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sORIGINAL RESEARCH ARTICLE

DETERMINATION OF THE PHYSICO-MECHANICAL PROPERTIES OF THREE CULTIVARS OF COWPEA (VIGNA UNGUICULATA) GRAIN

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ABSTRACT

This study evaluated the physico-mechanical properties of IT89KD-288, Ife brown, and IT98K-573-1-1 varieties of cowpea. The cowpeas were obtained from local farmers in different parts of North Eastern Nigeria. The crop varieties were identified, sundried and cleaned before testing. The results for length, width, thickness, equivalent diameter, arithmetic diameter, sphericity, surface area, volume, mass, angle of repose, frictional angle, and bulk density were obtained at pre-determined moisture contents. Other results for IT98K-573-1-1 seed-chaff ratio, pod angle of internal friction, hardness, compressive force in the major, intermediate and minor axes, shear force in the major, intermediate and minor axes are 4.0±0.18, 44.4±1.0°, 1.46±0.0.99 kgf/mm², 62.0±6.5 N, 38.3±1.6 N, 81.0±11.7 N, 61.0±4.74 N, 45.1±2.4 N, and 76.5±9.8 N respectively. There was significant difference between the physical and gravimetric properties of IT89KD-288, Ife brown, and IT98K-573-1-1 varieties of cowpea.

1.0 Introduction

Cowpea (*Vigna unguiculata (L.) Walp*) is an annual grain legume indigenous to tropical Africa but also cultivated in Latin America, South Eastern Asia and Southern United States (IITA, 2005; Da Silva et al., 2018; Ng and Marechal, 1985). Africa accounts for over 87% of global cowpea production, with Nigeria responsible for 58% of global production (FAOSTAT, 2017 as cited in Nkomo et al., 2021). In Africa, 52% of cultivated cowpea is useful for food, 13% serves animal feed, 10% is utilized for seeds, 9% is used for other purposes, and 16% is wasted (IITA, 2009; Baysah, 2013). Cowpea and other legumes, are responsible for up to 80% of the total protein intake for adults and are wholly the only source of protein for lots of children in West Africa (FAO, 2015). It is also a vital source of soil fertility improvement through the fixation of nitrogen and is relatively drought-tolerant (Nkomo et al., 2021; Olajide and Ilori, 2017).

Rapid and accurate determinations of physical attributes are needed in processing agricultural materials (Stroshine and Hamann, 1995). Physico-mechanic and aerodynamic data of agricultural products are necessary for the development of machines required for several operations ranging from harvesting, separation, handling and storage; and the conversion into food, feed and fodder (Gursory and Guzel, 2010). The size and shape properties of agricultural produce are vital in designing cleaning, grading, conveying equipment, and in thin layer drying (Singh and Meghwal, 2019). Bulk density and true density are used in determining floor space, structural loads, and quality of the product. Porosity is useful in determining other properties like thermal conductivity, volume change, or diffusion coefficient (Kumar et al., 2018). The study of the engineering properties of agro-produce is useful in the design and simulation of food processes and equipment. The angle of repose and coefficient of friction aided the precise development of the hopper, silos and the conveyor belt. The conveyor belt serves purposes ranging from transportation, loading and unloading, dehulling and packaging (Malik and Saini, 2016; Vashishth et al., 2020). In milling operations, the hardness of grains (soft or hard) determines the particle size distribution in the extracted flour (Hrušková and Švec, 2009).

Many studies have been carried out on the properties of cowpea (Soyoye et al., 2020; Kayode et al., 2018; Chukwu et al., 2010), however, only a few went further to observe the pod characteristics as handling begins from the point of harvest (Dalha et al., 2018). This study is to determine some engineering properties of three cowpea varieties that are popular in North Eastern Nigeria. It would offer researchers and agro-processing technologists a tool for furthering development in cowpea processing.

2. Materials and Methods

2.1 *Material Selection and Preparation*

Cowpeas were obtained from Cham community in Gombe state, Ngurore and Sangere areas of Adamawa state directly from farmers as shown in Figure 1. The seeds were taken to the Agricultural Development Programme (ADP) office in Adamawa state for identification. it was identified as IT98K-573-1-1, Ife Brown and Sampea 11 (IT89KD-288). After the identification, the seeds were collected, cleaned and sorted for testing. The oven dry method was used to determine its moisture content prior to testing according to ASAE standards, (2003).

