INVESTIGATION OF SOME MOISTURE DEPENDENT CHARACTERISTICS OF MAIZE (*ZEA MAYS*) KERNELS

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ABSTRACT

The study was carried out to determine moisture-dependence of some physical properties of Sammaz14 and 37 at dry and soaked conditions with the moisture content variation of (13.5±0.02% - 19.07±0.03% (wb) and 12.8±0.52 - 17.43±0.02% (wb), respectively. The results showed that the physical properties of the two maize varieties significantly varied with moisture content. Mean values of length, width, thickness, arithmetic mean diameter (Da), geometric mean diameter (Dg), square mean diameter (Ds), equivalent diameter (De), surface area (As), sphericity (∅) and aspect ratio (Ra) of the seeds varied in from 11.07±0.56 - 12.01±0.90 mm, 7.81±0.68 - 9.54±0.67 mm and 3.31± 0.46 - 4.65±0.45 mm, 7.40±3.91-8.73±3.75 mm, 5.63±4.46-7.69±3.96 mm, 2.72±0.04-2.96±0.04 mm, 5.25±0.05-6.46±0.04 mm, 99.60±0.01-185.68±1.6 mm^2, 0.60±0.02-0.69±0.01 and 0.71±0.02 and 0.79±0.02 for sammaz14 and from 10.96±0.77-11.39±0.76 mm, 8.80±0.58-9.09±0.71 mm and 4.13±0.41-4,44±0.47 mm, 7.96±0.03 - 8.31±0.03 mm, 7.35±0.03 - 7.71±0.03 mm, 2.82±0.02 - 2.88±0.02 mm, 6.04±0.04 - 6.3±0.3 mm, 169.74±2.94 - 186.77±2.02 mm^2, 0.16±0.03 - 0.18±0.03 and 0.80±0.02 - 0.83±0.03 for sammaz37, respectively. Mean values of mass, volume true density, bulk density and porosity of the seed varieties also varied with moisture content. The true density, bulk density and porosity varied from 0.92±0.03-0.88±0.03 kg/m^3, 0.86±0.02-0.79±0.02 kg/m^3 and 7.00±2.00-10.00±1.99 for sammaz14 and from 0.91±0.02-0.86±0.02, 0.88±0.02-0.69±0.03 and 3.00±0.04-20.00±0.04 for sammaz37, respectively. The mean values of angles of repose and the coefficients of static friction of the seed varieties also varied with moisture content. Given that values of angles of repose for the seed varieties varied from 51.00±2.55º – 62.00±3.00º for sammaz14 and from 50.00±2.00º – 62.00±2.55º for sammaz37, respectively. While values of coefficient of static friction of the seeds against plywood, galvanized iron and plastic glass surfaces varied from 0.45±0.04 – 0.55±0.02, 0.31±05 – 0.38±0.01 and 0.25±0.06 – 0.30±0.01 for sammaz14 and from 0.46±0.02 – 0.57±0.04, 0.330.01 – 0.40±0.04 and 0.27±0.01 – 0.35±0.03 for sammaz37, respectively. The result of this research could be used as a valuable data and information for design of postharvest handling facilities, equipment and machines for maize and other related crops.

Keywords: Data base, Maize kernels, Moisture dependence, Physical properties, Post-harvest handling
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INTRODUCTION

Maize (*Zea mays* L.) is one of the most versatile cereal crops in the world and third next to wheat and rice. It is an important cereal crop which serves as staple to large population of sub-Saharan Africa, Asia and North and South America [1, 2]. Maize production is estimated at 856 million tons over 158 million hectares worldwide, with Nigeria being the largest producer in sub-Saharan Africa, with about 43% of the total maize production in West Africa [2]. It is an important and the cheapest source of carbohydrates, protein, iron, vitamin B and minerals for human being and animals and serves as an ingredient to thousands of industrial products that include starch, oil, protein, alcoholic beverages, sweeteners, pharmaceutical, cosmetic, plastics, fabrics, gum, package and paper industries [3, 4]. Maize is an affordable cereal which is easy to process, readily digestible and contains 60-80% starch, 8-12% protein, 3-5% fat, 1-5% minerals and considerable proportion of vitamins [5]. It is a major source of dietary fiber and calories which can be processed into different breakfast items, food and feed ingredients, and beverages for its consumption throughout the world [6]. Maize is a good source of energy with a huge economic, nutritional and medicinal importance, essential for human diet [7]. Despite the huge economic importance of maize and its significant role in food requirements of the entire populace in Nigeria, lack of efficient postharvest handling facilities, equipment and machines for proper shelling, cleaning, grading, dehulling, milling, packaging and storage poses a great challenge to farmers [8]. To improve postharvest handling, processing and storage of grain crops using suitable and efficient post-harvest handling and processing facilities, equipment and machines requires adequate knowledge of physical properties of their kernels [9].

