Thermo-physical properties of rubber seed useful in the design of storage structure

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Abstract: This study was carried out to determine the thermo-physical properties of rubber seed in the moisture range of 9.1% to 14.8% (w.b.). The length, width, thickness, measured surface area, bulk density and true density increased with increasing moisture content with high coefficients of determination (significant at $p<0.05$). Their optimum values at 14.8% moisture content were 17.00 mm, 11.94 mm, 8.26 mm, 285.20 mm^2, 295.00 kg/m^3 and 470.67 kg/m^3, respectively. The angle of repose increased as moisture content increased with low coefficient of determination and has optimum value of 28.81° at 14.8% moisture content. The specific heat capacity and thermal conductivity decreased linearly while thermal diffusivity varied exponentially with an increase in moisture content (significant at $p<0.05$). The optimum values of specific heat capacity, thermal conductivity and diffusivity at 14.8% moisture content were 55.84 kJ/kg.K, 0.032 W/m.K and 1.93×10^{-9} m^2/s, respectively. The data obtained are essential in the design of storage structure for the seed.

Keywords: thermo-physical properties, rubber seed, storage, specific heat capacity, bulk density

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1 Introduction

Rubber tree (*Hevea brasiliniensis*) is one of the leading commercial agricultural trees in the world and is one of the most important revenue generating trees in Nigeria. Apart from its use in latex production for foreign exchange, the tree produces oil-bearing seed whose oil content in dried kernel varies between 35% to 45% and is by far more than that obtainable in jatropha and karanj seeds[1]. The rubber seed oil is non-edible, but has many areas of potential applications. These include its use in the production of biodiesel as fuel for compression ignition engines, and foaming agent in latex foam in the synthesis of resins used in paints and coatings. The thermal properties are considered by some investigators for storing fruits and vegetables and in the design of heat treatment plants for agricultural materials. For example, thermal properties of agricultural seed or its product have the ability of retaining or transmitting heat when subjected to heat treatment[4]. Bulk density and true density can be useful in sizing seed hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying process. Seed bed with low porosity will have greater resistant to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans. Seed densities have been of interest in breakage susceptibility and hardness studies[5]. The physical properties such as size and shape are important in the electrostatic separation from undesirable materials and in the development of sizing and grading machinery. The shape of the material is important for an analytical prediction of its drying behavior[6].

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Iyayi et al.[7] reported that rubber seed deteriorates very rapidly in storage and the losses occurring as a result of this are enormous, thus there is a need to establish a convenient storage facility. However, study on thermo-physical properties that will help in the design of rubber seed storage structure was not undertaken. Therefore, this research was carried out to investigate some thermo-physical properties of rubber seed to establish a convenient reference data for the design of its storage structure.

2 Materials and methods

The rubber seeds used for this study were obtained from Rubber Research Institute of Nigeria (RRIN), Benin City. The seeds are shown in Figure 1. The seeds were manually cleaned to remove foreign materials such as broken and immature tree branches, sands, stones, leaves and so on. A moisture content drop of 8.4% from an initial content of 29.7% of whole seed after two months exposure on bare floor was reported by[8].

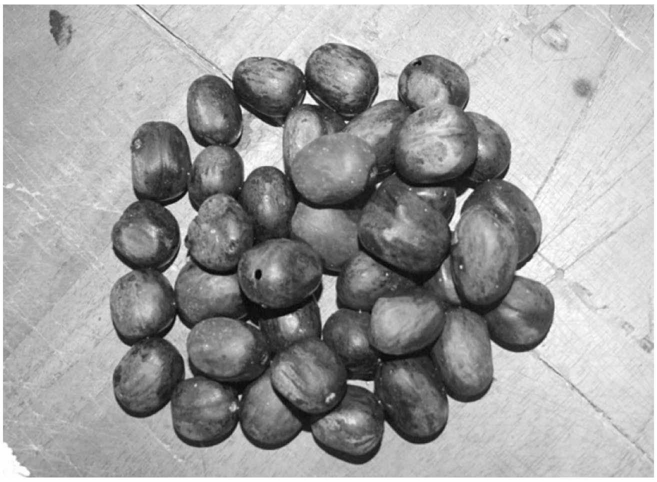

Figure 1 Rubber seeds

The method described by[9] was used to determine the initial moisture content of rubber seed and found to be 9.1% (w.b.). The moisture content was varied by adding some calculated amount of distilled water to three other portions of rubber seeds in separate polyethylene bags and kept in the refrigerator for one week. The final moisture contents were obtained as 11.3%, 12.4% and 14.8% (w.b.).

