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# Physical and Thermal Properties of Baobab Fruit Pulp Powder

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## ABSTRACT
**In this study the physical and thermal properties of baobab (*Adansonia digitata*) fruit pulp powder which are essential for designing engineering processes, material handling, storage, equipment design and fabrication were determined. The physical properties, namely, mean particle size, bulk density, true density and porosity were determined. Also, angle of repose and coefficient of friction were tested on mild steel, plywood and PVC plastic which are probable engineering materials for construction of food processing equipment. The specific heat capacity, thermal diffusivity and thermal conductivity were also determined. The mean particle size of the powder was 0.953 mm, while the bulk density, true density and porosity were found to be 301 kg/m$^3$, 1167 kg/m$^3$ and 73%, respectively. The angle of repose and coefficients of static friction of the fruit pulp powder were found to be 40.63$^o$ and 0.8339, 39.18$^o$ and 0.7796, 37.28$^o$ and 0.7501, respectively for mild steel, plywood and PVC plastic surfaces. The specific heat capacity and thermal conductivity decreased with increase in temperature, while thermal diffusivity increased from 1.217×10$^{-5}$ to 2.341×10$^{-5}$ m$^2$/s within the temperature range of 40 and 60$^o$C.**

**Keywords: Baobab pulp powder, thermal conductivity, thermal diffusivity, specific heat capacity, particle size**

## 1.0 INTRODUCTION
The baobab is a deciduous tree which belongs to the plant family called Bombacacee.Though, it is of central Africa origin, it has been distributed throughout the savanna region of Africa (Sidibe*et al*., 1996).The baobab fruit pulp which is primarily used as drinks and licked in raw form has been reported to provide both soluble and insoluble fibres which constitute about 50grams/100grams of the pulp (Murray *et al.*, 2001).
The search for lesser known and underutilized crops and legumes, many of which are potentially valuable as human and animal foods has been intensified to maintain a balance between population growth and agricultural productivity, partially in the tropical and subtropical areas of the world(Devries, 1991). Baobab (*Adansonia digitata*) is an example of a less known and underutilized crop in Nigeria. This promising but underutilized legume has potential in the formulation and development of new food product such as baked goods and milk which could provide a local alternative to imported beverage (Prentice *et al.*, 1993).
Over the years, research effort has been directed towards the study of various engineering properties of food crops particularly those properties that influence the design of equipment for planting, harvesting, handling, storage and processing of crops. Reports has shown that bulk density determines the capacity of storage and transport systems, while true density is useful for separation equipment and the porosity of material determines the resistance to airflow during aeration and drying (Vilche, *et. al.*, 2003). Angle of repose had been known as a useful parameter for calculation of belt conveyor width and for designing the shape of storage. Static friction between the powder and conveyor belt affects the maximum angle with the horizontal which the conveyor can assume when transporting the powder. Knowledge of the thermal properties of food stuffs such as the specific heat, thermal conductivity and thermal diffusivity are fundamentally important in mathematical modeling studies for the design and optimization of food processing operation involving heat and mass transfer which are beat exemplified by food drying.
Therefore, the specific objective of the study is to determine the physical and engineering properties of powder obtained from baobab fruit pulp.

## 2.0 MATERIALS AND METHODS
### 2.1 Materials
The baobab fruit pulp (*adansonia digitata* L.) powder used in this study was collected from parent trees around Ladoke Akintola University of Technology, Ogbomoso. The capsules in dried form were broken to extract the white pulp and sieved into powdery form.

### 2.2 Methods
#### 2.2.1 Determination of the particle size distribution
The particle size distribution of the baobab fruit pulp powder was determined by measuring 25g of the sample into an electric sieve shaker with varying sieve sizes ranging from 0.150 mm to 0.780

mm for 30min. The mass of the sample adsorbed by each sieve were weighed using an electronic weighing balance. The mean particle size of the baobab powder was calculated using the equation,

$$Mp = \frac{\sum Xi.\emptyset}{\sum \emptyset} \quad (1)$$

where, $M_p$is the mean particle size, $X_i$ is the sieve size (mm) and $\emptyset$ is the mass fraction

### 2.2.2 Determination of the bulk, true density and porosity

The method of mass-volume relationship by Fraser *et al.*(1978) was adopted in determining the bulk density of the baobab fruit pulp powder. The sample was filled in a cylinder of predetermined volume and was gently tapped against a flat surface to get the new volume.

The true density of the baobab fruit pulp powder was determined by water displacement technique (Dutta*et al.*, 1988). The sample was weighed and lowered into measuring cylinder containing water such that the powderdid not float during immersion in the water. The volumetric water displacement was rapidly taken and thus recorded.