Knowledge of physical properties constitutes important and essential engineering data in the design of machines, storage structure and processes [10]. Scientific data on physical properties of biological materials in relation to their moisture content is of great importance as a basis for design or selection of appropriate equipment and machines for processing operations such as drying, shelling, winnowing, separation, grading and aeration as well as equipment for planting, harvesting and storage [11, 12]. The amount of moisture in maize cobs has a significant effect on the number of seed breakage during shelling and dehulling and deterioration in storage [13]. To Process maize either from cobs to kernels or from kernels to flour or dehulling the kernels require some form of changes in the moisture content of the produce, either by drying or soaking [14].

The absorption and desorption of moisture from any agricultural material is partly influenced by its physical properties. Information on the difference in physical property of biomaterials is helpful for data collection in the design of post-harvest machines, structures, processes and controls; and in determining the efficiency of a machine or an operation. Although there have been a lot of researches on physical properties of many agricultural crops, literatures on the combined effects of moisture variations on physical properties of kernels of locally grown maize varieties appear to be scanty [15]. The objective of this study was to investigate some physical properties of Sammaz14 and sammaz37 maize varieties at different moisture content levels.

MATERIALS AND METHODS

Material collection and preparation

Sammaz14 (white) and sammaz37 (yellow), two locally developed maize varieties from the Seed Production Unit of the Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria, Nigeria, were used for the study. Bulk samples of the two maize varieties were cleaned manually to remove all undesirable materials such as chaffs, cobs, stones, insects and damaged, unhealthy and immature seeds. The moisture contents of the seeds at dry and soaked conditions were determined by dividing the two bulk samples into two equal parts (A and B), each. The moisture content of part A was taken with the seeds dry, while the moisture content of part B was taken after soaking the seeds in distilled water for six (6) hours at room temperature. Conducting two experiments, the first experiment determined the physical properties of the two maize seed varieties at dry condition, while the second experiment determined the physical properties of the maize seed varieties at soaked condition [16]. The initial moisture contents of the two maize seed varieties (sammaz14 and 37) were determined by oven drying method at 105 ± 1°C for 24 hrs [17]. The part B of the seed varieties was conditioned by adding a desired quantity of distilled water which was mixed thoroughly by hand. The moistened samples were sealed in high density poly ethylene bags and kept in a refrigerator at 5±10°C for 24hr for uniform moisture distribution throughout the samples [18]. After equilibration, the moisture content of the samples was determined before each experiment. Prior to the conduct of each experiment, the required quantity of the sample was withdrawn from the refrigerator and reconditioned at room temperature (30±2°C) [19]. The moisture contents of the two maize seed varieties at dry and soaked conditions were determined using the expression below [20]:

$$M=\frac{Wi-Wf}{wi}\ x\ 100 \qquad (1)$$

Where, M = Moisture content of seed sample (%), Wi = initial weight of sample (g) and Wf = final weight of sample (g).

