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PHYSICAL AND THERMAL PROPERTIES OF GORGON NUT

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ABSTRACT

Bulk density, true density, angle of repose, coefficient of friction on metal surfaces, specific heat, thermal diffusivity and conductivity of gorgon nut were determined using standard techniques for different sizes of nuts at moisture contents and temperatures ranging from 15 to 60% (dry basis) and 25 to 55C, respectively. The physical properties varied quadratically with moisture content. Specific heat increased with moisture and temperature but decreased with the size of the nut; whereas, the thermal diffusivity showed a reverse trend. Thermal conductivity increased with moisture content but did not follow any trend with temperature within the range of the study. The physical and thermal properties data at various moisture contents and temperatures were used to develop equations for different sizes of gorgon nuts.

INTRODUCTION

Gorgon nut (*Euryale ferox*), seeds of an aquatic herb, is a monotypic genus of family Nymphaeacea and characterized by its hard seed coat (shell), black color and round shape, diameter ranging from 4.5 mm to 14.5 mm. It is grown in the stagnant fresh water pools of North and Northeastern states of India. Its wild populations are also available in China, Japan, USSR and North America (Jha *et al.* 1991). Since this crop is unexploited in the world as a food, its production data is not available in any literature. However, it is estimated that,

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in India, more than one million tons of gorgon nut is produced and processed annually by traditional methods. The edible part of the nut is the starchy kernel, which cannot be separated easily from the raw nut. It is, therefore, necessary to give proper thermal treatments and subsequent mechanical action to the nut in order to separate out the edible kernel (Jha and Prasad 1990).

Practically no information is available on the physical and thermal properties of the nut in the literature. The main objective of this investigation was to determine the physical and thermal properties of gorgon nut and to correlate them with moisture content, temperature and size of nut.

MATERIALS AND METHODS

Physical Properties

The bulk density, true density, angle of repose coefficient of friction at different moisture levels and sizes of gorgon nut were determined. Fresh raw nuts were procured from a grower for the study. One lot of 5 kg of sample was separated into three grades according to diameter, and they were categorized as large > 10mm; 10mm ≥ medium ≥ 8mm; and small < 8mm. Graded samples were air dried and roasted to different moisture levels; covering the entire range of moisture content. The moisture contents of the samples were determined by vacuum oven method (Hall 1970). Prepared samples were kept in desiccators at room temperature to maintain a particular moisture content before using them for the experiments. Standard techniques for determination of properties of agricultural materials in Mohsenin (1978) were followed and replicated five times.

Bulk and True Density

Bulk density of gorgon nut was determined by platform scale method. It was read directly from the scale in kg/L and the same was expressed in kg/m^3. For determining true density, the samples of five nuts from each lot were randomly selected. The true volume and weight of samples were measured with the help of an air comparison pycnometer and an electronic digital balance, respectively, and the true density of nut was computed.

Angle of Response

For determination of angle of repose of gorgon nut a cylinder was filled and slowly raised so that material could slide and form a heap on the floor. The height (H) and diameter (D) of the heap were measured with the help of a scale and the angle of repose of the nuts (ϕ) was computed using the following expression:

$$\phi = \tan^{-1} (2\,H/D) \qquad (1)$$

Coefficient of Friction

Coefficient of friction of gorgon nut was determined on two surfaces; galvanized iron (GI) and mild steel (MS) sheets. A table top set-up was made and consisted of a bottomless plastic ring with small thickness having height and diameter of 25 and 100 mm, respectively. The middle of the ring was tied with a rigid string and connected to a metallic disc. A frictionless pulley was fixed at one end of the table in such a way that the disc connected with the end of the string passing over the pulley could hang freely. The weights of the samples (W_n) and the disc connected to the string were initially taken and then the plastic ring was kept in horizontal position on MS or GI sheet. The plastic ring was filled and weights were added to the hanging disc in small amounts until the ring filled with the nuts began to slide on the surface. Total weight (W_t) required to slide the cylinder on metal surface was recorded and the coefficient of friction was computed by the expression:

$$\mu = W_t / W_n \qquad (2)$$

The Physical properties were determined at 15, 30, 45 and 60% (db) moisture content and replicated five times. Data were analyzed using a computer, Cyber-180/120. Equations that best fitted to the data were determined.