Figure 1: Cowpea varieties commonly grown in parts of north east Nigeria.

2.2 Physical Properties

2.2.1 Dimensions and shape

Sixty whole seeds were selected at random and their corresponding length (L), width (W) and thickness (T) were measured and recorded using a digital Vernier Calliper having a resolution, reliability and maximum error of 0.01 mm, 0.01 mm and 0.02 mm respectively as found in de Araujo et al. (2020). Sphericity (%), Arithmetic mean diameter (D_a)(mm), Equivalent diameter (D_e)(mm), Surface area (S)(mm^2) and Volume (V)(mm^3) were estimated using equations 1, 2, 3, 4, and 5 respectively (Stroshine and Hamann, 1995; Khodobakhshian et al., 2016).

$$\text{Sphericity} = \left(\frac{LWT}{L}\right)^{\frac{1}{3}} \qquad (1)$$

$$D_a = \frac{(L+W+T)}{3} \qquad (2)$$

$$D_e = (LWT)^{\frac{1}{3}} \qquad (3)$$

$$S = \pi {D_e}^2 \qquad (4)$$

$$V = \frac{\pi}{6} {D_e}^3 \qquad (5)$$

where: L = mean length of the seeds (mm); W = mean width of seeds (mm); and T = mean thickness of the measured seeds (mm).

2.2.2 *Mass of cowpea seeds*

The apparatus used were sample container and electric weighing balance. A 1000 whole seed of each variety were selected, placed in a container with known mass; it was weighed and the mass of the container was subtracted from the gross mass. The procedure was repeated 10 times and corresponds with Igbozuike and Aremu (2009). The average mass of the individual seed is estimated as shown in Equation (6) (Mohsenin, 1986),

$$\text{Mass of seed (g)} = \frac{\text{Total mass}}{\text{Number of seeds}} \quad (6)$$

2.2.3 Bulk density

The bulk density is the ratio of the mass sample of the seeds to its total volume. It was determined using procedure outlined by Botelho et al. (2021) by filling predetermined container from a constant height. The bulk density (γ) was determined by filling a 100ml beaker with seeds by dropping them from a height of 150mm and the seeds weighed. Dropping the seeds from a height of 150mm produces a tapping effect in the container to reproduce the settling effect during storage. The bulk density of the sample was calculated as shown in Equation (7).

$$\text{Bulk density } (\gamma) = \frac{M}{V} \quad (7)$$

where: γ is bulk density of cowpea sample, g/cm^3, M is bulk mass of cowpea sample, g, V is bulk volume of cowpea sample, cm^3.

2.2.4 Angle of repose

Sample container, metal funnel and meter rule were used. The metal funnel was erected on flat metal surface. A known quantity of cowpea seed was filled into the funnel by means of the sample container. The funnel was lifted gradually from the flat metal surface to allow the seeds flow freely to form a conical shape on the flat surface (Togo et al., 2018). The height, H(cm) and length of the base of the conical heap, L_B(cm) were measured and the corresponding angle of repose (°) computed following the relationship given by Ozguven and Kubilay (2004).

$$\theta_r = tan^{-1}[\frac{2H}{L}] \quad (8)$$

The procedure was repeated 10 times for each variety and the mean value determined and the values were recorded. Similar method was used by Togo et al. (2018).

2.2.5 *Coefficient of static friction*

The tilting table was used to compute coefficient of static friction. It was determined against plywood. The coefficient of static friction was calculated from Equation (9). The procedure was similar to that found in Dalha et al. (2018).

$$\mu = tan\theta \quad (9)$$

where: μ is the coefficient of static friction and θ is the angle of tilt of the experiment table.

2.3 Mechanical Properties

2.3.1 Compression test

The Instron Universal Testing Machine at the Department of Mechanical Engineering at the Bayero University, Kano (BUK) was used for performing compression test on the cowpea seeds. A seed of cowpea was placed between the two heads of the compressing device while the upper head is lowered at the rate of 1.25mm/min (Chukwu and Sunmonu, 2010). Reading was immediately taken as displayed by the digital force gauge. Ten seeds were observed for each variety and in the three major axis of Major, Minor, and the Intermediate.