Experimental procedure

One hundred maize grains of sammz14 and 15 at dry and soaked conditions were selected randomly to determine the geometric properties of the seed varieties. For each individual grain, Length (L), width (W) and thickness (T) were measured by using digital Vernier caliper of 0.01mm accuracy [21]. These values were used to calculate the derived values of arithmetic mean diameter (Da), geometric mean diameter (Dg), square mean diameter (Ds), equivalent mean diameter (De), surface area [As], sphericity (∅) and aspect ratio (Ra) of the seeds under dry and soaked conditions of the seeds were determined [22]. True density (ρT), bulk density (ρB) and porosity (ε) were determined using mean values of solid mass (Ms), unit volume (Vs), bulk mass (Mb) and bulk volume (Vb) of the seed varieties at dry and soaked conditions. The solid mass (Ms) of individual seeds was measured using electronic balance of 0.01g accuracy, while the unit volume (Vs) by water displacement method. Individual seeds were dropped separately into a 25ml measuring cylinder filled with toluene up to 20ml. The rise in volume of toluene level indicated the solid volume (Vs) of each seed [23]. The bulk mass (mb) and volume (vb) of the maize kernels were determined by filling a 500ml calibrated beaker of known mass with maize kernels from each of the four batch samples and weighed. Subtracting the mass of empty beaker from the total mass represents the bulk mass (mb) of the seeds contained in the beaker, while the volume of the beaker represents the bulk volume (vb) of the seeds [24]. The angles of repose of the maize seed varieties were calculated using an open-end cylindrical frame of 15 cm diameter and 50cm height. The container was filled with seeds on a flat and smooth surface, gradually raised above the surface and a cone-shaped pile of seeds was formed on the surface. Using a pair of dividers and a metre rule, the height (H) and diameter (D) of the cone were measured [15]. The static coefficients of friction of the two seed varieties were determined using a hollow cylindrical frame against adjustable tilting surfaces of plywood, galvanized iron and plastic glass. Placing the cylindrical hollow frame filled with seeds on the test surface, it was raised slightly so as not to touch the test surface, using a screw device, until the cylinder with seeds began to slide down. The angle of inclination (α) with the horizontal base was measured by a scale provided [26].

Geometric properties

Mean values of tri-axial dimensions were used to determine the derived geometric properties of the seed varieties as follows:

Arithmetic mean diameter (Da):

$$Da = \frac{L+W+T}{3} \text{ mm} \quad (2)$$

Geometric mean diameter (Dg):

$$Dg = (L \times W \times T)^{1/3} \text{ mm} \quad (3)$$

Square mean diameter (Ds):

$$Ds = [\frac{ab+bc+ca}{3}]^{1/3}, \text{ mm} \quad (4)$$

Equivalent mean diameter (De):

$$De = \frac{Da+Dg+Ds}{3} \text{ mm} \quad (5)$$

Surface area (As):

$$A_s = \pi(D_g)^2 \text{ mm}^2 \quad (6)$$

Sphericity (∅):

$$\emptyset = \frac{Dg}{L} \quad (7)$$

Aspect ratio (Ra):

$$R_a = \frac{W}{L} \quad (8)$$

Where, Da = arithmetic mean diameter, Dg =geometric mean diameter, Ds = square mean diameter, De = equivalent mean diameter, Ra = aspect ratio, A_s = surface area and ∅ = sphericity

Gravimetric properties

Mean values of solid mass (ms) and volume (vs), and bulk mass (mb) and volume (vb) were computed to determine the density and porosity of the two maize seed varieties at dry and soaked conditions.

True density (ρT)

$$\rho t = \frac{Ms}{Vs} \text{ kg/m}^3 \quad (9)$$

Bulk density (ρB)

$$\rho b = \frac{Mb}{Vb} \text{ kg/m}^3 \quad (10)$$

Porosity (ε)

$$\varepsilon = (1 - \frac{\rho b}{\rho t}) \times 100 \quad (11)$$

Where, ρT = true density (kg/m^3), ρB = bulk density (kg/m^3) and ε = porosity.

Frictional properties

The height (H) and the diameter (D) of the spread of pile of seeds on the flat surface and the angle of inclination (α) of the seeds against plywood, galvanized iron and plastic glass surfaces were computed to determine the angle of repose and coefficients of static friction of the seeds, as follow:

Angle of repose (θ)

$$\theta = \tan^{-1}(\frac{2H}{D}) \quad (12)$$

Where, H = height of the cone (mm), D = diameter of spread of the cone shaped pile of the seed (mm)

Coefficient of static friction (μ)

$$\mu = \tan \alpha \quad (13)$$

Where, μ = static coefficient of friction and α = angle of tilt (°).

Data analysis

Descriptive statistics with mean, standard deviation and coefficient of variation as statistical tools was used for the computation and comparison of data generated during the study.