Thermal Properties

The thermal properties, such as specific heat and thermal diffusivity, were determined experimentally; whereas, thermal conductivity was computed from specific heat, thermal diffusivity and bulk density of the nut.

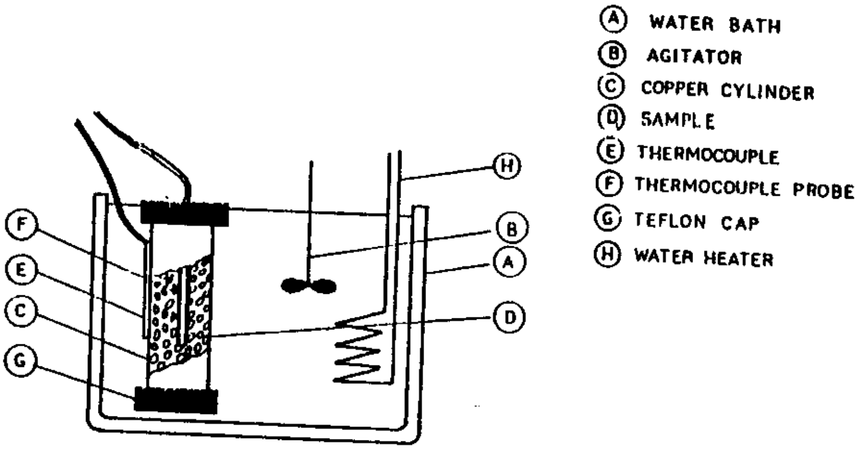
Specific Heat

Specific heat of the nut was determined by the method of mixture. Sample of a known mass and temperature was placed in calorimeter of known specific heat containing water of known weight and temperature. The specific heat of the sample was then computed from a heat balance equation:

$$Cp = W_w((T_w - T_{eq})/(W_g(T_{eq} - T_g)) - W_{eq}/W_g \qquad (3)$$

where,

$$W_{eq} = W_w(T_g - T_{eq})/(T_{eq} - T_w)$$



IG. 1. SCHEMATIC ARRANGEMENTS OF APPARATUS FOR DIRECT MEASUREMENT OF THERMAL DIFFUSIVITY

ermal Diffusivity and Conductivity

An apparatus described by Dickerson (1965) based on transient heat asfer condition, which requires only time temperature data, was used for ermination of thermal diffusivity (α). The apparatus (Fig. 1) consisted of a er bath (A) with an agitator (B), a water heater (H), a high thermal ductivity copper cylinder (C) of length 246 mm and inner and outer diameter 1 and 33 mm, respectively, containing the sample (D), thermocouple (E) ered to the outer surface of the cylinder to monitor the temperature of the ple at radius R, a thermocouple probe (F) to indicate the temperature at the r of the sample, and the top and bottom caps made of teflon (G) to mize the heat transfer in axial direction and to prevent water leakage into ylinder. The cylinder was filled with the prepared sample and was tapped g filling to obtain uniform packing, and it was weighed using an electronic l balance. The bulk density of material filled in cylinder was computed. ylinder filled with sample was immersed in a water bath at a constant initial temperature and a thermocouple probe was inserted at the center of the sample. When the temperature of the sample reached that of the bath, the heater was switched on and a stop watch was started. Temperature was recorded at 5 min intervals until a constant rate of rise of temperature was obtained for both inner and outer thermocouples (Fig. 2). The following expressions as reported by Mohsenin (1980) was used for determination of thermal diffusivity (α),

$$\alpha = A\,R^2/\{4\,(T_g - T_c)\} \qquad (4)$$

The reliability of the apparatus was tested by determining the thermal diffusivity of quartz sand and comparing the same with the reported values. The variation in computed and reported values in literature was found to be neglible. The thermal conductivity of the sample was computed by the following expression:

$$k = \alpha\, C_p\, \rho_b \qquad (5)$$

A randomized factorial design was adopted to study the effect of moisture content, temperature and size of the nut on thermal properties. Levels of the variables were selected considering the variation of moisture and temperature of the nut during processing operations. However, the nut temperature was limited up to 55C because of the possibility of moisture migration and evaporation loss that might occur at higher temperatures.

