4th International Engineering Conference (IEC 2022)
Federal University of Technology, Minna, Nigeria

Determination of Physical and Mechanical Properties of Some Selected Varieties of Commonly Grown Maize in Nigeria

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ABSTRACT

Knowledge of physical and mechanical properties of maize grains is significant in designing a processing machine whose energy depends on these properties**.** The aim of this study is to determine the physical and mechanical properties of some commonly selected varieties of maize grown in Nigeria, namely SAMMAZ/14, SAMMAZ/15, SAMMAZ/17, SAMMAZ/37, and SAMMAZ/50. Linear dimensions (length, width (W), thickness (T)) and moisture contents of Undehusked maize (leaf) kernel and seeds of each variety were determined. Angle of repose, bulk density, geometric mean diameter, deformation, compressive strength, and rapture energy measurements were also performed on each of the maize seeds varieties. Results shows the average linear dimensions of Undehusked maize (leaf) kernel and seeds varieties determined in terms of length, width (major, minor), thickness (major, minor) of SAMMAZ/14, SAMMAZ/15, SAMMAZ/17, SAMMAZ/37 and SAMMAZ/50 are 457.7mm, W(31mm, 27mm), T(6mm, 9.4mm), 565mm, W(40mm, 31mm), T(7mm, 5.5mm), 7.450mm, W(32mm, 19mm), T(5mm, 9mm), 426mm, W(29mm, 23mm), T(6mm, 3.4mm), 610mm, W(46mm, 19mm), T(4.1mm, 2.4mm) and 11mm, W(9.6mm, 7.4mm), T(4.4mm, 6mm), 9.5mm, W(9.3mm, 6.9mm), T(4mm, 3mm), 9.0mm, W(9.2mm, 7mm), T(4.1mm, 2.9mm), 9.3mm, W(8.8mm, 2.3mm), T(1.4mm, 3.4mm), 6.1mm, W(8.6mm, 7mm) T(4mm, 3.5mm), while moisture contents for both undehusked maize (leaf) kernels and seed varieties were 16%, 17%, 20%, 16%, 21% and 17%, 16%, 16%, 11%, 12% respectively. Average angle of repose, Bulk density, geometric mean diameters, deformation, compressive strength and rapture energy of the maize seed SAMMAZ/14, SAMMAZ/15, SAMMAZ/17, SAMMAZ/37 and SAMMAZ/50 varieties are 22.2^o, 0.71gcm^{-3}, 8.4mm, 1.201mm, 2.7N/mm^2, and 0.0840Nm, 20.1^o, 0.72gcm-^{3}, 8.1mm, 2.123mm, 6.6N/mm^2, and 0.1907Nm, 24.0^o, 0.70gcm^{-3}, 7.1mm, 0.825mm, 8.8N/mm^2, and 0.165Nm, 23.3^o, 0.8gcm^{-3}, 6.2mm, 0.132mm, 3.34N/mm^2, and 0.066Nm and 22.5^o, 0.76gcm^{-3}, 6.3mm, 0.456mm, 3.4N/mm^2 and 0.0228Nm. To prevent kernel damage during processing and handling, the measured rapture energy and compressive strength during compression can be used as the limit value for designing machine.

Keywords: *Animal Feed, Machine design, maize, mechanical, physical, varieties.*

1 INTRODUCTION

Corn (Zea mays L) ranks as the third most important cereals corps in the world. Asian countries are significant producers of sweet maize and more than 62% of their maize production is consumed in the form of animal feed, while the balance is for human consumption.

The knowledge of physical and mechanical properties of crops is essential in the design; fabrication and adjustment of machines utilize in processing, separation, cleaning, handling of Agricultural materials such as maize, and convert them into foods, feed, and fodder.

