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Effect of Moisture Variation on the Thermal Properties of Mucuna Pruriens and Veracruz Verities

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Abstract

Thermal properties of bio-materials are properties which depict the reaction of the materials as a result of change in temperature. This study determined the effects of moisture variation on some thermal properties of ***Mucuna Pruriens*** and ***Veracruz*** seeds grown in Nigeria under different moisture contents range of 6.04 to 15.82% (db) employing standard experimental equipments and procedures. From the analysis of the results the thermal properties of both species were observed to increase as the moisture content increases but varied slightly between both species. Their values were found to range from 102.86 to 196.46KJ/kgK; 17.53 to 32.82W/m and 2.46 x10^{-7} to 8.39 x $10^{-7}ms^{-1}$ for specific heat, thermal conductivity and thermal diffusivity respectively. From the result and analysis of this study, it can be stated that knowledge of engineering properties of crops are very vital for design of processing equipment and post harvest handling. It is expected that the information obtained will be put to use by researchers who wish to work further on this legume species.

Keywords: Thermal properties, specific heat, thermal conductivity, thermal diffusivity and moisture content.

Introduction

Mucuna (Pruriens and Veracruz) Agbara as is commonly called by the Igbos in Eastern part of Nigeria is an annual climbing legume that belongs to the fabaceae family, sub family of papillionaceas. It is a tropical legume, commonly known as velvet bean or cowitch or cowhage. It is one of the most popular medicinal plants in Africa and Asia, and is constituent of more than 200 indigenous drug formulations. It is found in the plains of India [1]. The demand for ***Mucuna*** in India as well as in international drug markets increased many fold only after the discovery of the presence of L3, 4-Dihydroxyl Phenyl Alamine (L-DOPA), an anti-Parkinson's (PD) disease drug in the ***mucuna*** seeds [2]. The genus ***mucuna*** belongs to the family leguminosae and consists of 100 species of climbing vines and shrubs. The name of the genus is derived from the word ***mucuna*** [3], and found in the woodlands of tropical areas especially in tropical Africa, India, and the Caribbean. ***Mucuna*** is a twining annual crop that can reach 15m in length. The plant is almost completely covered with fuzzy hair when young, but almost free of hairs when older. The leaves are trifoliate, alternate, or spiralled, gray-silky beneath; petioles are long and silky, 6.3 to 11.3cm. Leaflets are membranous, terminal leaflets are smaller, lateral very unequal sized. Flowers are dark purple, white or lavender in colour, pea-like but larger with distinctive curved petals and occur in drooping racemes. The seeds are shiny black or brown, ovoid and 12mm long [4].It has also been shown to be neuro-protective and as a fertility agent (in men), has analgesic and anti-inflammatory activities. ***Mucuna*** bean seed is rich in protein (23- 35%), has nutritional qualities comparable to that of other pulses and considered viable source of dietary proteins due to its high protein concentration in addition to its digestibility. Legume proteins are used as ingredients primarily to increase nutritional quality and to provide a variety of functional properties, including desirable structure, texture, flavour and colour characteristics in formulated food products. Many varieties and accessions of ***mucuna*** have great demand in food and pharmaceutical industries.

The moisture content is a very important constituent of biomaterial that determines its safety, stability and quality. Recently harvested products normally contain large amount of water which speed up the rate of its deterioration. However, baked or dry agricultural materials are poor in water but they are more stable than fresh product even though their nutritional value might have been depleted during drying [6]. The effect of roasting on cashew nut regarding its dimensions and moisture content which resulted in the shrinkage of the nut was reported by [7]. This was due to loss of moisture from the cashew nuts during roasting and thus the size of the nut reduces as its moisture content decreases. This favors market for the product as buyers prefer nut with considerably low moisture content. Furthermore, another effect that set in when the moisture content of biomaterial is reduced drastically is case-hardening. Case-hardening occurs when the micro-porous structure (epicarp) which encloses agricultural material collapses. This phenomenon tends to limit moisture migration through surface layer of the material that is being dried. Casehardening is detrimental to agricultural material, as it does not allow for moisture transfer from within it to the immediate environment in order to attain equilibrium moisture content. This leads to rapid deterioration or spoilage within the agricultural material.