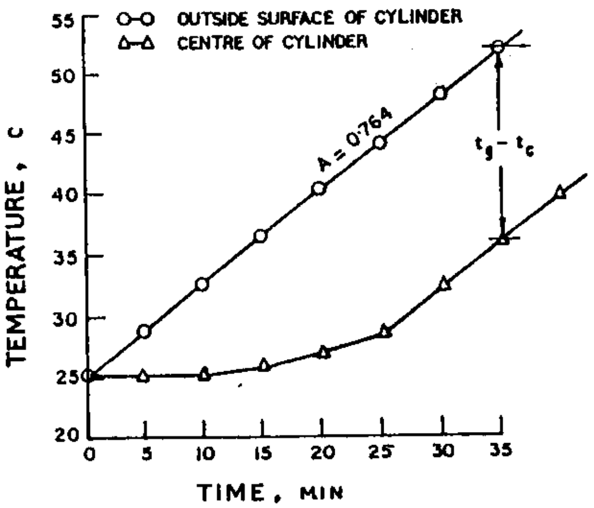


FIG. 2. TIME-TEMPERATURE DATA OBTAINED USING THERMAL DIFFUSIVITY APPARATUS FOR GROUNDNUT (m.c. 60.5%)

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RESULTS AND DISCUSSION

Physical Properties

The physical properties data were analyzed and five equations, viz., quadratic, linear, power, logarithmic and exponential, were tested for the best fit of the data. Among these, the quadratic form of the equation was found to be the best for all the physical properties with the correlation coefficient more than 0.98. The best fitted equations are given through Eq. (6–19).

Bulk density:

$$\rho_l = 369.2 + 12.9M - 0.102M^2 \tag{6}$$
$$\rho_m = 396.7 + 13.3M - 0.108M^2 \tag{7}$$
$$\rho_s = 434.0 + 16.6M - 0.842M^2 \tag{8}$$

True density:

$$\tau_l = 995.9 + 8.3M - 0.064M^2 \tag{9}$$
$$\tau_m = 1039.7 + 6.9\ M - 0.042M^2 \tag{10}$$
$$\tau_s = 1025.7 + 9.3M - 0.080M^2 \tag{11}$$

Angle of repose:

$$\phi_l = 20.5 + 0.04M - 2x10^{-4}M^2 \tag{12}$$
$$\phi_m = 21.2 + 0.05M - 4x10^{-4}M^2 \tag{13}$$

Coefficient of friction on MS Sheet:

$$\mu_l = 0.529 + 10^{-4}M + 2x10^{-5}M^2 \tag{14}$$
$$\mu_m = 0.516 + 3x10^{-4}M + 2x10^{-5}M^2 \tag{15}$$
$$\mu_s = 0.474 + 2x10^{-4}M + 8x10^{-6}M^2 \tag{16}$$

Coefficient of friction on GI Sheet:

$$\mu_l = 0.428 - 2x10^{-4}M + 2x10^{-5}M^2 \tag{17}$$
$$\mu_m = 0.425 - 2x10^{-4}M + 2x10^{-5}M^2 \tag{18}$$
$$\mu_s = 0.372 + 10^{-4}M + 10^{-5}M^2 \tag{19}$$

Bulk density, true density and angle of repose of gorgon nut increase with moisture content and decrease with size of the nut.

This trend of bulk and true densities is because the proportionate increase in weight with moisture content may be more than that of the volume and better packing ability of the smaller size nut. The increase in angle of repose with moisture and decrease with size of nut may be due to increase in internal friction with moisture content and decrease in the same with size of the nut. Coefficient of friction increases with the moisture content and size of the nut. Increased moisture content and size of nut may result in increase of adhesion characteristics and decrease in smoothness of nut, respectively. The coefficient of friction on MS sheet is higher than that on the GI sheet. More roughness of MS sheet than GI may be the cause of this. Angle of repose increases with the moisture content but decreases with the size of the nut.

