Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.2020.v01i02.015

Turk J Agr Eng Res
(TURKAGER)
e-ISSN: 2717-8420
2020, 1(2): 415-424

Research Article

Moisture Influences of Some Physical and Gravimetric Properties of Ackee Apple Seeds (*Blighia sapida*)

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ABSTRACT

This research evaluated and determined some moisture-influenced physical and gravimetric properties of *Blighia sapida* seeds relevant to machine design at 11.9, 17.0, 22.0, 27.0 and 32.0% moisture levels (wet basis). These properties are vital in handling and seed process design. With increasing seed moisture (11.9 to 32.0%), there was no statistically significant effect on the seed axial dimensions, principal diameters, sphericity and surface area. This is because seed axial dimensions relatively determine other properties afore stated. However, there were significant and linear increases in thousand seed mass (189.3 – 230.3 g), bulk (377.0 - 418.3 kg m^{-3}) and true (714.3 - 771.1 kg m^{-3}) densities but decrease in porosity was not significant. Increase in bulk and true densities is due to the rate of increase in the seed mass being more rapid than the rate of increase in its volume, as the seed moisture increased. A non-linear decrease showed in seed volume (3.4-3.2 cm^3). Behavioral patterns of ackee seeds and their investigated properties, under increasing moisture was expressed using regression models. Required primary data for the design of handling techniques and process machinery for ackee apple seeds were generated.

RESEARCH ARTICLE

Received: 19.08.2020
Accepted: 20.10.2020

Keywords:

- Bulk density,
- Length,
- Porosity,
- Sphericity,
- Surface area

To cite: Sadiku OA, Omogunsoye D (2020). Moisture Influences of Some Physical and Gravimetric Properties of Ackee apple Seeds (*Blighia sapida*). Turkish Journal of Agricultural Engineering Research (TURKAGER), 1(2): 414-423. *https://doi.org/10.46592/turkager.2020.v01i02.015*

INTRODUCTION

Ackee apple (*Blighia sapida*) hails from a family called *Sapindaceae* and it is a native of Jamaica and West Africa, which includes Nigeria among other countries. *Ackee* trees exist as wild and spread over the humid parts of the Nigerian agro ecological zone. They are usually up to 18 m in height, large in size and known for dense dark green leaves (providing canopy) and having bright, red fruits (Keay *et al.*, 1989). Propagation of ackee is by seed planting, use of cuttings or by grafting. Omosuli (2014) quoted Lancashire in his work that the ackee tree produces long (7.5 – 10 cm), lipid-bearing fruits all through the year having January - March and June – August as peak seasons for fruiting.

The ackee fruit has an oval shape, which makes it look capsule-like, having three fleshy valves. The ackee fruit experiences a self-split opening when mature and ripe. At this stage, it contains three or more black seeds attached to cream-colored arils (Figure 1).

Figure 1 (a): Split Ackee fruit at maturity; **(b):** Dried Ackee seeds without arils.
Source: (a) Anonymous (2020); (b) Laboratory experiment (2020)

The arils are eaten when cooked or fresh as meat substitute in meals: this is common in South West of Nigeria. The Arils are eaten as a meal in Jamaica where it is also produced as canned food. All parts of the ackee apple tree are useful in traditional medicine in Nigeria, Ghana, Côte d'Ivoire, Togo and Republic of Benin for treating different ailments. Ackee apple seeds are used to treat vomiting and nausea: they are pounded and used to treat stomach related problems. Also, the aqueous extracts from the seeds can be also be used to get rid of parasites like termites. In addition, the whole fruit except the aril is used for soap making and for fishing (Ekue *et al.*, 2009). Bello *et al.* (2012) revealed that Congo Red Dye can be removed from aqueous solutions using the extract from ackee seeds as adsorbent. Onuekwusi *et al.* (2014) found out that oil extracted from ackee seeds can be used in the production of therapeutic agents and industrial oil. However, handling and processing of ackee fruits and seeds had been manual hitherto, especially in Nigeria. Therefore, if all the benefits of ackee seed must be commercialized, its handling and processing must be mechanized which requires the knowledge of its engineering properties. This knowledge is very necessary to generate baseline data needed in developing handling equipment and processing machinery generally for biomaterials. Food scientists also use this same knowledge to discover and develop new uses for existing biomaterials. Example, porosity, bulk and true densities are essential physical properties considered in the design of storage structures; design of separation equipment and transport systems; determination of airflow resistance during aeration and drying of seeds; and the determination of the power requirement of the dryer. Aperture size and shape on separating screens are determined by the seeds' principal diameters and shape. Meanwhile, agricultural materials undergo a number of important changes in their internal structure due to moisture content changes (Andrejko and Kaminska, 2005).