RESULTS AND DICUSSION

The moisture contents of the two maize seed varieties (sammaz14 and 37) at dry and soaked conditions ranged from 13.5±0.02%(wb) -19.07±0.03%(wb) for sammaz14 and from 12.8±0.52% (wb) - 17.43±0.02%(wb) for sammaz37, respectively. Tables 1 presents the variations in geometric properties of sammaz14 and 37 seed varieties with respect to moisture level variation in the seeds at dry and soaked conditions.

Table 1a: Mean geometric properties of dry and soaked sammaz14

Property	Dry			Soaked		
	Mean	**SD**	**CV**	**Mean**	**SD**	**CV**
Moisture content (%)	13.5	0.02	1.48	19.07	0.03	0.15
Length (mm)	11.07	0.56	5.04	12.01	0.90	7.47
Width (mm)	7.81	0.68	8.80	9.54	0.67	7.03
Thickness (mm)	3.31	0.46	13.86	4.65	0.45	9.49
Arithmetic dia. (mm)	7.40	3.91	52.81	8.73	3.75	42.92
Geometric dia. (m)	5.63	4.46	79.17	7.69	3.96	51.46
Square mean dia. (Ds)	2.72	0.04	1.4	2.96	0.04	1.35
Equivalent mean dia.	5.25	0.05	0.95	6.46	0.04	0.62
Surface area (mm$^{2)}$	99.60	0.01	0.01	185.68	1.6	0.86
Sphericity	0.60	0.02	0.18	0.69	0.01	0.06
Aspect ratio	0.71	0.02	2.99	0.79	0.02	2.00

Table1a shows that all selected geometric properties of sammaz14 seeds increased linearly with increase in moisture content. Mean length, width, thickness, arithmetic mean diameter (Da), geometric mean diameter(Dg), square mean diameter (Ds), equivalent diameter (De), surface area(As), sphericity (∅) and aspect ratio (Ra) of sammaz14 seeds at dry and soaked conditions varied in the range of 11.07±0.56 - 12.01±0.90 mm, 7.81±0.68 - 9.54±0.67 mm and 3.31± 0.46 -4.65±0.45 mm, 7.40±3.91-8.73±3.75 mm, 5.63±4.46-7.69±3.96 mm, 2.72±0.04-2.96±0.04 mm, 5.25±0.05-6.46±0.04 mm, 99.60±0.01-185.68±1.6 mm^2, 0.60±0.02-0.69±0.01 and 0.71±0.02 and 0.79±0.02, respectively.

In similar manner, Table1b shows that all selected geometric properties of sammaz37 seed increased linearly with increase in moisture content. Mean length (L), width (W), thickness (T), arithmetic mean diameter (Da), geometric mean diameter (Dg), square mean diameter (Ds), equivalent diameter (De), surface area (As), sphericity (∅) and aspect ratio (Ra) of sammaz 37 seeds at dry and soaked conditions varied in the range of 10.96±0.77-11.39±0.76 mm, 8.80±0.58-9.09±0.71 mm and 4.13±0.41-4,44±0.47 mm, 7.96±0.03 - 8.31±0.03 mm, 7.35±0.03 - 7.71±0.03 mm, 2.82±0.02 - 2.88±0.02 mm, 6.04±0.04 - 6.3±0.3 mm, 169.74±2.94 - 186.77±2.02 mm^2, 0.16±0.03 - 0.18±0.03 and 0.80±0.02 - 0.83±0.03, respectively. The results conform to available literature reports that geometric properties of maize kernels increase linearly with increase in moisture content [27], and moisture absorption in the soaked maize kernels causes expansion in the length, width and thickness as well as other geometric properties of the kernels [28].