Thermal properties are properties which depicts the reaction of a substance as a result of change in temperature. [8] Expressed thermal properties as properties upon which change in temperature largely depends. He further stated that, to define the magnitude and location of a temperature that denotes the heat content of the material at any time during a heating or cooling process, knowledge of thermal characteristic of the material is required. [9] showed that thermal properties of biomaterial are important for the development of thermal processing systems which include heating, cooling, freezing, drying systems etc. [10] reported that information on thermal properties, like the specific heat capacity, thermal diffusivity and thermal conductivity are important in the design and development of a cryogenic system and to simulate and model heat transfer phenomena in the grinder. Different researcher works has been carried out on thermal properties of agricultural and bio-materials, especially heat capacity specific heat, thermal conductivity and thermal diffusivity. [11] Reported that information or knowledge on the thermal behavior of food crop during processing is necessary, as heat is known to have effect on handling and processing equipments and more importantly on the crops nutritional quality.

There is limited literature on the influence of moisture content on the thermal properties of the two varieties of ***Mucuna.*** The data generated from the effect of moisture variation on thermal properties of ***Mucuna Pruriens*** and ***Veracruz*** varieties will aid in the design and fabrication of machines or parts of machine, and, in computer simulation, optimize, to analyze and control of temperature during thermal treatment or processing of bio-materials. The knowledge of thermal properties is also useful in the design of pre-threshing dryers and dryers in food processing industries.

Materials and Method

Sample Collection The two varieties of ***Mucuna Pruriens*** samples (***Pruriens*** and ***Veracruz)*** used for this research work were collected at a suitable moisture content from a local farm in Urban in Udenu Local Government Area of Enugu State, Nigeria on 27th April 2021, at geographical coordinates are 60 59'0'' North 70 27'0'' East

(A) (B)

Figure 1: Mucuna seeds varieties (a = Pruriens and b = Veracruz)

Sample Preparation

The clean seeds of ***Mucuna samples***1kg were soaked in clean water at 25°C ± 2°C for 10 hours after which they were manually dehulled. The cotyledons were dried in an oven for 10 hours at 105°c. The dried seeds were then kept in an airtight container at 4^{0}C prior to use. The experiments were done at three moisture levels [6.04, 10.37 and 15.82% dry basis] and three moisture levels.

Procedures for Evaluating the Thermal properties

The Association of official Analytical Chemist (A.O.A.C) (2002) method was used which involves igniting the sample in oxygen bomb calorimeter (under a high pressure of oxygen gas). This method was based on the assumption that the heat loss of hot source is equivalent to heat gained by the cold source in the isolated ambiance. The heat energy that was released was absorbed by the surrounding water inside the bomb calorimeter. This gave rise to a temperature increase of the surrounding water. All the experiments were repeated three times at 6.04%, 10.37% and 15.82% moisture content (dry basis).

Specific Heat determination

The specific heat of a material is the heat capacity of a body per unit mass of the body. The heat capacity of the calorimeter was determine using equation 1 [12, 13]

$$H_f = \frac{M_{cw}\, C_w (T_e - T_{cw}) - M_{hw} C_w (T_{hw} - T_e)}{(T_{hw} - T_e)} \quad (1)$$

$$M_{cw} = \text{mass of the cold water (kg)}$$

$$C_w = \text{specific heat of the water } (KJ/kg°C)$$

$$T_e = \text{equilibrium temperature } (°C)$$

$$T_{cw} = \text{Temperature of the cold water } (°C)$$

$$M_{hw} = \text{Mass of the hot water (kg)}$$

$$T_{hw} = \text{temperature of hot water } (°C)$$

The heat capacity of the samples were determine using equation 2 [12, 13]

$$H_c = \frac{(H_f + m_{cw})(T_e - T_{cw})}{T_c - T_e} \quad (2)$$

$$\text{Where } T_c = \text{temperature of the sample } (°C)$$

The specific heat capacity of the sample was calculated using equation 3 [12, 13].

$$C_p = \frac{(H_f + M_{cw} C_w)(T_e - T_{ew}) - M_c (T_s - T_e)}{M_s (T_m - T_e)} \quad (3)$$

Where Cp = specific heat capacity (KJ/kg°C)

Tc = temperature of the sample

Ms = mass of the sample (kg).