The properties which are useful during design must be known and these properties must be determined at laboratory conditions. The geometric properties such as size and shape are one of the most important physical properties considered during separation and cleaning of agricultural grains (Barnwal et al., 2012, Ganjeer & Banjare, 2020). Determination of physical properties as function of machine is important to the design of equipment for handling, conveying separation, drying, aeration, storage, and processing. The size and shape are for instance importance in their separation from undesirable material and in the development of sizing and grading machinery (Adesokan *et al.*.2019). Determination of physical and aerodynamic properties of some varieties of wheat, barly, chickpea and lentils, in terms of their length, width, thickness, geometric mean diameter, terminal velocities, drag coefficient of each grain were determined. Average experimental terminal velocity was found to be in the ranges of 7.52 to 8.14m/s for wheat varieties, 7.72 to 7.78m/s for lentil varieties and 11.15mto 12.01m/s for chickpea varies. S. Gursoy and E. Guzel (2010). Ahmadi and Mollazade. (2009) determined the physical and mechanical properties of funnel (seeds) as a function of moisture content. The angle of repose was used to select the angle at which the trapezoidal section of the hopper was slanted. The bulk density and moisture content were used to determine the uniformity of distribution of the maize seed, while the machine is in operations.

Adesokan (2019) cited criteria for evaluating performance of dehusking- shelling mechanism include dehusking-shelling efficiency grain loss, grain damage, output capacity, cleaning efficiency, power equipment and dehusking shelling recovery. These criteria are measured against some variables namely crop moisture content, cylinder dehusking, shelling speed, crop federate, concave clearance, cylinder diameter and dehusking, shelling length. Crop material which are of importance include moisture content biometric properties such as size of grain spent cob ratio, grain bulk density, sphericity, angle of repose, terminal velocity, one thousand grain mass and porosity. For processing of maize product in general and dehusking – shelling in particular, (Isiaka *et al.* 2006) stated, it is necessary to determine some physical properties, which in most cases are dependent on moisture content. These properties include dimension (size shape), bulk density, and porosity, coefficient of static frictions, volume, surface area, angle of repose and angle of internal friction. Dula (2019) pointed out their practical utility in machine and structural design process and control engineering. Physical properties of agricultural product are studied by considering them individually due to their irregular shape and variability in sizes.

Understanding mechanical properties of maize kernel reduces mechanical damage through establishing and developing the mechanical system of harvesting, dehusking-shelling. Mechanical properties such as compressive strength, rapture forces, modulus of elasticity, rapture energy, deformations and others are important engineering data needed in studying size reduction of maize. Mechanical damage decreases seed corn viability and result in lower yields. Researchers have conducted many investigations to solve problems related to serial products through their mechanical properties (Wang, B. & Wang, 2019). Mechanical properties of fresh maize corn kernels were obtained for two varieties. White dent corn single hybrid 10 and yellow dent maize corn kernel single hybrid 155 at different moisture content ranged from 30.26 to 988 (w.b%).The mechanical properties obtained for white maize corn kernel include yield energy (YE), rapture energy (RE), at a moisture content of 9.81% and the yellow maize corn kernel obtained were yield energy (YE), and rapture energy (RE) at moisture content of 10.12% (Mohammed and Abdelmaksond (2009).

To determine some physical and mechanical properties of five selected varieties of commonly grown maize in Nigeria, was carried out.

2.0 LITERETURE REVIEW

Pradhan et al. (2008) stated that the repose angle of corn seeds increased with seed moisture content from 8.56% to 22.22%. The values were observed to rise from 27.69^0 to 37.33^0. The tendency towards the repose angle with moisture content takes place because of the surface layer of moisture around the particles, which holds the total seeds together by surface tension.

Esehaghbeygi et al. (2009) measured the shear stress of canola stalk for four levels of moisture content (35%, 43%, 50% and 57%, wet basis), with different cutting heights, two kinds of varieties, three levels of the fertilizer. The knife oblique angle of 30 º was found to apply the slightest shearing pressure.