Table 1b: Mean geometric properties of dry and soaked sammaz37

Property	Dry			Soaked		
	Mean	SD	CV	Mean	SD	CV
Moisture content (%)	12.8	0.52	4.02	17.43	0.02	0.12
Length (mm)	10.96	0.77	6.95	11.39	0.76	6.65
Width (mm)	8.80	0.58	6.61	9.09	0.71	7.86
Thickness (mm)	4.13	0.41	9.95	4.44	0.47	10.20
Arithmetic dia. (mm)	7.96	0.025	0.31	8.31	0.03	0.36
Geometric dia. (m)	7.35	0.03	0.41	7.71	0.025	0.33
Square mean dia. (Ds)	2.82	0.02	0.71	2.88	0.02	0.69
Equivalent mean dia.	6.04	0.04	0.66	6.3	0.3	4.76
Surface area ($mm^{2)}$	169.74	2.94	1.73	186.77	2.02	1.08
Sphericity	0.16	0.025	0.75	0.18	0.025	0.73
Aspect ratio	0.80	0.02	2.5	0.83	0.025	3.16

The result in Tables 2a and 2b presents effect of moisture content on mass and volume as well as density and porosity of sammaz14 and 37 seed varieties at dry and soaked conditions, respectively. The values mass, volume, density and porosity of the two seed varieties varied with variation in moisture content.

Table 2a: Mean gravimetric properties of dry and soaked sammaz14 maize (white)

Property	Dry			Soaked		
	Mean	SD	CV	Mean	SD	CV
Moisture content (%)	13.5	0.02	1.48	19.07	0.03	0.15
Unit mass (g)	0.72	0.1	14.29	0.84	0.1	12.5
Unit vol. (cm^3)	0.78	0.32	16.43	0.96	0.25	10.19
Bulk mass (g)	50.25	2.00	4.00	53.34	2.00	4.00
Bulk vol. (cm^3)	58.65	0.1	1.64	67. 48	0.02	0.59
True density (kg/m3)	0.92	0.03	2.56	0.88	0.03	1.72
Bulk density (kg/m3)	0.86	0.02	2.47	0.79	0.02	3.13
Porosity (%)	7.00	2.00	6.67	10.00	1.99	3.52

Table 2a shows that mean solid mass (ms), solid volume (vs), bulk mass (mb), bulk volume (vb), true density, bulk density and porosity of sammaz14 the seed variety at dry and soaked conditions varied in the range of 0.72±0.1-0.84±0.1 kg, 0.78±0.32-0.96±0.25 m^3, 50.25±2.00-53.34±2.00 kg, 58.65±0.1-67.48±0.02 m^3, 0.92±0.03-0.88±0.03 kg/m^3, 0.86±0.02-0.79±0.02 kg/m^3 and 7.00±2.00-10.00±1.99, respectively.

The result in Table2b also shows that the mean solid mass (ms), solid volume (vs), bulk mass (mb), bulk volume (vb), true density, bulk density and porosity of sammaz37 seed variety at dry and soaked conditions varied in the range of 0.60±0.1-0.70±0.1, 0.66±0.02-0.81±0.025, 50.08±2.00-54.15±2.00, 56.84±1.34-78.48±2.05, 0.91±0.02-0.86±0.02, 0.88±0.02-0.69±0.03 and 3.00±0.04-20.00±0.04, respectively.

Table 2b: Mean gravimetric properties of dry and soaked sammaz37 maize (yellow)

Property	Dry			Soaked		
	Mean	SD	CV	Mean	SD	CV
Moisture content (%)	12.8	0.52	4.02	17.43	0.02	0.12
Unit mass (g)	0.60	0.1	16.67	0.70	0.1	14.29
Unit vol. (cm^3)	0.66	0.02	1.00	0. 81	0.025	1.26
Bulk mass (g)	50.08	2.00	4.00	54.15	2.00	4.00
Bulk vol. (cm^3)	56.84	1.34	2.14	78.48	2.05	2.62
True density (kg/m3)	0.91	0.02	1.24	0.86	0.02	1.35
Bulk density (kg/m3)	0.88	0.02	2.5	0.69	0.03	4.94

Porosity (%)	3.00	0.04	0.79	20.00	0.04	0,70

The results show that all the gravimetric properties, with exception of true density and bulk density, increased linearly with increase in moisture content. True density and bulk density at dry and soaked conditions decreased from 0.92±0.03kg/m^3 – 0.88±0.03 and 0.86±0.02 – 0.79±0.02kg/m^3 for sammaz14, and from 0.91±0.02 – 0.86±0.02kg/m^3 and 0.88±0.02 – 0.69±0.03kg/m^3 for sammaz37, respectively, with increase in moisture content of the maize seeds. Similar trend of decrease in true and bulk densities were reported for lentil seed [29] and red bean grains [30]. Trends of increase in porosity with increase in moisture content have also been reported for lentil [29] and sweet corn seeds [31].