Determination of the Thermal Conductivity of the *mucuna* samples.

The thermal conductivity of a material is the quantity of heat that flow in unit time across unit area between two surfaces of the material. The line source method was sued to determine the thermal conductivity of the samples. This uses the transient – state method. it makes use of thermal conductivity probe as a heating source and determines the thermal conductivity based on the relationship between the sample temperature and heating time KD_2 thermal property analyzer (Decagon devices, Inc) was used.

Determination of the Thermal Diffusivity of the Mucuna Samples.

The thermal diffusivity of a bio-material is the rate at which heat is diffused out of the materials. In this study, the thermal diffusivity was calculated by using [12,13] equation 4.

$$\propto = \frac{K}{\rho\, Cp} \qquad (4)$$

$Where \propto = thermal\ diffusivity\ (m^2\ S^{-1})$

$K = thermal\ conductivity\ (W/M°C)$

$\rho = bulk\ density\ in\ (kg/m^3)$

The results of the thermal properties of ***Mucuna Pruriens and veracruz*** at three different moisture contents are presented in Tables 1 and 2respectively..

Results and Discussion

TABLE.1: Results for Thermal Properties of *Mucuna Pruriens* at the selected Moisture Content

MOISTURE CONTENT (%)	BULK DENSITY (G/CM^3)	SPECIFIC HEAT CAPACITY KJ/KGK	THERMAL CONDUCTIVITY (W/M)	THERMAL DIFFUSIVITY (M/S) X 10^{-7}
6.04	1.66	102.86	17.56	2.46
10.37	1.49	117.91	26.09	4.04
15.82	1.10	196.46	30.84	8.21

TABLE 2: Results for Thermal Properties of *Mucuna Veracruz (white)* at the selected Moisture Content

MOISTURE CONTENT (%)	BULK DENSITY (G/CM^3)	SPECIFIC HEAT CAPACITY KJ/KGK	THERMAL CONDUCTIVITY (W/M)	THERMAL DIFFUSIVITY (M/S) X 10^{-7}
6.04	1.64	106.38	17.53	2.48
10.37	1.47	110.28	25.21	4.15
15.82	1.24	194.77	33.82	8.39

