930.0 (37.1) a	494.3 (5.5) a	0.47 (0.02) a	30.8 (5.1) a
MC 3	912.7 (50.2) a	484.9 (17.2) a	0.47 (0.04) a	32.4 (4.2) a

Note: Means with same letter (s) across rows are not significantly different at p<0.05.

Analysis of variance indicates that moisture content had significant effect (p<0.01) on the bulk density but not on true density. The decrease in bulk density of *tawain* fruits might be due to the increase in size with harvest date, which gives rise to a decrease in the quantity of fruits occupying the same bulk volume. Altuntas and Erkol (2010) observed the same trend for shelled and kernel Walnuts.

The mean porosities were all obtained as 47% for MC1, MC2 and MC3. Bulk density, true density and porosity have practical applications in predicting physical structure and chemical composition, affect resistance to airflow of the stored mass and are useful in sizing hoppers and storage facilities, transport and separation systems; they can affect the rate of heat and mass transfer of moisture during aeration and drying (Irtwange and Igbeka, 2002; Mohammad and Reza, 2010; Simonyan et al., 2009). The results obtained for porosity of *tawain* fruit points to the fact that there is considerable amount of voids between the fruits and this implies that there will be free air flow during heat treatment resulting in better heat transfer. The porosity of *tawain* fruit is close to that obtained for *Siah mashad* cultivars of sweet Cherry fruit (Naderiboldaji et al., 2008) and were within the range for *Doum* palm fruit (Aremu and Fadele, 2011).

3.5 Angle of repose

The angle of repose ranged from 27.1°-33.6° (2.65°), 25.1°-35.9° (5.10°) and 25.7°-36.7° (4.18°) for MC1, MC2 and MC3 respectively (Table 3). The representative value of the angle of repose is the overall average of the three moisture levels which is 30.8°±3.98°. The values for *tawain* falls within the range of obtained for green gram (Nimkar and Chattopadhyay, 2001) and lower than those for tacca tubers (Raji and Ahemen, 2008). For all the harvest dates (moisture contents), there was no significant increase in angle of repose. However, the value was highest at the third harvest date compared to the first and second harvest dates. This property could be useful in the design of storage and transporting structures for the fruits.

3.6 Compressive strength of *tawain* fruit

The mean with the standard deviations of the compressive strength at the three harvest periods are presented in Table 4. During the initial harvest date, the *tawain* fruits offered less compressive stress, which increased proportionally to the reduction in moisture content, that is, through the second harvest date. However, it appeared that it had become harder during the third harvest date. Hence a low compressive stress at break. It was observed that tenderness of the fruit when wet and its hardness when dry contributed to the trend. This tendency may be due to the gradual change in the integrity of the cellular matrix, with the reduction in moisture content (Gupta and Das, 2000). For both axes at all harvest dates, there was no significant difference (p<0.01) in the force required to break *tawain* fruits though lower at second harvest. It was observed that as the force at break decreased at second harvest date with a corresponding increase in deformation for both compression axes, hence lower energy. This period could be regarded as the appropriate period for breaking the fruit with corresponding moisture content. The transverse loading orientation recorded higher resistance to force at break with lower deformation. Also, the force deformation obtained at second harvest indicates that for forces closer to those at first and third harvest higher deformation were obtained hence tendency to break. These findings are important as they give the energy requirement and consideration governing equipment selection in size reduction operations. Gurhan et al. (2001) reported that rupture force increased as deformation rate increased for apricot fruit. This behavior is similar to what was obtained in a study by Kalkan and Kara (2011) where the deformation at rupture point of wheat grains was found not to show any regular variation with the moisture content.

Table 4 Strength of *tawain* fruits at break

Harvest Date	Longitudinal Axis			Transverse Axis		
	First	Second	Third	First	Second	Third
Stress at break (MPa)	0.024^{a}	0.405^{b}	0.028^{a}	0.055^{a}	0.527^{b}	0.042^{a}
Force at break (N)	137.782^{a}	127.340^{a}	159.952^{a}	189.966^{a}	165.563^{a}	237.085^{a}
Deformation at break (mm)	9.723^{a}	10.049^{a}	9.785^{a}	7.772^{a}	10.029^{a}	8.296^{a}
Strain at break (mm mm^{-1})	0.098^{a}	0.648^{b}	0.097^{a}	0.076^{a}	0.647^{b}	0.083^{a}
Energy at break (J)	0.649^{a}	0.637^{b}	1.119^{a}	1.185^{a}	0.819^{a}	1.463^{a}

Note: Means with same letter(s) across rows are not significantly different at p<0.01.

The trend in the deformation at break resulting from increase in harvest date is similar to the trend for stress and is indicative of the *tawain* fruit firmness during the second harvest date as the moisture content reduced from first to third harvest dates. Contrary to this however Krokida et al. (2000) reported that changes in the mechanical properties are caused by moisture loss, so that the mechanical resistance tends to be lower for apple and banana. According to Gonçalves et al. (2005) the total moisture content decreases in the course of ripening process, evincing that the pumpkin pulp (*Cucurbita moschata* and *Cucurbita maxima*) becomes dryer and this reduction in moisture content tends to cause an increase in firmness, as fruits tend to lose flexibility, when they lose water. An increase in the mechanical properties, on the other hand, has been reported for reductions in the moisture content (Ribeiro et al., 2007).

4 Conclusions and recommendations

In this study, the effect of harvest date on some physical properties of *Tawain (Hexalobus crispiflorus*) fruits was determined. However, it is obvious there are still facts about the fruit which are not known but the information obtained in this study will go a long way in providing necessary data for the design of handling, processing and storage equipment for the fruit. To this end further researches are recommended on propagati on methods and proper management of planted trees in order to promote *tawain* for planting as a fruit tree, the engineering properties of *tawain* seeds in order to have a detailed report about the fruit, evaluation of the changes in quality/properties of the fruit with a view to determining effective means of storage and determination of the nutritional properties of *tawain* fruit so as to fully exploit its food and economic value.

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Nomenclature

abbreviations	
$MC_{(wb)}$:	moisture content in percent wet basis
w_i:	initial weight of fruits before oven drying
W_f:	final weight of fruits after oven drying
L:	longest intercept (Length of fruit)
B:	longest intercept normal to L (width)
T:	longest intercept normal to 'L' and 'B' (thickness)
D_m:	geometric mean diameter
ψ:	sphericity
ρ_t:	true density
W_t:	individual mass
V_t:	volume
ρ_b:	bulk density
W_b:	bulk weight
(V_b):	bulk volume
ε:	porosity
φ:	angle of repose
H:	height
D:	base length