Assessment of Physical and Thermal Properties of Velvet Bean (*Mucuna pruriens)* as Potentials for Development of Processing Machines

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Abstract- The engineering properties of food materials have helped design, develop, and select suitable equipment for preservation, processing, packaging, and storage of food material, including velvet bean, an underutilised legume. Therefore, this research work is aimed at assessing the influence of moisture variation on some engineering properties of velvet beans. The velvet bean seed used was conditioned to moisture content ranging between 8.12 and 28.21 % to determine some selected physical properties. The thermal properties were determined using a KD2-Pro thermal analyser. The physical properties results indicated that the arithmetic mean, geometric mean, volume, and surface area increased with varying moisture content while there was a decrease in the sphericity and aspect ratio. Thermal conductivity, thermal diffusivity, and specific heat capacity ranged from 0.18 to 0.65 W/mK, 1.2×10-7 to 3.1×10-7 m2/s and 1.57 to 2.16 kJ/kgK, respectively. The physical and thermal properties of the seeds were measured and their respective high correlation coefficients indicate that they can be used to simulate these parameters within the moisture domain investigated. The physical and thermal properties of velvet bean differ significantly with moisture contents. The information obtained on some engineering properties of velvet bean seeds could help design processing machinery and optimise milling operations.

Keywords- Coefficient of Friction, Moisture-dependent, Physical Properties, Thermal Properties, Velvet Bean.

1 INTRODUCTION

Velvet bean (*Mucuna pruriens)* is a tropical legume described as one of the most popular plants with a high medicinal value used in drug formulation in some parts of Africa and Asia (Eze *et al.*, 2017). It is also called itching bean and has two primary varieties (*M. pruriens* var *pruriens* and *M. pruriens* var *utilis)* that have been reported to be annual or sometimes short-lived perennial crops. The difference in these two varieties has been characterized by the colour of the seed, pubescence of the shell and the required days to reap them (Lampariello *et al*., 2011).

Legumes crop has been found to play an essential role in the traditional diet of many regions in the world because they have a low amount of fat and are an excellent source of protein, dietary fibre, specific micronutrients and phytochemicals (Maphosa and Jideani, 2017). The use of velvet bean seed has gained acceptance in natural product processes, especially in the sports nutrition industry. Report according to Gurumoorthi *et al.* (2003) shows that *Mucuna pruriens* has high protein content (23-25%) which digestibility could be compared to other pulses like cowpea, soybean, lima bean and rice. Despite its promise, Mucuna bean has been underutilized in many countries' agricultural sectors (Eilitta and Carsky, 2003).

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Empirical data on the physical properties of velvet beans will assist in choosing appropriate equipment and also the development of handling, processing and preservation equipment. The knowledge of the engineering properties of food materials has helped design, develop, and select suitable equipment for preservation, processing, packaging, and storage (Hayford *et al*., 2019).

This equipment is needed to ensure the safety and quality of food. The development of equipment for handling, processing and preservation of agricultural products has been noticed to have effects on the environment and climate change (Kumar and Kalita, 2017). Hence, in other to ensure the development of this equipment, appropriate data must be generated. This will ensure that re-invention of similar equipment which waste natural are avoided. The effectiveness of different kinds of food processing equipment such as planting, grading and pneumatic transport systems, are concerned by the axial dimensions. Therefore, the analysis of these properties must be defined and done perfectly.

Processing of velvet beans requires either soaking or drying which causes alterations in the moisture content of the crops. These attributes relatively affect the absorption and desorption of its moisture content hence, affecting the physical attributes of the biological materials. Sobukola *et al*. (2013) affirmed that data generated on the physical characteristics of any food crop as touching moisture content is exceptionally important in the design, development and selection of appropriate processing equipment for (aeration, drying, winnowing, grading, separation) as well as planting, harvesting and storage equipment.

To make accurate decisions in selecting and designing equipment for planting, reaping, processing and preserving, scientific information on the engineering properties of food crops is important. There is scanty information provided in the literature on the physical attributes of velvet beans (Tavakoli *et al*., 2009; Eze *et al*., 2017); however, little or no information in the literature is available on moisture-dependent thermal and physical properties of velvet beans. As a result of these, the study is aimed to analyse the effect of moisture content on the thermal and physical properties of velvet bean.