Ince et al. (2005) reported that bending stress was less with increasing moisture content. The estimation of the compressing bending got was about two times at low moisture content compared with high moisture content. The mean compressing bending ranged from 9.71 to 47.49 MPa.

Batos et al. (2015) conducted a study on the wheat stalks. The cutting tests were done for two cutting velocities and two cutting angles. The moisture content of the samples ranged from 5.5% to 7.1%. The main cause for this difference was the greater friction at the larger cutting angle.

According to Miu (2016) the mechanical and physical properties of plant stalks affect their behavior under the impact of the mechanical forces exerted through the harvester combine, in terms of plant curvature (towards cutting unit), cutting (shear stress), and pick up cob. To assist modeling, emulation, and optimizing of combine operations, it is absolutely required to consider credible experiential data. For some properties after harvesting of the cereal stalks, these presented plant stalk data depends on ripeness of plant, and environmental conditions during harvesting. This means that consideration should be given to physical properties of the maize corn plant and the related mechanical properties of the plant components, which is crucial in the process of modeling and engineering design of agricultural machines.

Knowledge of all the mechanical properties of biological materials is necessary for the layout of technological processes as mentioned by Szymanek et al. (2006).

3.0 METHODOLOGY

Undehusked maize (leaf) kernel used in this study was purchase and experiment was conducted in Ahmadu Bello University (Zaria) Nigeria in 2019 include SAMMAZ/14, SAMMAZ/15, SAMMAZ/17, SAMMAZ/37 and SAMMAZ/50 varieties. The grain varieties were collected through the seed production unit of Instituted of Agricultural Research (IAR) Zaria. The Undehusked maize (leaf) kernel measuring 5kg of each variety was measured and their linear dimensions were taken, including their moisture content of each variety. Similarly, the seeds, of similarly varieties, measuring 5kg samples for each grain variety and randomly selected for the measurement of their linear dimensions (Length, width, and thickness) of each variety was measured. All the seeds were clean manually to remove all foreign matters, broken seeds, and dust e.t.c.

The dimensions of each seed, namely length, width and thickness were measured in three directions by using Vernier caliper with 0.001/mm accuracy.

3.1 Determination of geometric mean diameter. (d_g)

Geometric mean diameter measurement is used to for the design of concave sieve radius of the processing machine. Equations (1) was used to determine the geometric mean diameter of each variety of the maize seed (Mohsenin, 1980)

$$D_g = (abc)^{\frac{1}{3}} \quad (1)$$

$where$

$d_g = \text{ geometric mean diameter in mm}$

$a = \text{ length of seed in mm}$

$b = \text{ width of seed in mm}$

$c = \text{ thickness of seed in mm}$

3.2 Determination of Bulk density (ℓ_b)

Bulk density is used in determination of uniformity of distribution of Agricultural material while the machine is in operation. It is the ratio of mass to volume and express in g/m^3. The bulk density of the five varieties of maize were determined by weighing the grains in a measuring cylinder of known volume of (1000cm^3) and the weight of the seeds obtained as outlined by Waziri and Mittal (1983) using equation (2).

$$\ell_b = \frac{M_1 - M_2}{V} \quad (2)$$

$Where\ \ell_b = \text{ Bulk density in gcm3}$

$M_1 = \text{ mass of filled container in, gram}$

$M_2 = \text{ mass of empty container in gram}$

$V = \text{ measured volume of container, } 1000cm^3$

3.3 Determination of Angle of repose (O_F)

The angle of repose of the five varieties of maize was obtained. Angle of repose of grain is the angle the seed made with the horizontal at which the grain will stand when filled. It was obtained with the aid of an open container of 45cm and 20cm diameter and height respectively.
A container of 45cm diameter was filled with the grain after positioning it on a high round plat form. The container was removed gradually until the grain formed a shape of a cone. The height of the shaped cone was measured, and angle was computed as reported by Mustafa (2021) using equation (3). The same procedure was carried out for the remaining four varieties of the maize.