The processing of *Ackee* apple seeds causes seed moisture changes either by drying or by washing which would definitely result in seed structural changes that may affect the engineering properties of the seeds that would surely influence the behavioral trends of the seeds. In addition, there is hitherto a dearth of knowledge of the behavior of *ackee* seeds influenced by their moisture change. Though the knowledge of the engineering properties of seeds is wide, this research work determined the physical and gravimetric properties of ackee apple seeds subject to their moisture changes as part of the process of bridging the knowledge gap earlier stated. Researchers have reported the effect of moisture content on the engineering properties of seeds or grains among which are Milani *et.al.* (2007) for Cucurbit seeds; Ghodki *et.al.* (2016) for Cassia seeds; Davies (2010) for Arigo seeds; Malik and Saini (2016) for Sunflower seeds; Abubakar and Benjamin (2019) for Moringa seeds.

MATERIAL and METHODS

Sample collection

Ackee seeds samples were got from Lanlate, Oyo State (7° 36′ 0″ North, 3° 27′ 0″ East), South – Western part of Nigeria where ackee trees grow predominantly. The ackee seed lot was cleaned by removing debris, damaged and immature seeds. Afterwards, the seeds were dried in air under a shade. Determination of the initial seed moisture was by drying few seeds in the Oven at 103 ± 1^{0}C for 72 hours (ASAE, 1999) and the seed lot later divided into five bulk samples of equal weight. Distilled water at calculated amount was added to each of Four seed sample lots to obtain four different desired seed moisture levels viz: 11.9 – 32% at about 5% interval. This is to cover ackee apple seeds' moisture content at harvest, when air – dried and when soaked and washed in water during processing. The calculation was done using equation 1 below.

$$W_m = \frac{M\,(MC_f - MC_i)}{100 - MC_f} \quad (1)$$

W_m = amount of water in grams (g) to be mixed with the samples;
M = quantity of seed sample in grams (g);
MC_f and MC_i = the seed sample's desired final and initial moisture content in wet basis respectively (Davies, 2010; Bajpai *et al.*, 2020; Jaiyeoba *et.al.,* 2020).

Doubled, low density black polythene bags were used to package each sample to preserve the moisture content. For Five days, a refrigerator was used to store the seed samples at 5°C (Davies, 2010). This allows moisture to circulate uniformly in each seed sample lot. Each time an experiment was to be carried out, the needed seeds quantity was removed from refrigerated samples. The seeds taken are left in the laboratory for one hour to equilibrate with ambient temperature.

Physical properties
Seed dimension

30 seeds from each sample were picked at random. With Vernier caliper (0.05 mm accuracy), the values of length, breadth and thickness of each seed were taken. (Andrejko and Kaminska, 2005; Kumar *et.al.,* 2018).

Mean diameters
Seed axial measurements were used to determine mean diameters (Arithmetic and Geometric) as given in equations 2 and 3. (Kumar *et al.,* 2018; Jaiyeoba *et.al.,* 2020).

$$A_d = \frac{(X+Y+Z)}{3} \quad (2)$$

$$G_d = (XYZ)^{1/3} \quad (3)$$

Length is given as X, width as Y and thickness as Z in cm.