The result in Tables 3 presents the effect of moisture content on the frictional properties of sammaz14 and 37 maize seed varieties. The angles of repose and coefficients of static friction of the two maize seed varieties varied with moisture content.

Table 3a shows that mean values of angles of repose for sammaz14 seeds on a horizontal wooden platform and the coefficients of static friction against plywood, galvanized iron and plastic glass surfaces varied in the range of 51±2.55º - 62±3.00º and from 0.45±0.04 - 0.55±0.02, 0.31±0.05 - 0.38±0.01 and 0.25±0.06 - 0.30±0.01, respectively, with increase in moisture content.

Table3a: Mean frictional properties of dry and soaked sammaz14 maize (white)

Property	**Dry**			**Soaked**		
	Mean	**SD**	**CV**	**Mean**	**SD**	**CV**
Moisture content (%)	13.5	0.02	1.48	19.07	0.03	0.15
Angle of repose	51.00	2.55	5.00	62.00	3.00	4.84
Coef. of static friction						
Plywood	0.45	0.04	10.00	0.55	0.02	5.26
Galvanized iron	0.31	0.05	7.22	0.38	0.01	5.44
Plastic glass	0.25	0.06	7.14	0.30	0.01	5.37

Similarly, in Table 3b, the mean angles of repose the sammaz37 seeds on a horizontal wooden platform and the coefficients of static friction against plywood, galvanized iron and plastic glass surfaces varied in the range of 50±2.00º - 62±2.55º and from 0.46± 0.02 – 0.57±0.04, 0.33±0.01 - 40±0.04 and 27±0.01 - 35±0.03, respectively, with increase in moisture content.

Table 3b: Mean values of frictional properties of dry and soaked sammaz37 maize (yellow)

Property	**Dry**			**Soaked**		
	Mean	**SD**	**CV**	**Mean**	**SD**	**CV**
Moisture content (%)	12.8	0.52	4.02	17.43	0.02	0.12
Angle of repose	50.00	2.00	3.39	62.00	2.55	4.18
Coef. of static friction:						
Plywood	0.46	0.02	5.26	0.57	0.04	5.18
Galvanized iron	0.33	0.01	5.24	0.40	0.04	5.17
Plastic glass	0.27	0.01	5.20	0.35	0.03	5.19

The increasing trends of angle of repose due to increase in moisture content for most of biological materials have been reported. The increase in angle of repose with increase in moisture content could be attributed to increase in the internal friction with increase in moisture content. Increase in coefficient of static friction of the maize seeds due to increase in moisture content has been attributed to increase in adhesion characteristics and roughness of the surface of maize [1]. Similar increasing trend for static coefficients of friction have been reported for lentil seed, sweet corn seed, flaxseed, anardana seeds and wheat [1].

CONCLUSIONS

The study was carried out to determine moisture-dependence of some physical properties of Sammaz14 at dry and soaked conditions. From the results, the following conclusions are drawn:

1. The Length, width and thickness of the two maize seed varieties increased linearly with increase in moisture level.
2. The arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent mean diameter, surface area, sphericity and aspect ratio of the seed varieties increased linearly with increase in moisture level.
3. The true density and bulk density decreased linearly from, respectively while porosity increased linearly from with in- crease of the moisture content.
4. The angle of repose of the seeds on a wooden platform decreased linearly, while the static coefficients of friction against plywood, galvanized iron and plastic glass surfaces increased linearly, with increase in moisture level.
5. The highest and lowest coefficients of static friction were observed with plywood and plastic glass surfaces, respectively.