2.3.2 Shear strength

Shear strength of the samples were determined using the Universal testing machine at the Department of Mechanical Engineering in Bayero University, Kano. The slots of the tester were screwed to compress the material in-between them. The reading was taken at the instance of the seed crack. This can be observed from the graph and its recordings. Similar process was reported by Chukwu and Sunmonu (2010).

2.3.3 Hardness

Hardness was tested using the Rockwell Brinell Hardness Tester according to ASTM E10-14 test method. The Brinnel Hardness tester is shown in Figure 2. The upper part of the instrument slot was a steel ball indenter with known diameter. It was lowered on the sample with a weighted force (kgf) to create an indentation. The first sound made by the sample when tightly pressed indicates its hardness. The counter reading was taken where the sample was not making a total contact with the tester. The hardness value divided by contact area gives the contact hardness number.

$$BHN = \frac{2P}{\pi D(\sqrt{D^2 - d^2})} \qquad (10)$$

where: BHN is the Brinell Hardness Number (kgf/mm^2); P is the applied load in (kgf); D is the diameter of the indenter (mm); and d the diameter of the indentation (mm).

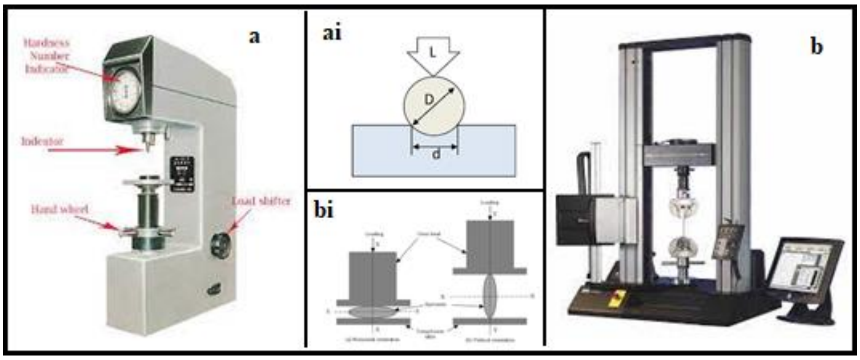

Figure 2. The Brinnel Hardness Tester is shown in (a) and the test demonstration (ai). The Universal Testing Machine (b) demonstrating test of a specimen (bi)

2.4 Statistical Analysis

Descriptive statistics, analysis of variance (ANOVA) and post hoc testing of mean difference using Tukey were computed to test and describe the cowpea varieties. These tests were run with the IBM® SPSS® 26 Statistics (IBM Corp. © Copyright IBM Corporation 2019) and the Microsoft® Office Excel® 2019 Software's for Microsoft Windows.

3. Results and Discussion

3.1 Seed Dimensions

The Table 1 showed the mean dimensions of the three varieties of cowpea tested and the moisture content at which the test was conducted. The dimensions of length, width and thickness for the three varieties of cowpea investigated showed significant difference at ($p \leq 0.01$). The mean comparisons using the Tukey's HSD test indicated that the IT98K-573-1-1, Ife brown and IT89KD-288 differ significantly with one another. With regards to length, the IT89KD-288 is longer while IT98K-573-1-1 is the shortest. The IT89KD-288 is the widest and thickest of the varieties; while Ife brown has the least width and thickness (Table 1). The result for length, width and thickness were similar to results obtained by Nimesh and Sharanagat (2016), and Banjpai et al. (2019) for chicken pea and Jamun (Syzgium cuminii) seeds respectively. The results by Hamid et al. (2016) for red and black cowpea were comparatively smaller. Sieve apertures among other parameters in the designing process of agricultural machines are selected based on grain dimensions (Mohsenin, 1986).