Area of seed surface
Equation (4) below was adopted in calculating the seed surface area.

$$S_a = \pi\, {G_d}^2 \quad (4)$$

S_a and G_d are area of surface and geometric mean diameter respectively. (Ofori *et.al.,* 2019; Oyerinde *et.al.,* 2020).

Sphericity
Sphericity was obtained using the equation (5) below as given by Abubakar and Benjamin (2019):

$$\varphi = \frac{(XYZ)^{1/3}}{X} \quad (5)$$

Sphericity is φ and other parameters given as in equations 2 amd 3.

Gravimetric Properties
Volume of seed
The liquid displacement method was adopted for determining seed volume. 20 ml of Toluene (C_7H_8) was poured into a measuring cylinder and individual seed was dropped into the cylinder to record the displaced volume. The displaced toluene volume is the seed volume. Experiment was repeated Five times for each sample lot. Toluene was used based on low dissolution power, low surface tension and its low seed absorption compared to water. (Milani *et al*., 2007).

Mass of thousand seeds
Hundred seeds were selected at random and weighed using an electronic weighing balance. Thousand seed mass was obtained by multiplying a hundred-seeds mass by 10 which was repeated Five times for each sample lot. (Milani *et al*., 2007; Jaiyeoba *et al.,* 2020).

True density

Same method used for seed volume experiment was adopted here except for the Ten grams of ackee seeds dropped in toluene to record the displaced volume. The ratio of ten grams seeds to its displaced volume is the true density of the seeds. The experiment was also replicated Five times. (Bajpai *et al.*, 2020).

Bulk density

This experiment was carried out by filling a 320 ml beaker to the brim with ackee apple seeds and weighed on a digital weighing balance. Five taps were made on the beaker to ensure a consolidating filling of the beaker while removal of excess seeds was done with a flat to level up the beaker surface. The ratio of the mass of seed bulk to the beaker volume which it occupies is the seed bulk density. The experiment was replicated Five times. (Abubakar and Benjamin, 2019; Bajpai *et al.*, 2020). The following equation was used to determine Bulk density:

$$\rho_b = \frac{m}{v} \qquad (6)$$

Where ρ_b = bulk density in kg m^{-3}; m = mass of the seed sample; and v = volume of beaker (also taken as volume of seed sample).

Porosity

Porosity was determined by the equation (7) stated below.

$$P = \frac{(\rho_t - \rho_b)}{\rho_t} 100 \qquad (7)$$

P is the porosity, ρ_t and ρ_b as true and bulk densities respectively. Bulk and true density results were used to determine porosity for each replicate of the samples. (Milani *et.al.*, 2007; Abubakar and Benjamin, 2019; Bajpai *et al.*, 2020)

Analysis of results

Results were analyzed with Analysis of Variance (ANOVA) using Genstat Discovery Edition 4. Least Significant Difference (LSD) was adopted for separation of means at 5% probability level.

RESULTS and DISCUSSION

Physical properties

The effect of seed moisture on the physical properties of ackee apple that were assessed was not significant (at 5% level of significance) as shown in Table 1.

Table 1. Means of the Physical properties of Ackee seeds under moisture influence

Moisture content (%)	Length (cm)	Width (cm)	Thickness (cm)	Arithmetic dimension (cm)	Geometric dimension (cm)	Surface area (cm^2)	Sphericity %
11.9	2.45 ± 0.19	1.82 ± 0.13	1.42 ± 0.12	1.90 ± 0.13	1.85 ± 0.12	10.78 ± 1.40	0.76 ± 0.04
17.0	2.39 ± 0.13	1.79 ± 0.08	1.38 ± 0.09	1.85 ± 0.08	1.81 ± 0.07	10.27 ± 0.84	0.76 ± 0.02
22.0	2.41 ± 0.11	1.82 ± 0.09	1.42 ± 0.09	1.89 ± 0.08	1.84 ± 0.08	10.68 ± 0.92	0.76 ± 0.02
27.0	2.45 ± 0.13	1.84 ± 0.11	1.42 ± 0.11	1.90 ± 0.10	1.86 ± 0.10	10.86 ± 1.18	0.76 ± 0.02
32.0	2.44 ± 0.12	1.87 ± 0.11	1.45 ± 0.11	1.92 ± 0.10	1.87 ± 0.10	11.06 ± 1.20	0.77 ± 0.03