$$\Theta_F = tan^{-1}\frac{2H}{D} \quad (3)$$

$Where\ \Theta_F = \text{ Angle of repose}$
$H = \text{ height of shape cone formed, m.}$
$D = \text{ Diameter of shape cone form, m.}$

3.4 Determination of Moisture content (M.C)

Moisture content is used in determination of uniformity of grains materials while the machine is in operation.
Moisture content of five varieties of Undehusked maize (leaf) kernel and the maize seed of each varieties of the selected maize of SAMMAZ/14, SAMMAZ/15, SAMMAZ/17, SAMMAZ/37, and SAMMAZ/50 at a moisture content of 16%, 17%, 20%, 16%, 21% of Undehusked maize (leaf) and of maize (seeds) at moisture content of 17%, 16%, 16%, 11%, and 12% was determined respectively (Mohsenin, 1980), using the same equation as stated in equation, 4.

$$M.C = \frac{W_1 - W_2}{W_1} \times 100 \quad (4)$$

Where,
$M.C. = \text{ moisture content}$
$W_1 = \text{ weight of Undehusked (leaf) before heating, kg.}$
$W_2 = \text{ weight of Undehusked (leaf) after heating, kg.}$
$Similarly,$
$\text{Moisture content of maize (seed) was determined using the equation (5)}$

$$M.C_1 = \frac{W_6 - W_7}{W_6}\ x\ 100\% \quad (5)$$

Where;

$M.C_1 = moisture\ content\ of\ maize\ seed$

$W_6 = weight\ of\ maize\ seed\ before\ heating\ (kg)$

$W_7 = weight\ of\ maize\ seed\ after\ heating\ (kg)$

3.5 Determination of compressive strength and rapture energy of maize seeds

The forces and deformation at the time of rapture of the grain samples between the base plate and the plunger head of universal materials testing machine (cat.Nr.261) was read directly from the universal testing machine, Ahmadu Bello University Zaria. The machine was operated in accordance with ASAE (2003). The values of the raptures forces, deformations were obtained directly from the machine. While the compressive strength, and the rapture energy was calculated using equation (6) and equation (7) from the results of rapture forces, and the deformation for the five varieties of the maize samples

$$Cs = \frac{F}{A} \qquad (6)$$

$$E_a = \frac{FD}{2} \qquad (7)$$

$Where\ C_s = compressive\ strength$

$F = rapture\ force, N.$

$A = x - sectional\ area, m^2$

$E_a = Rapture\ energy, joules$

$D = Deformation\ (mm)$

Table 1: Present the Linear Dimensions of the five selected varieties of Undehusked maize (leaf) kernel.

S/N	Sample	Length (L) mm	Width (w), mm		Thickness (t) mm	
			Major	Min	Major	Min
	SAMMAZ/14					
1		500	30	25	6.5	4.5
2		450	35	28	5.2	3.3
3		420	29	27	5.0	4.7
	Average value	457.7	31	27	6	9.4
	SAMMAZ/15					
1		605	40	35	7.5	5.8
2		550	45	30	6.0	4.7
3		540	35	28	7.0	5.5
	Average Value	565	40	31	7	5
	SAMMAZ/17					
1		400	35	20	6.5	5.6
2		430	30	22	4.5	2.5
3		520	32	15	4.7	3.2
	Average value	450	32	19	5	9
	SAMMAZ/37					
1		450	27	20	6.5	3.3
2		420	29	26	6.2	3.4
3		410	30	22	5.2	3.2
	Average Value	426	29	23	6	3.4
	SAMMAZ/50					
1		620	25	15	5.2	2.2
2		600	30	25	4.0	2.4
3		610	46	19	4.1	2.4
	Average Value	610	46	19	4.1	2.4

Table2. Presents the Linear Dimension, Angle of Repose, Bulk Density, and geometric mean