2 Materials and Methods

The velvet bean (*Mucuna pruriens*) was collected from a local farm in Ogbagba, Iwo local Government, Iwo, Osun State, Nigeria. The velvet bean was sorted by removing the broken, spoiled, and split beans. The sample was divided into six equal parts by weighing. Initial moisture content was determined using a digital moisture analyser (MD7822 Model) as reported by Oriola *et al.* (2016).

The sample was then constrained to varying moisture content with distilled water and then placed in the refrigerator to enhance the even distribution of the moisture to the seed. Using equation 1, the samples were conditioned to raise the moisture content to the expected different levels considered in this study (Coskun et al., 2006). Five levels of moisture contents, specifically, 8.12, 12.27, 16.54, 20.31, 24.18 and 28.21% moisture contents were obtained for velvet beans. Ziploc polythene was used to pack the samples and kept in a refrigerator for uniform moisture distribution until used.

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_f)} \quad (1)$$

Where; Q = amount of additional water (kg), W_a = sample's initial mass (kg), M_a = sample's initial moisture content (%, d.b) and M_b = sample's final moisture content (%, d.b.).

2.1 Determination of Physical Properties

The method used by Mohsenin (1986) was adopted to determine the seed sizes. One hundred seeds of the velvet bean were selected randomly from the bulk sample. Vernier calliper of 0.01mm precision value was used to measure the axial dimension of the seeds such as length (L), width (W) and thickness (T). Mathematical relationships as presented in equation (1) and (2) was used to calculate the arithmetic mean diameter, (D_a) and geometric mean diameter, (D_g) (Mohsenin, 1986). Sphericity (Φ) was calculated using equation 4 (Dutta *et al*., 1988). Aspect ratio (Ra) was calculated, using the method described by Mohsenin (1986).

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

$$D_g = (LWT)^{1/3} \quad (3)$$

$$\Phi = \frac{(LWT)^{1/3}}{L} \quad (4)$$

Each of the velvet seeds' surface area, Sa, was determined using the relationship shown in equation (4).

$$A = \frac{\pi D^2}{4} \quad (5)$$

where A is the surface area in mm², D is the diameter of velvet bean in mm and $\pi = \frac{22}{7}$.

$$Ra = \frac{W}{L} \quad (6)$$

The volume of each the velvet seed was established from the values of (a, b, c) which are major, minor and intermediate diameter respectively in equation (4);

$$V = \frac{LWT}{6} \quad (7)$$

2.2 Determination of Thermal Properties

The thermal analyser otherwise known as KD2-Pro (Decagon devices, USA, Dual-Needle SH-1sensors was used to determine thermal conductivity, specific heat capacity and thermal diffusivity of velvet bean seeds (Oriola *et al.*, 2016). This Dual-Needle SH-1 sensor has two needles that are stainless steel with each having dimensions 1.3 mm, 30 mm and 6 mm for diameter, length of needles and distance between the needles respectively. A line heat source was attached to one of the needles while the other, which was the thermocouple, was used to determine the thermal properties of food materials. The thermal properties of velvet seeds were conditioned at an average temperature of 25.5°C and were evaluated in Agricultural Engineering Department Laboratory, Ladoke Akintola University Ogbomoso.

2.3 Statistical Analysis

The results obtained from the physical and thermal properties analysis of the seed were subjected to Analysis of Variance (ANOVA) with a significance level of $p<0.05$ while Duncan Multiple Range (DMR) test was used to separate the differences in the mean values obtained.

3 Results and Discussion

3.1 Effect of Moisture Content Variation on Physical Properties of Velvet Bean

The length, width and thickness of velvet bean ranged from 10.56 to 12.50 mm, 8.40 to 9.42 mm, and 5.89 to 6.73 mm, respectively as shown in Table 1. Analysis of variance of the data revealed a notable effect of ($p<0.05$) on major, minor, and intermediate samples (Table 1). This significant effect on major, minor and intermediate may be traced to the capability of the bean to absorb moisture. The axial dimensions were found to increase as moisture content increased. This is an indication that an increase in moisture contributes to the expansion of velvet beans. Eze *et al*. (2017) and Adeyanju *et al*. (2019) reported a similar observation for velvet bean and Jack bean at different moisture content, respectively. The variation of moisture content and axial dimensions can be expressed mathematically as given in polynomial equations 8–10:

$$L = -0.0034M^2 + 0.2117M + 9.165 \quad R^2 = 0.974 \quad (8)$$

$$W = -0.0023M^2 + 0.1282 + 7.5707 \quad R^2 = 0.962 \quad (9)$$

$$T = -0.002M^2 + 0.1176M + 5.005 \quad R^2 = 0.935 \quad (10)$$

As found in Table 1, the surface area of velvet bean ranged between 55.41 and 69.69 mm². The surface area increased with an increase in moisture content. The variance analysis pointed out that there was a notable difference at ($p<0.05$) in the surface area. The dependence of the surface area values on the axial dimensions of the

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velvet bean resulted in their increase. The result of the findings is similar to what Oluka and Nwuba. (2001) reported for cowpeas. As shown in Table 1, the seed volume of velvet bean using the axial dimension is 87.08 to 132.60. The increase in volume as moisture content increases is an indication that there was expansion in the geometry of the velvet bean seed which then resulted in the displacement of more liquid as described by Mohsenin, 1986) and Oduma *et al*. (2013) for sorghum seed. The relationship between moisture content and surface area and seed volume of velvet bean is shown in equations (11) and (12):

$$Sa = -0.0303M^2 + 1.7344M + 44.143 \quad R^2 = 0.964 \quad (11)$$

$$V = -0.0774M^2 + 5.0084M + 51.97 \quad R^2 = 0.993 \quad (12)$$

The arithmetic (D_a) and geometric mean (D_g) obtained from the axial dimension were 8.28 to 9.56 mm, and 8.04 to 9.25 mm, respectively, as presented in Table 1. A notable effect was obtained on the arithmetic meanwhile the geometric mean is not significantly different at ($p>0.05$). It is essential to determine the arithmetic mean and the geometric mean of material to help in the design and selection of equipment. It was observed that there was an increase in the arithmetic and geometric mean as moisture content increased. The increase could be attributed to an increase in seed axial dimensions as moisture content increased due to the velvet bean seed's moisture absorption capability. Similar effects of moisture content on arithmetic and geometric mean have been reported for green wheat (Al-Mahasneh and Rababah, 2007) and Jack bean seed (Al-Mahasneh and Rababah, 2007; Adeyanju *et al*., 2019). The irregularity of the shape of the seed also contributes to a significant difference. The regression equation relating the arithmetic and geometric mean of velvet bean to moisture content is given in equations (13) and (14):

$$D_a = -0.0025M^2 + 0.1505M + 7.2581 \quad R^2 = 0.989 \quad (13)$$

$$D_g = -0.0024M^2 + 0.1453M + 7.0406 \quad R^2 = 0.991) \quad (14)$$

The sphericity (Φ) results ranged from 0.73 to 0.76 (Table 2). The results did not show any notable difference at $p>0.05$ on the sphericity but this can be traced to the irregularity of the shape of the seeds. There was a decrease in the sphericity as the moisture content increased. A similar finding was reported for bush mango nut by Iyilade *et al*. (2018). Sphericity is an expression of the shape of the bean and the surface area shows the space occupied by each material. According to Adeyanju *et al*. (2019), a seed is considered spherical when the value of sphericity of the seed is more than 0.70.

From the results obtained, the velvet bean can be considered to be spherical, and this will help in the design and fabrication of the machine for the processing of the bean. The aspect ratio (R_a) according to Table 2 ranges from 0.75 to 0.79. This depicts that the aspect ratio of velvet bean decreased as the moisture content increased.

The result correlates with the findings of Eze *et al*. (2017) on velvet beans and Adeyanju *et al*. (2019) on Jack bean seeds. The determination of aspect ratio helps in the designing of processing equipment which helps to know whether the seed will roll or slide. The values of sphericity and aspect ratio of velvet bean exhibited the resulting relationship with its moisture content:

$$\Phi = -0.00003M^2 + 0.0002M + 0.755 \quad R^2 = 0.602 \quad (15)$$

$$R_a = 0.00005M^2 - 0.0039M + 0.8198 \quad R^2 = 0.964 \quad (16)$$

3.2 Effect of Moisture Content on Thermal Properties of Velvet Bean

The consequence of moisture variation on thermal diffusivity (α) ranges from 1.20×10^{-7} to 3.10×10^{-7} m^2/s as shown in Table 2. The thermal diffusivity of velvet bean experienced an increase with increasing moisture content. This increase can be significantly trailed by the decrease in the bulk density as the moisture increases. According to Abioye *et al*. (2016) for Bambara groundnut and Aviara and Haque (2001) for sheanut kernel, thermal diffusivity increases with moisture content.