Thermal Properties

The regression equations, for the specific heat, thermal diffusivity and conductivity within the range of variables studied, i.e., 15-60% (d.b.) moisture content (M) and 25-55C temperature (T) of large, medium and small size f the gorgon nut, are presented in Eq. (20-28).

$$C_{pl} = 1.95 - 3.2 \times 10^{-2}T + 2.3 \times 10^{-2}M + 6.3 \times 10^{-4}T^2 \qquad (20)$$

$$C_{pm} = 1.26 + 2.3 \times 10^{-2}T + 2.1 \times 10^{-4}T^2 \qquad (21)$$

$$C_{ps} = 1.53 - 2.2 \times 10^{-2}T + 1.8 \times 10^{-2}M + 3.9 \times 10^{-4}T^2 \qquad (22)$$

$$\alpha_l = 3.1 \times 10^{-4} - 1.7 \times 10^{-6}M - 1.5 \times 10^{-6}T \qquad (23)$$

$$\alpha_m = 3.3 \times 10^{-3} - 1.3 \times 10^{-5}M - 1.6 \times 10^{-6}T - 5.8 \times 10^{-9}M^2 \qquad (24)$$

$$\alpha_s = 3.5 \times 10^{-4} - 2.3 \times 10^{-6}M - 1.7 \times 10^{-6}T - 7.8 \times 10^{-9}M^2 \qquad (25)$$

$$\begin{aligned} k_l = {} & 5.9 \times 10^{-5} - 1.3 \times 10^{-6}T + 2.6 \times 10^{-6}M + 2 \times 10^{-8}T^2 \\ & - 8.4 \times 10^{-9}MT - 2 \times 10^{-8}M^2 \qquad (26) \end{aligned}$$

$$\begin{aligned} k_m = {} & 6.5 \times 10^{-5} - 1.2 \times 10^{-6}T + 1.9 \times 10^{-6}M + 1.5 \times 10^{-8}T^2 \\ & -6.6 \times 10^{-9}MT - 1.2 \times 10^{-8}M^2 \qquad (27) \end{aligned}$$

$$\begin{aligned} k_s = {} & 6.5 \times 10^{-5} - 1.2 \times 10^{-6}T + 1.9 \times 10^{-6}M + 1.5 \times 10^{-8}T^2 \\ & - 6.6 \times 10^{-9}MT - 1.1 \times 10^{-8}M^2 \qquad (28) \end{aligned}$$

All the coefficients of the variables appearing in second order multiple regression models were subjected to the F-test to examine significance at the 5% level, and the insignificant terms were excluded.

Specific heat increased with moisture content and decreased with the size of nut, but thermal diffusivity followed the reverse trend [Eq. (20-25)]. The thermal conductivity of the nut increased with moisture content [Eq. (26-28)]. This trend was due to fact that the thermal conductivity of water is about 0.628 W/mC at about 38C (Richey 1961), which is much higher than that of air and solid nuts. The equations also indicate that the variation in thermal conductivity was small and erratic with temperature. However, the specific heat and thermal diffusivity were significantly affected by the same and followed a certain trend with temperature. Neither the thermal properties of gorgon nut nor its chemical composition for predicting the former using the existing models (Heldman 1975) are available in literature for comparison. However, the values obtained are within the range of agricultural materials (Richey 1961).

CONCLUSIONS

Bulk density, true density, angle of repose and coefficient of friction of gorgon nut varied quadratically with moisture content. Specific heat and thermal conductivity of gorgon nut increased with moisture content and temperature; whereas, they decreased with the size of the nut. However, thermal diffusivity decreased with moisture content and temperature, but it increased with temperature in the range of 25 to 55C.

NOMENCLATURE

A	Constant rate of temperature rise, C/s
C	Integral constant and specific heat, J/kg C
D	Diameter of heap, m
H	Height of heap, m
k	Thermal conductivity, W/m C
M	Moisture content, % (d.b.)
R	Radius, m
T	Temperature, C
t	Temperature, C
W	Weight, kg

Greek Letters

α	Thermal diffusivity, m^2/s
τ	True density, kg/m^3
θ	Time, s
ø	Angle of repose,
ρ	Density, kg/m^3
μ	Coefficient of friction, fraction

Subscripts

b	bulk	n	normal
c	center	p	specific heat
eq	equivalent	r	radius
g	grain (nut)	s	small
l	large	t	tangential
m	medium	w	water

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