S/N	Sample	Length (L) mm	Width (w), mm		Thickness (t) mm		Angle of Repose (a)	Bulk density (g/cm^3)	Geometric diameter (g) mm
			Major	Min	Major	Min			
	SAMMAZ/14								
1		11.5	10.2	7.4	4.8	4.0			
2		10.8	9.9	8.0	4.4	3.0	22.2	0.71	8.4
3		9.4	8.6	6.8	4.0	2.9			
	Average value	11	9.6	7.4	4.4	6			
	SAMMAZ/15								
1		9.5	9.4	6.9	3.6	2.5			
2		10	9.2	7.6	3.8	2.8	20.1	0.72	8.1
3		9.0	9.2	6.3	4.7	3.7			
	Average Value	9.5	9.3	6.9	4	3			
	SAMMAZ/17								
1		9.0	9.4	7.9	4.0	3.1	24	0.70	7.1
2		9.0	9.1	6.8	4.0	2.5			
3		8.8	9.2	6.0	4.2	3.0			
	Average value	9.0	9.2	7	4.1	2.9			
	SAMMAZ/37								
1		10.2	10	2.2	6.5	3.3			
2		9.0	8	2.6	6.2	3.4	23.3	0.8	6.2
3		8.8	8.5	2.2	5.2	3.2			
	Average Value	9.3	8.8	2.3	1.4	3.4			
	SAMMAZ/50								
1		6.2	8.7	6.8	4.3	4			
2		6.0	8.0	6.2	4.2	3.8	22.5	0.76	6.5
3		6.1	9.0	7.9	3.4	2.6			
	Average Value	6.1	8.6	7	4	3.5	22.4	0.74	22.4

Table 3: illustrate the deformation, compressive strength, and rapture energy of the five Selected Varieties of Maize (Seeds)

S/N	Sample	Sample force (N)	Load (KN)	Deformation (mm)	Compression strength (N/mm^2)	Rapture Energy (NM)
1	SAMMAZ/14	140	0.14	1.201	2.7	0.0840
2	SAMMAZ/15	180	0.18	2.123	6.6	0.1907
3	SAMMAZ/17	400	0.4	0.825	8.8	0.165
4	SAMMAZ/37	100	0.1	0.132	3.34	0.0066
5	SAMMAZ/50	100	0.1	0.456	3.4	0.0228
Average Value		184	0.25	4.372	5	0.4512

3. RESULTS AND DISCUSSION

3.1 Physical Properties of the Undehusked Maize (leaf) Kernel.

Determination of the physical properties of undehusked maize leaf kernel is essential, as these parameters are required in the design and operation of harvesting machinery and postharvest machinery for the harvested undehusked maize and other plant biomass. The physical properties of maize plant reported in this study were from the samples taken from Ahmadu Bello University Farm Zaria Kaduna State, Nigeria.

Table 1 presents the five varieties of the physical properties data of undehusked maize (leaf) kernal. The average length of the undehusked maize (leaf) kernal of five varieties are 457.7 mm, 565 mm, 450 mm, 426mm and 610 mm which is higher than range indicated by Szymanek (2011) and Al-Mitewty et al. (2019) this increase may be due to soil type, environmental conditions and the varieties of the maize plant While, the average width (Major, minor) and thickness (Major, minor) of undehusked maize (leaf) kernal of five varieties are W(31mm, 27mm), W(40mm, 31cm), W(32mm, 19mm), W(29mm, 23mm), W(46mm, 19mm) which are within the range indicated by Szymanek (2011) and Al-Mitewty et al. (2019), and T(6mm, 9.4mm), T(7mm, 5.5mm), T(5mm, 9mm), T(4.1mm, 2.4mm) and T(6mm, 3.4mm) respectively.