Table 1. Mean and Standard deviation results for length, width and thickness of the cowpea varieties

Variety	MC(%)	N	Length(mm)	Width(mm)	Thickness(mm)
IT98K-573-1-1	11.7+0.26	60	8.27+0.21^a	7.36+0.20^a	5.65+0.16^a
Ife Brown	12.0+0.19	60	9.59+0.14^b	6.99+0.30^b	5.18+0.22^b
IT89KD-288	11.8+0.20	60	11.3+0.11^c	8.57+0.17^c	6.57+0.02^c

All the parameters tested were highly significant at $p \leq 0.001$

3.2 *Arithmetic Mean Diameter (Da) and Equivalent Diameter (De)*

The results for the computed arithmetic mean and equivalent diameter are shown in Table 2 below. The results for Arithmetic mean diameter and Equivalent diameter for the three varieties observed showed significant difference ($p \leq 0.01$). Further mean comparison revealed that the arithmetic mean diameter for IT98K-573-1-1 (Mean, M=7.09, Standard Deviation, SD=0.19), Ife brown (M=7.26, SD=0.22), and IT89KD-288 (M=8.81, SD=0.12) were all significantly different with one another. For Equivalent diameter, IT98K-573-1-1 (M=7.00, SD=0.11) significantly differ from IT89KD-288 (M=8.60, SD=0.11); while Ife brown did not differ with IT98K-573-1-1 (M=7.03, SD=0.21).

3.3 Volume, Surface Area and Sphericity

Volume, surface area and sphericity for all the three varieties tested were significantly different ($p \leq 0.01$). The mean comparison test in Table 2 showed that Ife brown and IT98K-573-1-1 did not differ for volume and surface area. However, all three varieties differ significantly for sphericity ($p \leq 0.01$). A similar trend was reported by Theertha et al. (2014) for black grain; Ehiem et al. (2016) for Canarium Schweinfurthii Engl.fruits and Yalcin (2006) for cowpea seed.

Table 2. Computed values of shape and size for the three varieties from observed dimensions

Variety	Sphericity (%)	Da (mm)	De (mm)	SA (mm^2)	Seed Vol. (mm^3)
IT98K-573-1-1	82.86$\pm$3.2^b	7.09$\pm$0.19^a	7.00$\pm$0.11^a	154$\pm$2.42^a	180$\pm$2.83^a
Ife Brown	73.77$\pm$4.0^a	7.26$\pm$0.22^b	7.03$\pm$0.21^a	155$\pm$4.63^a	182$\pm$5.44^a
IT89KD-288	75.86$\pm$2.4^c	8.81$\pm$0.12^c	8.60$\pm$0.11^b	232$\pm$2.97^b	333$\pm$4.26^b

3.4 1000 Seed Mass

The variety of cowpea studied had significant impact on the seed mass, $F (2, 27) = 1533619$, p=.000. The 1000 seed mass for the three varieties tested showed that every variety is clearly distinct in terms of mass from another. The variety can be identified based on the mass (Table 3). Similar result was reported by Davies and Zibokere (2011) for cowpea seed mass; and by Ehiem et al. (2016) for Canarium Schweinfurthii Engl.fruits.

Table 3. Mean and Standard deviation results for Gravimetric properties of the cowpea varieties

VARIETY	MC	N	1000Seed Mass (g)	Angle of Repose (°)	Angle of Internal Friction (°)	Bulk Density
IT98K-573-1-1	11.7 ± 0.26^{a}	10	203 ± 6.19^{a}	20.7 ± 3.06^{a}	36.1 ± 4.24^{a}	711.3 ± 9.40^{a}
Ife Brown	12.0 ± 0.19^{b}	10	218 ± 5.22^{b}	19.2 ± 3.15^{b}	34.4 ± 3.11^{b}	740.1 ± 8.11^{b}
IT89KD-288	11.8 ± 0.20^{c}	10	359 ± 5.25^{c}	19.7 ± 3.04^{c}	35.5 ± 3.24^{c}	695.7 ± 11.2^{c}

3.5 Angle of Repose and Static Coefficient of Friction

The Table 3 above showed that the results of the angle of repose for IT89KD-288, Ife brown and IT98K-573-1-1 all differ significantly when compared. The mean angle of repose for all three varieties ranged between 19.2° and 20.7° with IT98K-573-1-1 having the larger angle, whereas Ife brown has the least. The observed angle of repose values is higher than those reported by Hamid et al. (2016) for red and black cowpeas; but lower than what was reported in Mirzabe et al. (2021) and Bajpai et al. (2019) for arugula and Jamun (Syzgium cuminii) seeds respectively. Materials with low angles are highly flowable and can be transported using gravitational force or a little energy (Bhattacharya, 2013; Hashemi and Al-Amoudi, 2018).