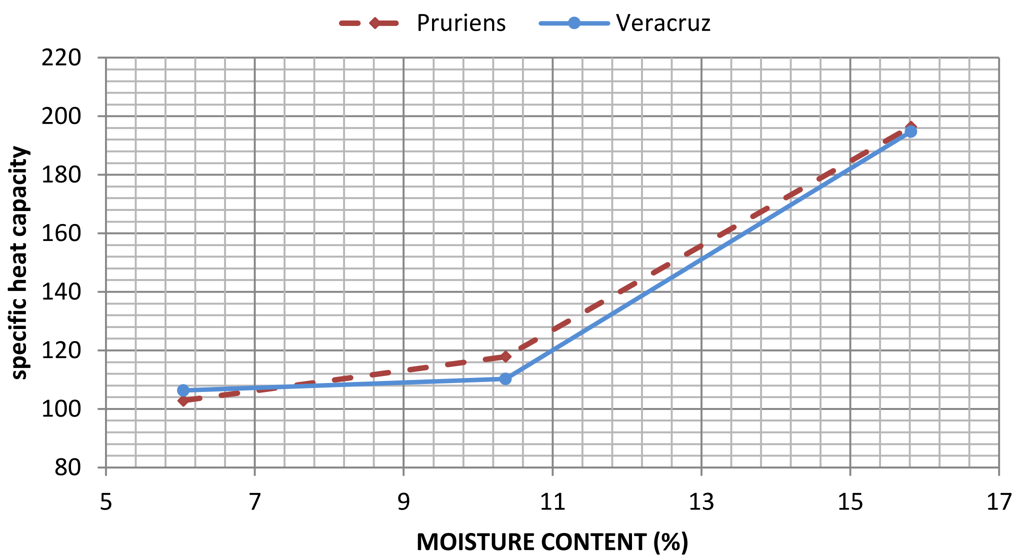

Fig.2. Plot of Specific Heat against Moisture Content for the two Species of *Mucuna*

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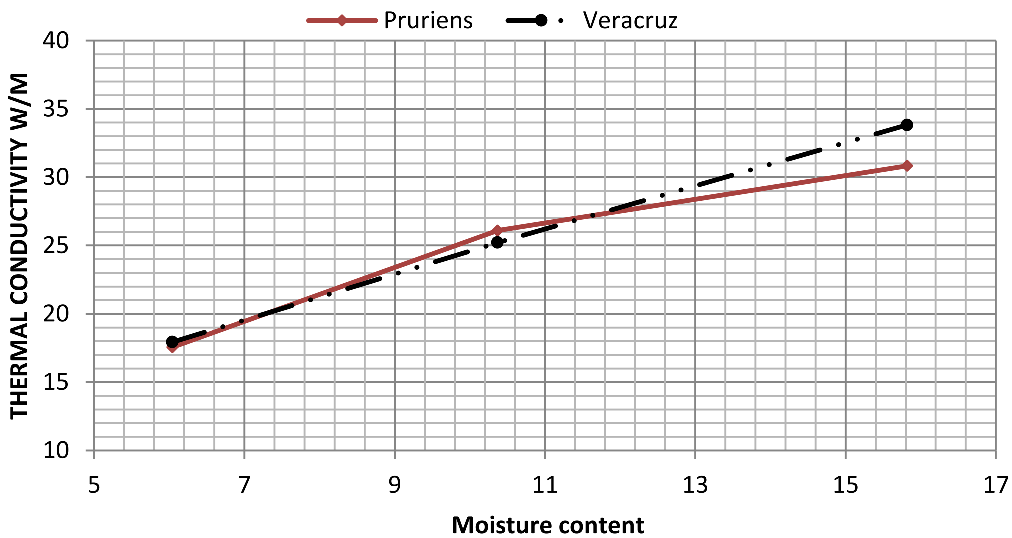