Note: No significant difference at 5% probability level

Seed axes

Seed length, width and thickness of ackee showed no significant difference which means that they are not moisture dependent. It therefore follows that the mean diameters, sphericity and surface area would not show a significant change being dependent on the values of the seeds' three axes. The changes in length, width and thickness of any seed determine its arithmetic and geometric mean diameters, which in turn determine sphericity and shape. The non-significant changes in the seeds' axial dimensions maybe due to the relatively impervious nature of ackee seed coat. Ofori *et.al.* (2019) recorded a similar result for Opeaburoo maize variety in which differences in both seed width and seed thickness were not significant with decrease in seed moisture during drying. The seed moisture and seed axes relationship are expressed in the second-order and third order polynomial equations in Table 2.

Table 2. Regression models showing the physical properties – seed moisture relationship of Ackee seeds

Property	Equation	R^2
Length= X	$X= -92.996x^3 + 64.008x^2 - 13.778x + 3.3372$	0.9979
Width= Y	$Y= 3.048x^2 - 1.0845x + 1.9041$	0.8579
Thickness= Z	$Z = -38.063x^3 + 27.579x^2 - 6.0771x + 1.814$	0.7639
A_d	$A_d = -53.518x^3 + 38.021x^2 - 8.3178x + 2.4374$	0.9382
G_d	$G_d = - 49.752x^3 + 35.522x^2 - 7.7794x + 2.3537$	0.9107
Surface area = S_a	$S_a = - 596.38x^3 + 426.55x^2 - 93.687x + 16.878$	0.9159
Sphericity = Φ	$\Phi = 6E - 05x^2 - 0.0021x + 0.7776$	0.8556

x = Moisture content; A_d = Arithmetic mean diameter; G_d = Geometric mean diameter.

The mean diameters

The mean diameters (arithmetic and geometric) determine the aperture (holes) size used in the design of screens in cleaning and separating machines for grain handling (Davies, 2010). From the result in Table 1, the mean diameters increased as seed moisture increased but not significant. It therefore implies that *ackee* apple seeds, at different moisture contents can be cleaned, sorted or separated using same screens. Regression models showing the relationship between the mean diameters of ackee apple seeds and their moisture content are stated in Table 2.

Surface area

As moisture content increased, seeds' surface area also increased though with a drop at 17% moisture content (Table 1). The increase in surface area was not significant. Surface area is important in determining coverage area when spraying the seeds, residue removal, seeds' rate of respiration, assessment of color and seeds' reflection of light: In heating and cooling processes, it is a necessary factor in determining the transfer of heat and mass; hence for ackee seeds, heating or cooling would be easy and uniform especially when they are moisture laden. Surface area is one of the primary factors affecting reaction rate in biochemical processes involving seeds; therefore, it is expedient to study it (Davies *et al*., 2014). The relationship between moisture content and surface area is shown in Table 2 above.

Sphericity

The average value for sphericity remained constant at approximately 0.76 with increasing moisture content though highest at seed moisture of 32% as presented in Table 1. Omobuwajo *et. al.* (2000) recorded a similar result for ackee apple seeds (75.5%)

though determined at one moisture level of 9.88% wet basis (i.e. not subjected to moisture variation). Seed with sphericity above 70% is considered to be spherical (Garnayak *et al.*, 2008; Jaiyeoba *et.al.,* 2020), therefore *ackee* apple seeds can be regarded as being spherical. High sphericity implies that *ackee* apple seeds will easily roll on surfaces regardless of the moisture content and roll on one another where seed flow is involved. It also determines the shape of aperture where screens are involved in cleaning or separating machines; hence ackee seeds will maintain a spherical shape at different moisture levels therefore aperture shape will not change. The relationship between moisture content and sphericity is shown in Table 2.