From the Table 3, the mean comparison test for angle internal friction revealed that all the varieties in the study differ significantly. The mean angle of internal friction for IT98K-573-1-1, Ife brown and IT89KD-288 cowpea varieties are $36.1\pm4.24°$, $34.4\pm3.1°$ and $35.5\pm3.24°$ respectively. Davies and Zibokere (2011) obtained similar result for some three varieties of cowpea studied. The angle of internal friction is an indication of the minimum positioned angle which will guarantee a continuous flow of materials (Mohsenin, 1986).

3.6 Bulk density

The mean bulk densities for IT89KD-288, Ife brown and IT98K-288 are 695.7 g/cm^3, 740.1 g/cm^3 and 711.3 g/cm^3 in that order. The mean comparison showed that all tested varieties differ significantly from the other. It was observed that larger volumes tend to have lesser bulk densities as can be seen with the IT89KD-288. It implies that more can be tightly packed together for small than the larger sized seeds thereby resulting in greater mass per unit volume of space as reported elsewhere by Mirzabe et al. (2021) and Hamid et al. (2016) for arugula seed, and red and black cowpea respectively. Mass, volume and density of agricultural products are vital in designing silos and storage bins, for determining seed purity and maturity evaluation (Gustustafson, and Kjelgard, 2000 as cited in Heidarbeigi et al., 2009).

3.7 Some Mechanical and Gravimetric properties of the IT98K-573-1-1

Besides the aforementioned properties tested for all three varieties of cowpea in this study, the IT98K-573-1-1 was isolated for further testing. The test comprised of Seed-Chaff ratio, Pod angle of friction, Compressive force test, Shear force test, and Hardness test as shown in table 4 below,

3.7.1 Seed-chaff ratio and IT98K-573-1-1 whole pod angle of internal friction

Seed-chaff ratio is the comparison by weight of the cowpea grain collected from a representative pod and the chaff of the pod. In the result presented in Table 4, the seed-chaff ratio for ten pods tested was 4.0±0.18. This data is useful during threshing, while separating pod from the chaff through different outlets.

The result of the angle of internal friction for the pod of cowpea is necessary in threshing, conveying and storage. The result, 44.4°±1.0, means that angular elevation above 44.4° on a plywood will produce sliding of the IT98K-573-1-1 cowpea pod.

Table 4. Mechanical properties of IT98K-573-1-1 cowpea variety

Parameter	N	Min.	Max.	Mean	SD	Range
Seed-Chaff Ratio	10	3.7	4.3	4.0	0.18	0.63
Pod Angle of Friction (°)	10	42.4	46.1	44.4	1.0	3.7
***Compressive Force* (N)**						
a-Major axis	10	53.0	72.	62.0^{a}	6.5	18.6
b-Minor axis	10	35.3	40.2	38.3^{b}	1.6	4.9
c-Intermediate	10	57.9	100.1	81.0^{c}	11.7	42.2
***Shear Force* (N)**						
a-Major axis	10	54.9	69.7	61.0^{a}	4.74	14.7
b-Minor axis	10	41.2	48.1	45.1^{b}	2.4	6.9
c-Intermediate	10	60.8	92.2	76.5^{c}	9.8	31.4
Hardness (kgf/mm^2)	10	0.04	3.18	1.455	0.99	3.14

3.7.2 Compressive force (IT98K-573-1-1)

In this study, it was observed that there was a significant difference between the compressive strength of the three geometrical axes, F (2, 27) = 75.80, P<.001, n_p^2 = .85. Post hoc testing using Tukey's HSD revealed that the Intermediate axis (M=81.0N, SD=11.7) was significantly different from the other geometric axis. Similarly, the Minor axis (M=38.3N, SD=1.6) has the least compressive force requirement; while the Major axis (M=62.0N, SD=6.5) had the comparatively moderate compressive force requirement as shown in figure 3a. The reason why the minor axis and the major had the least force requirement for compressive deformation is due to the dicot nature of cowpea which enables it to shatter along its axis of dicot separation, perpendicular to the direction of the impacting load. The compression test is similar to Nimesh and Sharanagat (2016) for chicken pea seed. The findings indicated that the minimum force required to shatter or rupture a cowpea kernel is 38.3N.