The density ratio was the quotient of mass density and bulk density and was expressed as percentage, while porosity was computed (Jain and Bal, 1997)

$$P = \frac{\rho_t - \rho_b}{\rho_t} \quad (2)$$

where, P is the porosity, $\rho_t$ is the true density (g/cm$^3$) and $\rho_b$ is the bulk density (g/cm$^3$)

### 2.2.3 Determination of the angle of repose

The angle of repose or the emptying angle was determined on different structural surfaces such as plywood, mild steel and PVC plastic using the method described by Maduako and Faborode (1990) with slight modification. A symmetrical reduction was made to the carton used to make 100 x 100 x 100mm$^3$ paper carton instead of the original 450 x 450 x 450mm$^3$used byMaduako and Faborode (1990). The carton was filled with the baobab pulp powder, lifted up to a distance above such that the bottom of carton was left opened. The gradual lifting up of the carton continues until a conical heap was formed. The emptying angle was then calculated from;

$$\tan\emptyset = \frac{2\pi h}{S} \quad (3)$$

where, h is the height of the heap (cm), S is the radius of the heap (cm), $\emptyset$ is the angle of repose and $\pi$ is 3.142.

### 2.2.4 Coefficient of friction determination

The method of inclined plane apparatus described by Dutta*et al.* (1988) was used to determine the coefficient of static friction which was tested with respect to three structural materials, namely; plywood, mild steel and PVC plastic. The table was gently raised and the angle of inclination to the horizontal at which the sample starts to slide was read off from the protractor attached to the apparatus. The tangent of the angle was reported as the coefficient of static friction.

$$C_f = \tan\emptyset \quad (4)$$

where, $C_f$ is the coefficient of friction and $\emptyset$ is the angle of inclination to the horizontal.

### 2.2.5 Determination of specific heat capacity

The specific heat capacity of the baobab fruit pulp powder was determined in an adiabatic drop calorimeter using the method of mixtures described by McProud and Lund (1983). 5g of the baobab fruit pulp powder, tightly wrapped in a thin polythene foil was dropped in calorimeter containing water at three different equilibrated starting temperatures. The temperature of the water and sample were recorded over time. The data was used to plot the heat loss curve and the specific heat capacity was calculated from the heat balance equation;

$$C_s = \frac{1}{M_s}\left[M_w C_w \left({}^{G_w}/_{G_s}\right) - M_c C_c\right] \quad (5)$$

where, $C_w$ and $C_c$ are the specific heat capacity of water and calorimeter respectively (kJ/kg$^o$C); $M_s$, $M_w$ and $M_c$ are the mass of sample, water and calorimeter, respectively (kg); $G_w$ and $G_s$ are the slopes of cooling for water and sample, respectively ($^o$C/s)

### 2.2.6 Determination of thermal diffusivity

The temperature history of the baobab fruit pulp powder was determined by using three different probes. Each probe was connected by K-type thermocouple wires to a digital multimeter(AldaAvd 890C$^{-1}$JENWAY, England). Each probe was fixed at different points, one being at the surface of the calorimeter, one being at the centre of the powder while the other measures the temperature of the water. The calorimeter (with the food powder ) was placed in hot water at 30$^o$C with a digital multimeter used to monitor the heating medium temperature via a probe and thermocouple wire at 4 min interval until the temperature of the water reached the desired temperature (Dickerson, 1965).

The thermal diffusivity was calculated using the equation;

$$D_t = \frac{Mr^2}{4(T_j - T_s)} \quad (6)$$

where, $D_t$ is the thermal diffusivity(m$^2$/sec), M, is the slope of $T_o$ against time i.e slope of heat curve ($^o$C/sec), r is the radius of container, $T_j$ is the temperature of the surface at any time t, $^o$C and $T_s$ is the temperature at the center of the food at time t, $^o$C

**2.2.7 Determination of thermal conductivity**

The thermal conductivity of the baobab pulp powder was determined using the line heat source techniqueas described by Nithatkusol (1998). The probe was made of a stainless steel needle used to house ni-chrome wire as a heater wire and thermocouple. The cylindrical sample holder was made of acrylic with adiameter of 50 mm and height of 95 mm. The probe was then inserted longitudinally into sample that was filled in the sample holder. The sample was equilibrated to the desired temperature by a water bath. Then a current was applied and time-temperature data was recorded. Thermal conductivity was calculated using.

$$k = \frac{Q \ln\left({}^{t_2}/_{t_1}\right)}{4\pi(T_2 - T_1)} \qquad (7)$$

where k is thermal conductivity (W/m°C), Q is heatinput per unit length of the line heat source (W/m), T is temperature (°C) and t is time (s).