Gravimetric properties

Thousand seed mass and individual seed volume:

For *ackee apple* seeds, thousand seed mass increased significantly and linearly from 189.3 to 230.3 g (Table 3) with increasing seed moisture content [11.9 to 32.0% wet basis]. It therefore implies that every moisture addition will result in an increase in seed mass. Similar result was recorded by Aviara *et.al.* (2019) for Mahogany seeds, Zewdu and Solomon (2007) for Tef seeds. The trend and relationship between seed moisture and thousand seed mass are shown in Figure 2.

Table 3. Moisture effect on Gravimetric properties of *Ackee* apple seeds

Moisture content (%)	Seed volume (cm^3)	1000-unit mass (g)	True density (kg m^{-3})	Bulk density (kg m^{-3})	Porosity %
11.9	$3.40^{c} \pm 0.55$	$189.3^{a} \pm 4.78$	$714.3^{a} \pm 0.08$	$377.0^{a} \pm 5.10$	47.22 ± 0.71
17.0	$2.60^{ab} \pm 0.55$	$196.6^{a} \pm 7.36$	$715.8^{a} \pm 36.29$	$387.1^{a} \pm 7.33$	45.84 ± 2.43
22.0	$2.20^{a} \pm 0.45$	$207.6^{b} \pm 8.17$	$725.3^{ab} \pm 24.55$	$384.9^{a} \pm 9.49$	46.85 ± 2.80
27.0	$3.00^{bc} \pm 0.71$	$226.2^{c} \pm 3.22$	$771.0^{b} \pm 42.15$	$411.5^{b} \pm 11.12$	46.50 ± 3.34
32.0	$3.20^{bc} \pm 0.45$	$230.3^{c} \pm 11.97$	$771.0^{b} \pm 42.15$	$418.2^{b} \pm 8.91$	45.60 ± 3.31
LSD	0.723*	10.17*	0.04367*	0.01138*	NS

Note: *Significant at p=0.05. Means along the same column with different letters are significantly different. NS = Non significant

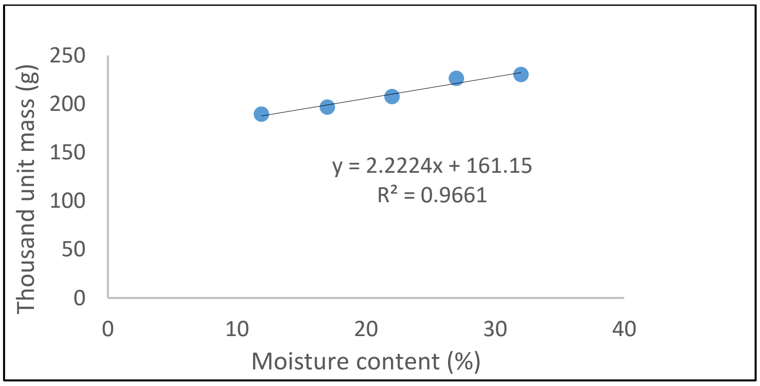

Figure 2. Thousand unit mass of *Ackee* apple seeds as affected by moisture content

A non – linear decrease in seed volume was recorded for ackee apple seeds as revealed in Table 3. The non – uniformity in individual seed size and weight might have accounted for such result since seeds were randomly selected from samples at each moisture level for the experiment. The relationship between seed moisture and seed volume is represented in equation 8.

$$V= 90.53x^2 - 39.763x + 6.79 \qquad R^2 = 0.7906 \qquad (8)$$

Where V is seed volume and x is seed moisture content.

Bulk and true densities

Ackee apple seeds increased in bulk density significantly (377.0 - 418.0 kg m^{-3}) and linearly too (Table 3). Mass of a grain bulk divided by its volume is its bulk density. Therefore, during storage, carriage or transportation, same volume of ackee seeds at higher moisture level will record higher weights than in lower levels of moisture. This is vital in design considerations for type and strength of material required for constructing equipment for storing, transporting or conveying ackee seeds. Same trait holds for true density (714.3 - 771.1 kg m^{-3}). Unal *et al.* (2013), Malik and Saini (2016) and Jaiyeoba *et. al.* (2020) reported similar results for Bitter gourd, Sunflower and Nutmeg seeds respectively. Graph and models showing the behavioral trend, and the relationship between seed moisture and bulk and true densities of ackee apple seeds is in Figure 3.