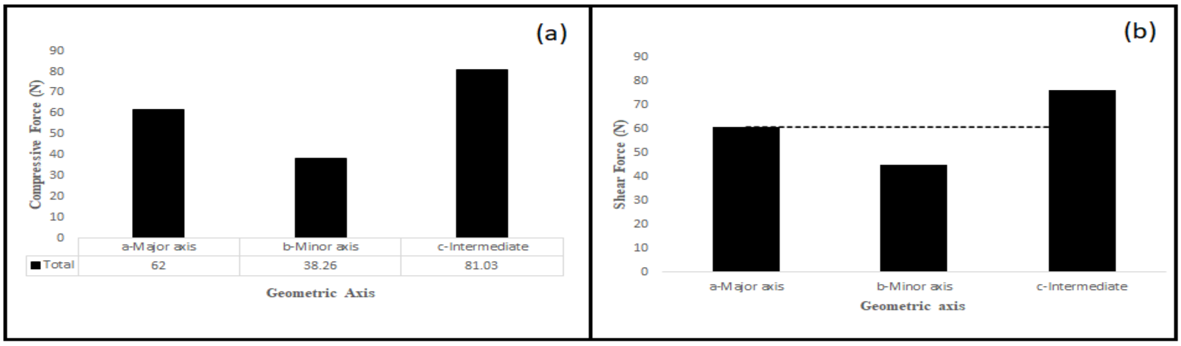

Figure 3. The compressive force **(a)** and shear force **(b)** test result for all three dimensions of the IT98K-573-1-1 cowpea. It was obtained from graphical plot on the computer screen of the UTM machine. It was the point of first failure of the plot.

3.7.1 Shear force (IT98K-573-1-1)

The shear force for IT98K-573-1-1 cowpea variety is presented in table 4 for the major, minor and intermediate axis. There was significant difference among the three geometrical axes on the shear strength, F (2, 27) = 59.9, P<0.001, n_p^2 = 0.82. The mean comparison test revealed significant differences between pairs of geometric axes. The Intermediate axis (M=76.5N, SD=9.76) requires the highest shear force, while the Minor axis (M=45.1N, SD=2.39) requires the least. From the results as represented in figure 3b, the minimum force required to shear a cowpea kernel is 45.1N. The eta square result showed that the geometric axis of the cowpea is the most important main effect of variance.

3.8 Hardness

The mean hardness test for the IT98K-573-1-1 cowpea was 1.455 kg-f/mm^2, and the values ranged from 0.04 to 3.18 kg-f/mm^2 for the 10 samples that were randomly tested. This result can be found in table 4. Material hardness indicates the degree of resistance of the material to various load applied. Chukwu and Sunmonu (2010) recorded grain hardness of 7.98$\pm$0.03kg and 11.96$\pm$3.57kg for the Sampea7 and Tvx 3236 cowpea varieties respectively.

4. Conclusion

The physico-mechanical properties of IT98K-573-1-1, Ife brown and IT89KD-288 varieties of cowpea seeds were determined. They were investigated at an average moisture content range of 11.7 and 12.0%wb. It is clear that the physical and gravimetric properties of cowpea can be used to distinguish its varieties. It is proven that the studied properties of cowpea are necessary for the development of cowpea post-harvest equipment.

References

ASAE S352.2. 2003. Moisture Measurement – Unground grain and seeds. American society of Agricultural Engineers. MI49085-9659, USA. 6-89

Bajpai, A., Kumar, Y., Singh, H., Prabhakar, PK. and Meghwal, M. 2020. Effect of moisture content on the engineering properties of Jamun (*Syzgium cuminii*) seed. Journal of Food Process Engineering, 43(2): 1–8.