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REFERENCES

1. BARNWAL, P. KADAM, D.M. & SINGH, K.K. (2012). Influence of Moisture Content on Physical Properties of Maize. *International Agrophysics*, **26**: 331-334. Doi:10.2478/v10247-012-0046-2
2. ODIA, F.N. (2015). Adoption of Oba 98 Maize Production Technologies by Farmers in Delta State, Nigeria. A Published Thesis. Department of Agricultural Extension, University of Nigeria, Nsukka. P. 1-10.
3. SANGA, U., OLABISI, L.S. & TASIE, S.L. (2018). System Dynamics Modelling of Maize Production under Future Climate Scenarios in Kaduna, Nigeria. Nigeria Agricultural Policy Project. Feed the Future Innovation Lab for Food Security Policy, Research Paper No**.** 97: 1-20. www.foodsecuritypolicy.msu.edu.
4. SOBUKOLA, O.P., KAJIHAUSA, O.E., ONWUKA, V.I. & ESAN, T.A. (2013). Physical Properties of High-Quality Maize (Swam 1variety) seeds (*Zea mays*) as affected by Moisture levels. *African Journal of Food Science,* **7**(1): 1-8. http://www.academicjournals.org/AJFS
5. AMARE, D., ENDALEW, W., YAYU, N., ENDEBLIHATU, A. & BIWETA, W. (2017). Evaluation and Demonstration of Maize Shellers for Small-Scale Farmers. *Journal of Applied Bionics and Biomechanics*, **1**(3): 00014. DOI: 10.15406/mojabb.2017.01.00014
6. BEYENE, Y., SEMAGN, K., CROSSA, J., MUGO, S., ATLIN, G.N., TAREKEGNE, A. & ALVARADO, G. (2016). Improving Maize Grain Yield under Drought Stress and Non-stress Environments in sub-Saharan Africa using Marker-assisted Recurrent selection. *Crop Science*, **56**(1): 344-353.
7. ADEMILUYI, I.O. (2014). Adoption of Improved Maize Varieties among Farmers in Bassa Local Government Area of Plateau State, Nigeria. *International Journal of Innovative Agriculture and Biology Research*, **2**(4): 26-33.
8. FAO (2007) FAOSTAT Statistics Division of the Food and Agriculture Organization .Available on line: http://faostat.fao.org
9. KAYODE, S.E. & OLORUNFEMI, B.J. (2018). Comparison of Some Physical and Mechanical Properties of Nigerian Local Soybean and Cowpea. *Leonardo Electronic Journal of Practices and Technologies*, **33**: 235-256.
10. ISIK, E. & ÜNAL, H. (2007). Moisture-dependent Physical Properties of White Speckled Red Kidney Bean Grains. *Journal of Food Engineering*, 82: 209-216.
11. OFORI, H., AMOAH, F., ARAH, K.I., AIDOO, I.A. & OKLEY, T.N. (2020). Moisture-dependent Physical Properties of Opeaburoo and Abontem Maize Varieties during Drying. *African Journal of Food Science*, **13**(8): 152-162. https://doi.org/10.5897/AJFS2019.
12. ADINOYI, A., AJEIGBE, H.A., ANGARAWAI, I.I. & KUNIHYA, A. (2017). Effect of Grain Moisture Content on the Physical Properties of Some Selected Sorghum Varieties. International *Journal of Scientific and Engineering Research*, **8**(6): 1797-1805. http://www.ijser.org.
13. ASONYE, G.U., ASOEGWU, S.N. & OHAERI, O.H. (2014). Effect of Moisture Content on Some Physical and Frictional Properties of

African Locust Bean (*Pakia biglobosa*). *Journal of Agricultural Engineering and Technology* (JAET), **22**(4): 24-37. www.niae.net.