Fig.3. Plot of Thermal Conductivity against Moisture Content

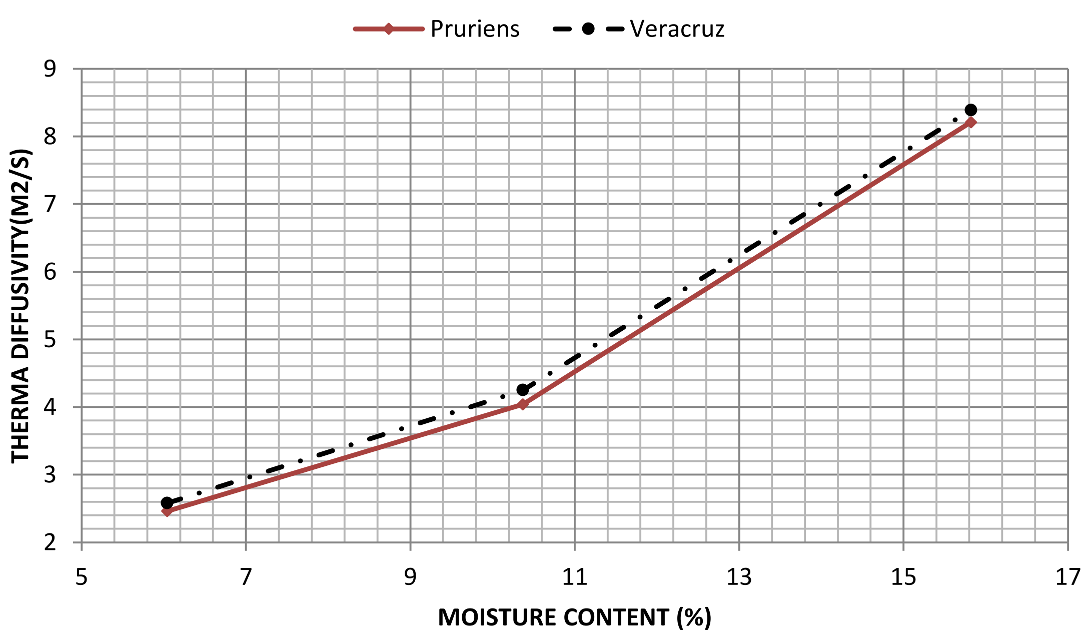

Fig.4. Plot of Thermal diffusivity against moisture content

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From the results of thermal properties of both species of the samples tested all properties tested were found to increase as the moisture content increases. Specific heat values were found to range from 102.86KJ/KgK to 196.46KJ/KgK for ***pruriens*** while it ranged from 106.38KJ/KgK to 194.77KJ/Kgk for ***Veracruz*** samples. Thermal conductivity had values which ranged from 17.56 W/m to 30.84W/m and 17.53 to 33.83W/m respectively for both species tested. This shows that as the moisture content increases, the ability of the samples to conduct heat also increases. The same trend was observed for thermal diffusivity of the samples and values were obtained in the range of 2.46×10^{-7} m/s to 8.21×10^{-7} m/s and 2.48×10^{-7} to 8.39×10^{-7} respectively for both species across the moisture content levels tested. [14] Experiment on maize showed that as the moisture content increases specific heat capacity, thermal conductivity and thermal diffusivity increases. Also [15] showed that when moisture content increases the specific heat capacity, thermal conductivity and thermal diffusivity of palm kernel increases. Njie *et al.,* 1998 also demonstrated that specific heat, thermal conductivity and thermal diffusivity increases with increase in moisture content. A decreasing trend in bulk density was reported for Jatropha [16]. It implies that, the packing factor of the sample decreases as the moisture content increases.

Thermal conductivity (Fig 3) showed a non linear relationship for ***mucuna pruriens*** while showing a linear relationship for ***mucuna Veracruz***. There was however increase in thermal conductivity as moisture content increased. Thermal diffusivity (Fig 4) on the other hand was observed to have non linear relationship with moisture content with very good R^2 values. Both species of ***mucuna*** had exponential relationship with moisture content and the mathematical equations that best describe their relationship are presented below (2 and 3).

$$TC_p = 14.58\ln(x) - 8.245 \quad (R^2 = 0.990) \quad (4.5)$$

$$TC_v = 1.622x + 8.218 \quad (R^2 = 0.999) \quad (4.6)$$

$$Tdf_p = 1.045e^{0.136x} \quad (R^2 = 0.999) \quad (4.7)$$

$$Tdf_v = 1.233e^{0.120x} \quad (R^2 = 0.999) \quad (4.8)$$

Conclusion

The thermal properties varied with moisture content and specie.
Specific heat and thermal diffusivity was found to have exponential relationship with moisture content for both species tested. Their best fit equations were obtained with R^2 values ranging from 0.845 to 0.999.
Thermal conductivity had R^2 values in the range of 0.990 to 0.999 and exhibited linear relationship for **Veracruz** specie and logarithmic relationship for ***pruriens*** specie.
The thermal properties such as: bulk density, specific heat capacity, thermal conductivity and thermal diffusivity at three different moisture content levels of the mucuna species were determined.

Recommendation

1. Further work can be carried out with wider moisture content ranges to also identify its effects on the tested properties and further determine electrical and electromagnetic properties of both species.

2. From the results obtained, work can be done to found out possible application of the ***mucuna pruriens and veracruz*** samples as an insulating materials due to their low thermal conductivity values.

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