Baysah, NS. 2013. Assessing the Effect of Seed Quality Characteristics on the Growth and Yield of Four Cowpea (*Vigna Unguiculata Walp*) Varieties. Postgraduate thesis submitted to the College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Botelho, FM., Botelho, SCC., Menezes-Junior, JAN., Souza, IP. and Araujo, MJI. 2021. Physical properties of Cowpea grains during drying. International Journal of Development Research, 11(7): 48416-48420.

Chukwu, O. and Sunmonu, MO. 2010. Determination of selected Engineering Properties of Cowpea (*Vigna unguiculata)* related to design of processing machines. International Journal of Engineering and Technology, 2(6): 373-378.

Dalha, IB., Yusuf, DD., Yunusa, SU. and Abubakar, M. 2018. Determination of physical and mechanical properties of some selected varieties of cowpea. Proceedings of the 2018 International Conference of the Nigerian Institution of Agricultural Engineers held at the Federal Institute of Industrial Research, Oshodi, Lagos, Nigeria, 10th – 14th Sept. 2018.

Davies, RM. and Zibokere, DS. 2011. Effects of moisture content on some physical and mechanical properties of three varieties of cowpea (*Vigna Unguiculata (L) walp*). Agricultural Engineering International: CIGR Journal, 13(1): 241-250.

Da Silva, AC., Santos, DC. and Junior, DLT. 2018. Cowpea: A Strategic Legume Species for Food Security and Health, IntechOpen, London, UK.

De Araujo, MEV., Barbosa, EG., de Oliveira, ACL., Milagres, RS., Carvalho, PF. and Corea, PC. 2020. Physical properties of yellow passion fruits seeds (*Passiflora edulis*) during the drying process. Scientia Horticulturae, 261.

Ehiem, JC., Ndirika, VIO. and Onwuka, UN. 2016. Effect of moisture content on some physical properties of Canarium Scheinforthii Engl. fruits. Research in Agricultural Engineering, 62:162 – 169.

FAO. 2015. Food Policy and Agriculture; South Africa, Richy Press.

Gürsoy, S. and Güzel, E. 2010. Determination of physical properties of some agricultural grains. Research Journal of Applied Sciences, Engineering and Technology, 2(5): 492–498.

Gustustafson, T. and Kjelgard, J. 2000. Production and Preservation of Animal Feeds. Hill Book Company, New York.

Heidarbeigi, KH., Ahmadi, K., Kheiralipour, A. and Tabatabaeefar, A. 2009. Some physical and mechanical properties of Khinjuk. Pakistan Journal of Nutrition, 8 (1): 74 –77.

Hamid, S., Muzaffar, S., Wani, IA., Masoodi, FA. and Bhat, MM. 2016. Physical and cooking characteristics of two cowpea cultivars grown in temperate Indian climate. Journal of the Saudi Society of Agricultural Sciences, 15(2): 127 – 134.

Hrušková, M. and Švec, I. 2009. Wheat hardness in relation to other quality factors. Czech Journal of Food Sciences, 27(4): 240–248.

Igbozuike, AO. and Aremu, AK. 2009. Moisture dependent physical properties of Garcinia kola seeds. Journal of Agricultural Technology, 5(2): 239-248.

IITA. 2005. Cowpea an Important Legume for Africa and Asia, University Press Ltd. Ibadan, Nigeria.

Kayode, SE. and Olorunfemi, BJ. 2018. Comparison of some physical and mechanical properties of Nigerian Local Soybean and Cowpea. Leonardo Electronic Journal of Practices and Technology, 33: 235-256.

Khodobakhshian, R., Emadi, B., Khojastehpour, M. and Golzarian, MR. 2016. Aerodynamic separation and cleaning of pomegranate arils from rind and white segments (locular septa). Journal of the Saudi Society of Agricultural Sciences, 17: 61-68.

Kibar, H., Ozturk, T. and Esen, B. 2010. The Effect of moisture content on physical and mechanical properties of rice (Oryza Sativa L.). Spanish Journal of Agricultural Research, 8(3): 741-749.

Kumar, MM., Prasad, K., Chandra, TS. and Debnath, S. 2018. Evaluation of physical properties and hydration kinetics of red lentil (Lens culinaris) at different processed levels and soaking temperatures. Journal of the Saudi Society of Agricultural Sciences, 17(3): 330–338.