The average value of the linear dimensions of maize (seed) varieties results (Table 2) shows that SAMMAZ/14 has the highest average length of 11mm, while SAMMAZ/15 has the least average length of 6.0mm which is within the range given by Balami et al. (2012). SAMMAZ/14 has the highest major width of 10.2mm while SAMMAZ/37 and SAMMAZ/50 have the least diameter of 0.8mm each. Minimum width diameter was recorded in SAMMAZ/37 as 2.0mm while SAMMAZ/14 has highest width diameter of 8mm which is within the range given by Szymanek (2011). thickness of maize seed was recorded with SAMMAZ/37 as the highest of 6.5mm major diameter, while SAMMAZ/50 has thickness to be 3.5mm. Minimum diameter of thickness was obtained in SAMMAZ/15 with 2.5mm. And maximum thickness and minimum diameter to be 4mm each in SAMMAZ/14 and SAMMAZ/50.

Moisture content of the Undehusked maize (leaf) kernel of SAMMAZ/14, SAMMAZ/15, SAMMAZ/17, SAMMAZ/37 and SAMMAZ/50 were found to be 16%, 17%, 20%, 16%, 21% respectively. With SAMMAZ/50 has highest moisture content of 21%, while SAMMAZ/14 and SAMMAZ/37 has least moisture content of 16%. Similarly, the various varieties of maize show that SAMMAZ/14 has the highest moisture content of 17%. While SAMMAZ/37 has least moisture content of 11%.

The average value of the load, deformation, compressive strength, and rapture energy of the five selected varieties of the maize seed are 0.25KN, 4.372mm, 5.0 N/mm^2 and 0.4512Nm which agreed with the results of Weronika et al. (2022)

4 CONCLUSION

Physical and mechanical properties of undehusked and maize seed are the most important properties in the design of agricultural machinery to determine standards of designed machine. The length, width, thickness, angle of repose, bulk density, geometric mean diameter, deformation, compression strength, and rapture energy have a significant role in designing maize processing machine component parts which include hopper, concave clearance and holes, cylinder drum and sieve shaker. Knowing the angle of repose, is utilize in the design of the hopper while the bulk density is to determine the stability of flow of the seed when the machine is in operation. Whereas the mechanical properties of the undehusked and maize seed is considerable in designing the dehusked-shelling unit and grinding unit. The average load, deformation, compressive strength, and rapture energy of the five selected varieties of the maize seed are 0.25KN, 4.372mm, 5.0 N/mm^2 and 0.4512Nm.

Symbols

$L = length\ of\ Undehusked\ maize$

$(leaf)\ kernel, mm.$

$W = width\ of\ Undehusked\ maize$

$(leaf)\ kernel, mm.$

$t = thickness\ of\ Undehusked\ maize$

$(leaf)\ kernel, mm.$

$L_1 = length\ of\ maize\ seed, mm.$

$W_1 = width\ of\ maize\ seed, mm.$

$L_1 = length\ of\ maize\ seed, mm.$

$t_1 = thickness\ of\ maize\ seed, mm.$

$d_g = geometric\ diameter$

$maize\ of\ seed, mm$

$\ell_b = bulk\ density, gcm^3$

$v = measure\ volume\ of\ cylinder, cm^3$

$\Theta_f = Angle\ of\ repose\ of\ maize\ seed, o$

$M.C = moisture\ content\ of\ Undehusked$

$maize\ (leaf)\ \%$

$M.C_1 = moisture\ content\ of\ maize\ seeds$

$C_s = compressive\ strength$

$of\ maize\ seed, N/mm2$

$F = force, N$

$A = crossectional\ Area, m^2$

$E_a = rapture\ energy, NM$

$D = Deformation, mm$

$A.V = Average\ value$

SAMMA Z/14 = Sammaru Z/14

SAMMA Z/15 = Sammaru Z/15

SAMMA Z/17 = Sammaru Z/17

SAMMA Z/37 = Sammaru Z/37

SAMMA Z/50 = Sammaru Z/50

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