Twenty randomly selected rubber seeds each taken from the four samples of different moisture content were used to determine the bulk and true densities, angle of repose, axial dimensions, specific heat capacity, thermal diffusivity and thermal conductivity. The true density was determined using toluene displacement method[10]. The bulk density was measured using a 250 mL graduated cylinder. The cylinder was filled and tapped 10 times to cause the seeds to settle. A flat sharp edge was used to remove excess seeds to level the surface at the top of the cylinder[11]. The angle of repose was determined by pouring the seeds at a spot to form a cone with a constant base angle; and the angle between the formed cone and the horizontal was the angle of repose[12]. The length, width and thickness were determined using vernier caliper with an accuracy of 0.01 mm. The surface area was measured by wrapping the seed with aluminium foil and then tracing the layout on the graph paper[12]. The specific heat capacity was determined by putting the seed into a calorimeter containing water at a temperature of 80℃. The temperature of the mixture was measured at two-minute intervals, until a constant reading was obtained, which marks the equilibrium temperature. The enthalpy change of the seed was calculated from the heat exchange between water, calorimeter and the seed[13]. The thermal conductivity was determined, at the bulk density corresponding to each moisture level, by placing the seeds between two copper plates with one side in contact with boiling water and the other side in contact with ethanol of a lower boiling point. The time taken to vaporize 1 mL ethanol was measured and recorded. With the thickness of the seed and time of vaporization of ethanol the thermal conductivity was calculated according to Fourier’s law of heat conduction[13]. The thermal diffusivity was calculated as thermal conductivity divided by the product of specific heat and bulk density[14]. The procedures were replicated three times for the four varied moisture contents and the average values recorded as thermo-physical properties of rubber seed.

3 Results and discussion

The variations of the seed axial dimensions (length, width and thickness) with moisture content of rubber seed were shown in Figure 2. There was a linear increase in these dimensions with increasing moisture contents of the seeds from 9.1% to 14.8% (w.b.) with high coefficients of determination (significant at $p<0.05$). This indicates that rubber seed expanded in axial dimensions on absorbing moisture from 9.1% to 14.8% (w.b.). The total average expansions were greatest along the seed length than along its width and least along the thickness. This indeed is connected with the shape of the seeds and their corresponding volumetric expansions at higher moisture content. Similar results are obtained for chickpea seeds reported by[12]. The relationships between the axial dimensions and moisture content of rubber seed are represented in the following regression equations:

$$a = 0.24M + 13.62 \qquad R^2 = 0.8816$$

$$b = 0.49M + 1.35 \qquad R^2 = 0.8474$$

$$c = 0.22M + 8.56 \qquad R^2 = 0.8881$$

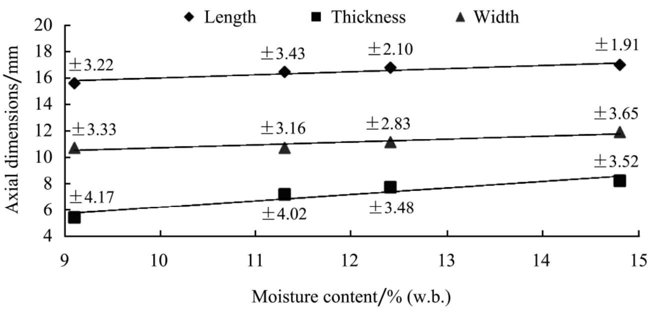

Figure 2 Effects of moisture content on principal dimensions of rubber seed

Variation of surface area of rubber seed with moisture content is shown in Figure 3. There was a linear increase in surface area with increasing moisture content of rubber seed from 9.1% to 14.8% (w.b.) with high coefficient of determination (significant at $p<0.05$). The surface area affected the rate of moisture loss during drying of grains, seeds, and other particulate materials. The rate of heat transfer to the material also significantly depends on the heat transfer surface. The smaller the volume of material per unit surface, the better its condition for rapid heat transfer. A similar linear increase in surface area with increase in moisture content for chickpea seeds was reported by[12]. The following regression equation shows the relationship between measured surface area and moisture content of rubber seed:

$$A = 17.00M + 36.51 \qquad R^2 = 0.9012$$

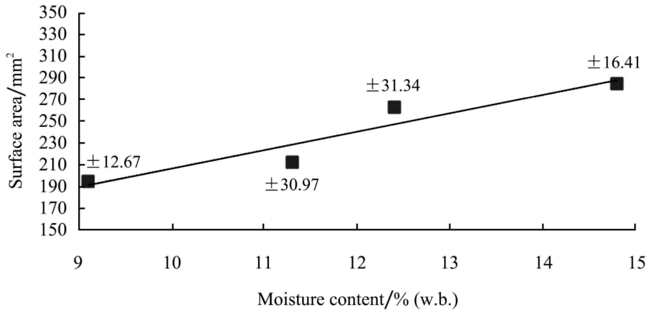

Figure 3 Effect of moisture content on surface area of rubber seed

The results obtained for bulk and true densities were related graphically with rubber seed moisture content as shown in Figure 4. The bulk and true densities increased with increase in moisture content from 9.1% to 14.8% (w.b.) with high coefficient of determination (significant at $p<0.05$). The increase in bulk and true densities was because of increase in mass owing to moisture in the seed which was higher than accompanying volumetric expansion of the bulk. In precision agriculture, diverse approaches are used to determine the volume of the existing grain in a combine hopper. To determine the weight of rubber seed in the hopper, knowledge of bulk density is necessary. The bulk density of seeds is also useful in the design of silos and storage structures. The regression equations between density and moisture content of rubber seed are the following:

$$\rho_t = 31.20M + 25.76 \qquad R^2 = 0.8975$$

$$\rho_b = 15.48M + 78.62 \qquad R^2 = 0.7988$$

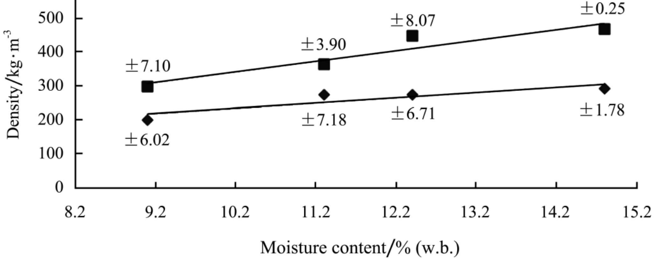

Figure 4 Effects of moisture content on densities and porosity of rubber seed

Figure 5 shows angle of repose increasing from 21.45° to 28.81° with increase in moisture content from 9.1% to 14.8% (w.b.) with low coefficient of determination. This increasing trend of angle of repose with moisture content occurs because surface layer of moisture surrounding the particle holds the aggregate of seed together by the surface tension. The angle of repose is important in designing the equipment for mass flow and structures for storage[15]. The relationship between angle of repose and moisture content of rubber seed is represented by the following regression equation:

$$\theta = 1.14M + 13.53 \qquad R^2 = 0.4794$$

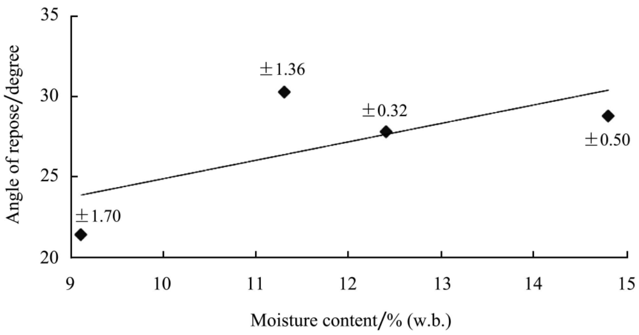

Figure 5 Effect of moisture content on angle of repose of rubber seed

The variation of specific heat capacity of rubber seed with moisture content is shown in Figure 6. The specific heat capacity of rubber seed decreased with increasing moisture content up to 14.8% (w.b.). The relationship was significant at p<0.05. The reason for this decrease is because at high moisture contents the enthalpy required to raise 1 kg of rubber seed through 1 K temperature raise is low. This property can be used to determine the amount of heat required in the processing of the seed and thus, assist in the selection of the best method to process the seed. The relationship between specific heat capacity and moisture content of rubber seed represented in the following equation:

$$C = -12.94M + 241.68 \qquad R^2 = 0.9559$$

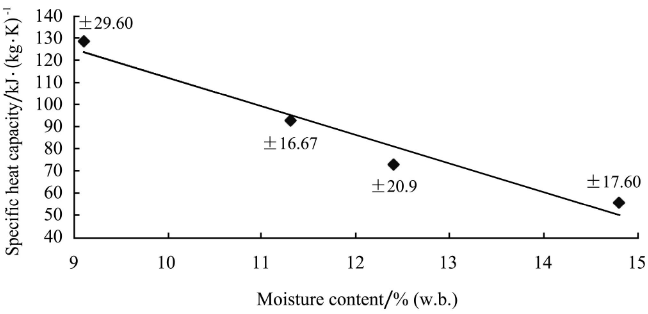

Figure 6 Effect of moisture content on specific heat capacity of rubber seed

Variation of thermal conductivity of rubber seed with moisture content is shown in Figure 7. A decreasing linear trend was observed in the thermal conductivity of the seed as the moisture content increased. The relationship was significant at p<0.05. At higher moisture contents, the bulk and true densities of rubber seed increased and individual seeds were more loosely packed relative to each other with low accompanying heat transmission. Based on this, the thermal conductivity of rubber seed was high at 9.1% (w. b.) and low at 14.8% (w. b.). The relationship between thermal conductivity and moisture content of rubber seed is represented in the following regression equation:

$$K = 156.5M + 789.4 \qquad R^2 = 0.9162$$

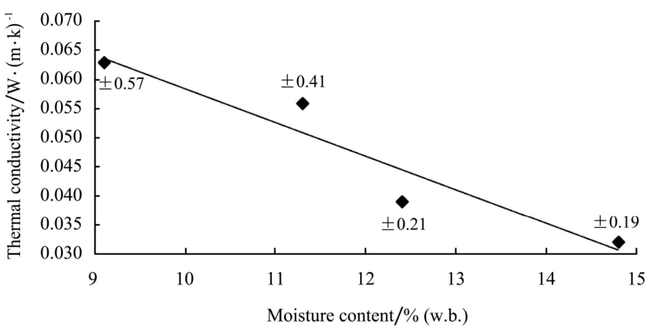

Figure 7 Effect of moisture content on thermal conductivity of rubber seed

Variation of thermal diffusivity of rubber seed with moisture contents is shown in Figure 8. A decay trend was observed in the thermal diffusivity of the seed as moisture content increased up to 14.8% (w.b.). The observed trend may be associated with the dependence of thermal diffusivity on bulk density which in turn affects the porosity of the seed thereby making it possible for the seed to transmit and store heat energy at lower moisture content. A sinusoidal trend was reported for doum palm fruits[4]. The relationship between the thermal diffusivity

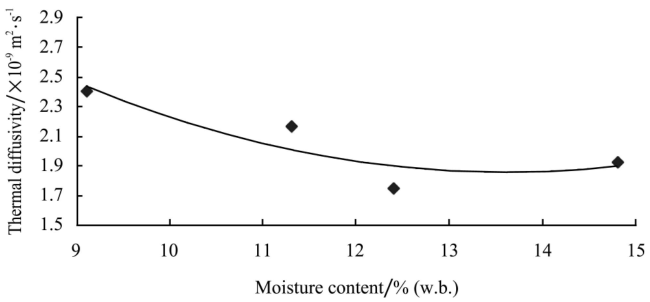

Figure 8 Effect of moisture content on thermal diffusivity of rubber seed

and moisture content of rubber seed is represented in the following regression equation:

$$\propto = 0.0287M^2 - 0.7797M + 7.1639 \qquad R^2 = 0.7992$$

4 Conclusions

The investigation into the thermo-physical properties of rubber seed has led to the following conclusions:

1) The specific heat capacity and thermal conductivity decrease linearly while thermal diffusivity varies exponentially with increasing moisture content (significant at $p<0.05$).

2) The length, width, thickness, bulk density and true density increased with increasing moisture content with high determination coefficients (significant at $p<0.05$) while angle of repose increased with low determination coefficient.

3) Once the moisture content is known the thermo-physical properties of rubber seed can be determined using the regression equations.

4) The determined thermo-physical properties are useful in the design of storage structure for rubber seed.

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