## 3.0 RESULTS AND DISCUSSION

Particle size is one of the most important physical properties which affect the flowability of powders. It is generally considered that powders with particle sizes larger than 200 µm are free flowing, while fine powders are subject to cohesion and their flowability is more difficult. The experiment (Table 1) revealed that the particle sizes of the baobab fruit pulp powder are larger than 200 µm. Thus, the baobab pulp powder exhibited a free flowing pattern. The true density and bulk density (Table 1) of the baobab fruit pulp powder at the moisture content 11.1% were found to be 1167 and 301 kg/m$^3$, respectively. The knowledge of the density can be used to design a separation and transportation technique for the powder. A similar higher true density was reported by Teunou*et al.* (1999) for various food powders such as flour, tea, milk and whey. The value of the true density of the baobab fruit pulp powder was observed to be higher than the value reported for milk powder while it was found to be lower than the values reported for flour, tea and whey. Since density is the ratio of mass to volume, it means that the rate at which water is absorbed in baobab powder is lesser in milk and higher in flour, tea and whey.The bulk density was found to have a lesser value than those values reported for various food powders by Teunou*et al.* (1999). The porosity was calculated from the relationship between the true density and the bulk density and it was found to be 73%.

The dynamic angle of repose (Table 1) of the baobab fruit pulp powder was tested on three different surfaces, such as, mildsteel, plywood and plastic. It was observed in the experiment that there was a free flow of the baobab fruit pulp powder on mildsteel compared to the other two surfaces used in the experiment. The high value exhibited on mild steel is being supported by the fact that fine particles or powder has high angle of repose. It is thus pertinent to note that the dynamic angle of repose on the baobab fruit pulp powder is lower due to its surface area than 45°, 46°, 47° and 52° reported for skim-milk, whey permeate, tea and flour (Teunou*et al.*, 1999).The static coefficients of friction for the powder at the moisture content of 11.1% (d.b) as shown in Table 1 were found to be 0.7501, 0.7796 and 0.8339 for plastic, plywood and mildsteel surfaces, respectively. The coefficient of friction was highest on mildsteel and lowest on plastic. The highest value obtained for mildsteel can be attributed to the surface of the mildsteel, therefore offering a higher resistance.

The specific heat capacity of the baobab fruit pulp powder between the temperature of 40 and 60°C was found to range from 0.34 and 1.55 J/gK, respectively. Corresponding value of cereal flour using the differential scanning calorimeter was found to be higher than the experimental value for baobab fruit pulp powder (GonulKaletunc, 2007). It was observed from the experiment that the specific heat capacity of baobab fruit pulp powder followed a decreasing trend with increase in temperature. This implies that the quantity of heat required toraise the temperature of 1g of baobab powder decreases as temperature increase. The decrease in the trend suggest that there may be alterations in the structure of the food materials upon mixing with water which led to decrease in the specific heat.This is true because most food processing operations usually involve heat transfer to and from the material. This heat transfer between the material and its surroundings can result in an increase or decrease in temperature and/or phase changes. Thus, specific heat capacity of food material being processed changes as function of temperature.

Thermal diffusivity quantifies a material's ability to conduct heat relative to its ability to store heat. The thermal diffusivity at each varied temperature of the baobab fruit pulp was found to range from 1.217 x 10$^{-5}$ to 2.341 x 10$^{-5}$ m$^2$/s, respectively. The result shows that thermal diffusivity is another property that changes with temperature. Corresponding value of defatted soy flour (Wallapapam, 1984) was found to range between 6.5 x 10$^{-8}$ to 13.1 x 10$^{-8}$ m$^2$/s, respectively. It was observed that the thermal diffusivity of the baobab fruit pulp powder increased as the temperature of the baobab fruit pulp powder also increased and it was found to diffuse faster as temperature increases than the values reported by Wallapapam (1984) for soy flour. The thermal conductivity of the baobab fruit pulp powder between the temperature range of 40 and 60°C were found to range between 5.68 and 2.40 Wm$^{-1}$K$^{-1}$, respectively. It was observed that the sample shows a decreasing trend with increase in temperature. The decreasing trend in the thermal conductivity of the baobab pulp powder may be affected by the chemical composition, physical structure, the stateofthe substance and temperature.

Table 1: Physical Properties of Baobab Fruit Pulp Powder

| PARAMETERS | UNITS | VALUES |
|---|---|---|
| Mean particle size | mm | 0.953±0.261 |
| True density | kg/m$^3$ | 1167±0.144 |
| Bulk density | kg/m$^3$ | 301±0.006 |
| Porosity | % | 73 |
| Angle of Repose | | |
| *Mildsteel* | degree | 40.63±0.589 |
| *Plywood* | degree | 39.18±0.788 |
| *Plastic* | degree | 37.28±0.367 |
| Coefficient of friction | | |
| *Mildsteel* | nil | 0.8339±0.092 |
| *Plywood* | nil | 0.7796±0.102 |
| *Plastic* | nil | 0.7501 ±0.099 |

## CONCLUSION

The knowledge of the particle size, angle of repose and coefficient of friction as studied in this experiment revealed that baobab pulp powder exhibited a free flowing pattern more on mild steel than plywood or PVC plastic. The results of the thermal properties showed that temperature has influence on the specific heat capacity, thermal diffusivity and thermal conductivity and that the data generated may be useful in the design and fabrication of processing equipment in the production of the powder.

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