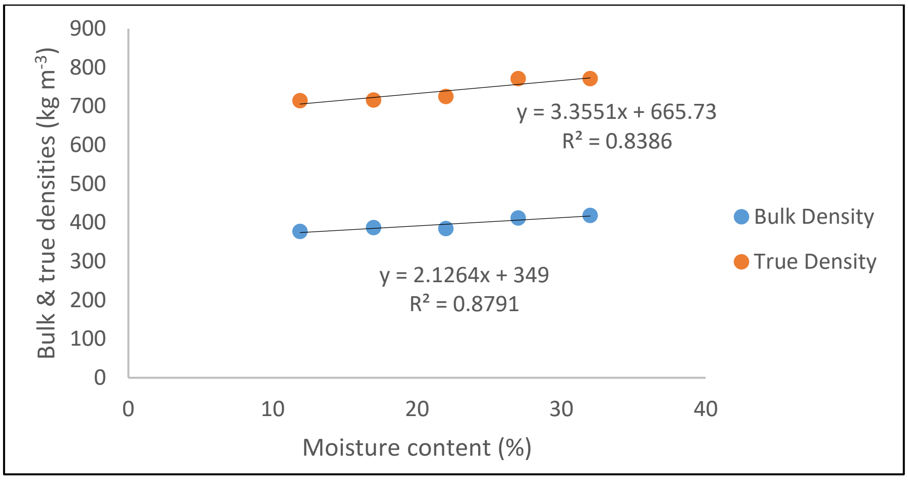

Figure 3. Bulk and true densities of *Ackee* apple seeds as affected by moisture content

Porosity

Porosity for *ackee* apple seeds reduced as seed moisture increased (Table 3) but was not statistically significant. Porosity of a grain bulk material is the ratio of voids (i.e the pore spaces) in it to the space it occupies. It implies that porosity will reveal the magnitude of pores in a grain bulk. In addition, at high moisture content when the seeds are wet on their surfaces, the water film partially fills the pores thereby reducing porosity. This research considered working at high moisture content because of seed washing in water, being part of the processing of the seeds. Porosity is important in packaging of the seeds and affects airflow through seed bulk and the free flow of hot air during drying. Decrease in porosity for ackee seeds with increasing moisture will resist aeration, prolong the drying process, and require more power from the dryer. Igbozulike and Aremu (2009), Sobukola and Onwuka (2010), and Jaiyeoba *et.al.* (2020) reported decrease in porosity for Melon seeds, Locust bean (*Parkia filicoidea*) seeds and Nutmeg seeds respectively.

Revealed in equation 9 is the relationship between ackee seeds' moisture to their porosity.

$$\varepsilon = -1923.2x^3 + 1256.7x^2 - 262.24x + 63.809 \qquad R^2 = 0.8373 \qquad (9)$$

where ε = porosity and x = moisture content

CONCLUSION

1. Physical and gravimetric properties of Ackee seeds were determined relative to increased seed moisture.
2. To predict the behavioral pattern of *Ackee* apple seeds under moisture influence, regression equations were generated.
3. The developed baseline data required for equipment and machine design is a proof that mechanization of ackee apple seeds' handling and processing is possible.
4. Appropriate and safe handling techniques for Ackee apple seed can be developed through the knowledge of the relationship between the properties and its moisture content as revealed by the regression models.

DECLARATION OF COMPETING INTEREST

On behalf of my co-author, I declare that we have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Olajide Ayodele Sadiku: The collection and preparation of samples; data analysis and interpretation; final editing of the manuscript.
David Omogunsoye: Performing the experiments; data analysis and interpretation; and writing the first draft of the manuscript.

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