14. SEIFI, M.R. & ALIMARDANI, R. (2010). Comparison of moisture-dependent physical and mechanical properties of two varieties of corn (Sc 704 and Dc 370). *Australian Journal of Agricultural Engineering*, **1**(5): 170.
15. BART-PLANGE, A, DZISI, K.A. & AMPAH, J. (2012). Effect of Drying on Selected Physical Properties of "Asontem" Cowpea Variety. ISRN Agronomy, 2012.
16. JIBRIL, A.N., YADAV, K.C., ABUBAKAR, M.S. & BINNI, I.M. (2016). Effect of Moisture Content on Physical Properties of Bambara Groundnut (*Vigna subterranean* L. Verdc.) Seeds. *International Journal of Engineering Research and Technology*, **5**(7): 248-258. http://www.ijert.org.
17. MALIK, M.A. & SAINI, C.S. (2016). Engineering properties of sunflower seed: Effect of dehulling and moisture content. *Cogent Food and Agriculture*, **2**(1): 1145783.
18. SOBUKOLA, O.P. & ONWUKA, I. (2011). Effect of Moisture Content on Some Physical Properties of Locust Bean Seed (*Parkia fillicoidea* L.). *Journal of Food Processing Engineering*, **30**: 1946-1964.
19. BAMGBOYE, A.I. & ADEBAYO, S. (2012). Seed Moisture dependent on Physical and Mechanical Properties of *Jatropha curcas*. *Journal of Agricultural Technology*, **8**(1): 13-26.
20. AZADBAKHT, M., GHAJARJAZI, E., AMIRI, E. & ABDIGAOL, F. (2015). Determination of Some Physical and Mechanical Properties of Pofaki Variety of Pea. *International Journal of Agricultural and Biosystems Engineering*, **9**(5): 486-493.
21. OPADOTUN, O.O., ADEJUMO, A.O., OLOTU, F.B. & MOHAMMED, F.A. (2015). Determination of Some Physical Properties of African Star Apple Seeds (*Chrysophyllum albidum*)**.** Proceedings of the 16th international conference and 36th annual general meeting of the Nigeria Institution of Agricultural Engineering (NIAE). **36**: 268-273
22. SALISU, A.S. (2018). Moisture Level Effect on Some Engineering Design Related Properties of Bambara Nut (*Vigna subterranean L. Verdc*) Seeds. Unpublish Project Report. Samaru College of Agriculture, Ahmadu Bello University, Zaria. P. 1-37.
23. KARABABA, E. & COŞKUNER, Y. (2007). Moisture-dependent Physical Properties of Dry Sweet Corn Kernels. *International Journal Food Processing*, **10**: 549-560.
24. FUMEN, G.A. (2018). Determination of Some Engineering Design Related Properties of Cowpea (*Vigna unguiculata* L.) Seeds. Book of Proceedings of the 2nd ABU SPGS 2018 Biennial Conference, 2018:1273-1280. http://conference.spgs.abu.edu.ng
25. ORHEVBA, B.A., ADEJUMO, B.A. & JULIUS, O.P. (2016). Determination of Some Selected Engineering Properties of Bambara Nut (*Vigna subterranea*) Related to Design of Processing Machines. OSR Journal of Agriculture and Veterinary Science (IOSR-JAVS), **9**(6): 42-47 www.iosrjournals.org
26. FUMEN, G.A. & KAAKUKA, T.K. (2018). Some Engineering Properties of Soybean (Glycine max) Seeds as Related to Primary Processing. *Journal of Engineering and Applied Scientific Research*, **10**(3): 1-26. www.cenresinpub.org
27. SANGAMITHRA, A., SWAMY, G.J., SORNA, P.R., NANDINI, K., KANNAN, K., SASIKALA, S. & SUGANYA, P. (2016). Moisture-dependent Physical Properties of Maize Kernels. *International Food Research Journal*, **23**(1): 109-115. http://www.ifrj.upm.edu.my
28. BALOGUN, A.L., OLANREWAJU, T.O., UTHMAN, F. & SHEHU, A.U. (2015). Determination of Some Engineering Properties of Neem (*Azadirachta indica*) Seed as related to Handling. Proceedings of the 16th International Conference and 36th annual General Meeting of the Nigeria Institution of Agricultural Engineering (NIAE), **36**: 321-327
29. GÜRSOY, S. (2020). Some physical properties of lentil seeds affected by harvest time. *Agricultural Science and Technology*, **12**(3): 264-271. http://www.agriscitech.eu
30. SINGH, Y. & CHANDRA, S. (2020). Study to assess physical properties of different types of kidney beans (*Phaseolus vulgaris*). *Journal of Pharmacognosy and Phytochemistry*, **9**(2): 2455-2459. www.phytojournal.com
31. COSKUN, M.B., YALCÝN, I. & OZARSLAN, C., (2006). Physical properties of sweet corn seed (*Zea mays* saccharata Sturt.). *Journal of Food Engineering*, **74**: 523-528.