The effect of moisture variation on velvet bean seeds increases the specific heat capacity (C_P) from 1.57 to 2.16 kJ/kgK as shown in Table 2. Several researchers have worked on the specific heat capacity of food materials using the method of mixtures. Hsu *et al*. (1991) show that the pistachious seed specific heat capacity varied with an increase in moisture content. Isa *et al*. (2014) also showed that the specific heat capacity of different of varieties melon seed increases linearly with an increase in moisture content. The specific heat capacity is an essential parameter in the design of a heat exchanger. The information derived from the determination of material will be useful in the choice of heat transfer medium and processing condition.

The effect of moisture variation on velvet bean increases the thermal conductivity (k) of velvet bean from 0.14 to 0.65 W/mK as given in Table 2. This result agrees with the observation of Mahapatra *et al*. (2011) for rice flour in which the thermal conductivity increases with an increase in moisture content.

Table 1. The effect of moisture content on velvet bean physical properties

Sample (%)	Length (mm)	Width (mm)	Thickness (mm)	Surface Area (mm^2)	Volume (mm^2)	Arithmetic Mean (mm)	Geometric Mean (mm)	Sphericity (mm^2)	Aspect Ratio
8.12	10.56d	8.40d	5.89d	55.41e	87.08e	8.28d	8.04b	0.76a	0.79a
12.27	11.45c	8.90bc	5.99c	62.21d	101.74d	8.78c	8.47b	0.74a	0.78a
16.54	11.73ab	9.08c	6.52ab	64.75c	115.74c	9.11ab	8.84b	0.75a	0.77a
20.31	11.97b	9.20b	6.57b	66.48b	120.59ab	9.24b	8.95b	0.75a	0.76a
24.18	12.28a	9.25a	6.67a	67.20a	126.27b	9.40a	9.09a	0.74a	0.75a
28.21	12.50a	9.42a	6.73a	69.69a	132.60a	9.56a	9.24a	0.73a	0.75a

*Values with different alphabet(s) along the same column are significantly different from each other at $p<0.05$

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The relationship between specific heat capacity, thermal diffusivity, thermal conductivity and the moisture content of the seeds was obtained as:

α = -9E-11M²+5E-9M+9E-8 $R^2 = 0.927$ (17)

C_p = 0.0023M²+0.1163M+0.7896 $R^2 = 0.992$ (18)

k = -0.0002M²+0.0271M+0.029 $R^2 = 0.844$ (19)

Table 2. Thermal properties of velvet bean at different moisture content

Sample (%)	C_p (kJ/m³K)	α (× 10^{-7} m²/s)	k (W/mK)
8.12	1.57b	1.20c	0.40b
12.27	1.87b	1.90ab	0.42b
16.54	2.10a	2.00b	0.42b
20.31	2.18a	2.10b	0.45b
24.18	2.20a	2.50b	0.49b
28.21	2.23a	3.10a	0.65a

*Values with different alphabet(s) along the same column are significantly different from each other at p<0.05

4 Conclusion

This study looked into some engineering properties of velvet bean that could aid in the design and development of handling and processing equipment. The moisture effects on physical properties show that the values increase as the moisture level rises from 8.12 to 28.27. The study discovered that the physical dimensions and size-related characteristics of the velvet bean vary significantly depending on moisture content.

This information is useful for designing storage structures, optimizing milling operations, and processing machinery, which will help farmers and processors gain more relevance for the seeds. The effect of moisture on thermal property determination shows that increasing moisture increases thermal diffusivity, and thermal conductivity, and decreases the specific heat capacity of velvet bean. Moisture also contributes to the thermal properties of velvet beans, implying that heat can easily diffuse through velvet beans with higher moisture content.

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