Malik, MA. and Saini, CS. 2016. Engineering properties of sunflower seed: Effect of dehulling and moisture content. Cogent Food and Agriculture, 2(1): 2–30.

Mirzabe, AH., Hajiahmad, A. and Asadollahzadeh, AH. 2021. Moisture-dependent Engineering Properties of Arugula Seed relevant in Mechanical processing and bulk handling. Journal of Food Process Engineering, 44(6): e13704.

Mohsenin, NN. 1986. Physical Properties of Plant and Animal Materials. 2nd Revised and Updated Edition. Gordon and Breach Science Publishers, New York.

Ng, NQ. and Marechal, R. 1985. Cowpea taxonomy, origin and germplasm. In Cowpea Research, Production and Utilization (Singh, SR. and Rachie, KO. Eds.), John Wiley & Sons, Chichester, NY, USA, 1985., pp. 11–21.

Nimesh, A. and Sharanagat, VS. 2016. Effect of moisture content on engineering properties of chickpea seed. Agricultural Engineering Today, 40(1): 13–21.

Nkomo, GV., Sedibe, MM. and Mofokeng, MA. 2021. Production constraints and improvement strategies of cowpea (Vigna unguiculata L. Walp.) genotypes for drought tolerance. International Journal of Agronomy, 2021, Art. ID 5536417, htttps://doi.org/10.1155/2021/5536417

Olajide, AA. and Ilori, CO. 2017. Genetic variability, performance and yield potentials of ten varieties of cowpea (Vigna unguiculata (L) walp) under drought stress. Legume Genomics and Genetics, 8: 17–25.

Ozguven, F. and Kubilay, V. 2004. Some physical, mechanical and aerodynamic properties of Pine (*Pinu spinea*) nuts. Journal of Food Engineering, 68: 191-196.

Putri, RE., Santosa, S. and Makky, M. 2018. Influence of Moisture content to the physical properties of unhusk rice grain. International Journal on Advanced Science Engineering Information Technology, 8(3): 708-713.

Singh, H. and Meghwal, M. 2019. Physical and thermal properties of various ajwain (Trachyspermum ammi L.) seed varieties as a function of moisture content. Journal of Food Process Engineering, 43(2): e13310.

Soyoye, BO. and Tehinse, TO. 2020. Determination of some physical and mechanical properties of cowpea and groundnut and their effects on the design analysis of a planter. International Research Journal of Engineering and Technology, 7(5): 5158-5164.

Stroshine, R and Hamman, D. 1995. Physical Properties of Agricultural Materials and Food Products, Course Manual. Purdue University, Indiana., pp. 30-89.

Su Y, Cui T, Xia G, Gao X, Li Y, Qiao M, Xu Y. 2021. Effects of different Moisture content and varieties on physico-mechanical properties of maize kernel and pedicel. Journal of food process engineering.

Theertha, DP., Alice, J., Sujeetha, RP., Kavitha Abirami, CV. and Alagusundaram, K. 2014. Effect of moisture content on physical and gravinmetric properties of black grain (Vigna mungol L.). International Journal of Advancements in Research and Technology, 3(3): 97 – 104.

Togo, JM., Wang, D., Ma, W. and He, C. 2018. Effects of moisture content on selected physical and mechanical properties of Alfalfa seeds. Journal of Biology, Agriculture and Healthcare, 8(14): 8-18.

Udoh, JE., Olanyanju, TMA., Dairo, OU and Alonge, AF. 2017. Effect of moisture content on the mechanical and oil properties of soursop seeds. Chemical Engineering Transactions, 58: 361-366, doi:10.3303/CET1758061

Vashishth, R., Semwal, AD., Pal Murugan, M., Govind Raj, T. and Sharma, GK. 2020. Engineering properties of horse gram (Macrotyloma uniflorum) varieties as a function of moisture content and structure of grain. Journal of Food Science and Technology, 57(4): 1477–1485.

Yalçin, I. 2007. Physical properties of cowpea (Vigna sinensis L.) seed. Journal of Food Engineering, 79(1): 57–62