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RESEARCH PAPERS

Moisture Diffusivity and Thermal Expansion of Gorgon Nut

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Moisture diffusivity of gorgon nut seed and its kernel, during roasting in an open pan at different moisture contents and pan temperatures was, determined. The coefficient of cubical thermal expansion of the kernel and the shell at various moisture levels was determined by a dilatometer. Moisture diffusivities of kernel and nut increased with increase in moisture content and temperature and have been correlated with the same. Cubical thermal expansion of the shell and kernel increased with increase of moisture content.

Keywords : Gorgon nut, Moisture diffusivity, Dilatometer, Cubical expansion, Kernel, Shell, Moisture ratio

Gorgon nut (*Euryale ferox*), commonly known as *Makhana* in India, is a seed of an aquatic herb. It is the main aquatic crop in Darbhanga, Kosi, and Purnea divisions of Mithila, North Bihar, India and is grown in large number of stagnant fresh water pools with not more than 1-1.5 m depth. Its present natural forms can be observed in the pools of North-Eastern and Central India, while it grows wild in China, Japan, USSR, and North America (Jha et al. 1991). The gorgon nut is characterized by its hard seed coat (shell), black colour and spherical shape, with diameter ranging from 4.5 to 14.5 mm. Edible part of the nut is its starchy kernel, which cannot be separated easily from the raw nut due to close adherance of the shell to the kernel at high moisture content. It is, therefore, necessary to give thermal treatments for mechanical separation of the popped (expanded) kernel. Expanded kernels contain (g/100 g) 12.8 moisture, 76.9 carbohydrates, 9.7 proteins, 0.1 fat, 0.5 total minerals, 0.02 calcium, 0.9 phosphorous and 0.0014 iron (Gopalan et al. 1987). *Makhana* is used for milk-based food preparations, like *kheer*, puddings and curry, due to its rich nutritive value. Fried *makhana* with salt or sugar is widely used as a snack food. *Makhana* has medicinal value and is used as an ingredient in the preparation of indigenous tonics. It also serves as a source of starch for textile industries (Lakhmani 1978), and its amino acid composition has also been determined (Nath and Chakraborthy 1985).

Processing of gorgon involves various operations such as drying, size grading, pre-heating, tempering, roasting and popping. Roasting of nuts is normally carried out in an open iron pan at about 300°C surface temperature (Jha and Suresh Prasad 1990). It is expected that high internal pressure will develop within the seed at this temperature, due to vapourization of water from kernel. But, the shell of the nut being strong, does not break in spite of possible high internal pressure. Sudden impulsive mechanical impact is needed to crack the shell. As soon as cracks develop, water vapour comes out with an explosion and the kernel gets popped out.

As the nut comprises of the kernel and hard shell, it is expected that the major moisture transfer during roasting will be from the kernel alone, while the cubical thermal expansion of the shell and the kernel may be different. Studies on these properties of the nut are not reported in the literature. Such studies are required for mathematical simulation of the roasting and popping processes and the knowledge would be useful in designing an efficient roaster for gorgon nut processing. The present investigation was, thus, aimed at determining the moisture diffusivity of whole nut, and the kernel, as well as the coefficient of cubical thermal expansion of the kernel and the shell of the nut.

Materials and Methods

Sample preparation : Samples of fresh gorgon nut of 60.2% moisture content (db) were procured from the market of Madhubani, Bihar. Medium-sized nuts (8-10 mm dia) were dried, preheated and roasted to bring down the moisture contents of nuts to about 33.7, 25.9 and 11.5%, respectively, as per procedure of Jha and Suresh Prasad (1990). The kernel was obtained from the preheated and roasted nut by manual decortication. Moisture contents in all the cases were determined by vacuum oven method (Hall 1970). The moisture contents of shell obtained from dried, preheated and roasted nuts

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were about 15, 5, and 2%, respectively, and those of the preheated and roasted kernels were about 33.4 and 15.3%, respectively. To increase the moisture content of the preheated kernel to about 48.6%, it was soaked in water at ambient temperature of about 30°C for 10 min. Conditioned samples were kept in different desiccators partly filled with saturated salt solutions to equilibrate and maintain the moisture content.

Moisture diffusivity : Conditioned samples were roasted in an open iron pan with continuous stirring. The heat source was 1.5 kW electric heater. Temperature of the pan surface was measured with an iron-constant (J-type) thermocouple attached to the millivoltmeter having the least count of 0.01 mV. For the corresponding millivolt, the temperature was noted from the standard chart of the thermocouple. For maintaining a particular temperature of the pan surface, input voltage of the heater was regulated by an autotransformer, connected to power source. When a preset temperature of the pan surface was obtained, the sample was put into the pan and the time of roasting was noted. Sample was agitated continuously and the representative samples at 0.5, 1, 2, 3, 4 and 5 min intervals were taken out and kept quickly in pre-weighed moisture box. Radii of the individual nuts and kernels of the sample were measured before roasting with the help of a vernier caliper. Equilibrium moisture content of the sample at roasting temperature was assumed to be negligible because of very high roasting temperature. Five equations, viz., quadratic, linear, logarithmic, power and exponential were tested for best fit of the data of moisture ratio (MR) and roasting time. Among these equations, correlation coefficients of the following exponential equation was found maximum, (>0.992).

$$MR = \frac{M}{M_0} = C_1 \exp(-C_2\theta) \quad \text{..... (1)}$$

Where, M is moisture content of the sample at any time θ (% db), M_0 is initial moisture content of the sample (% db), C_1 is constant (dimensionless), C_2 is constant (min^{-1}) and θ is roasting time (min).

The values of C_1 and C_2 were obtained from the exponential equations, best fitted to the data of moisture content ratio and roasting time and the constant C_2 of equation (1) was interpreted, considering the mass transfer from the porous bodies as follows (Luikov 1966) :

i.e.,

$$C_2 = \frac{D\pi^2}{r_0^2} \quad \text{or,} \quad D = \frac{C_2 r_0^2}{\pi^2} \quad \text{..... (2)}$$

Where D is moisture diffusivity (m^2min^{-1}) and r_0 is the average radius of the kernel or nut (m).

When $D\pi^2/r_0^2$ is greater than 1.2, the equation (2) gives satisfactory results (Luikov 1966). From Equation (2), the moisture diffusivities of the samples at 60.2, 33.7 and 25.9% moisture content (db) of gorgon nut, at 48.6, 33.4, 15.3% moisture contents of kernels and 200, 300 and 400°C pan surface temperature, were calculated using the average radius of the individual kernel and the nut. Each experiment was replicated thrice. To determine the relationships among moisture diffusivity, moisture content and roasting temperature, randomized design experiments were chosen. Levels of the moisture content of the samples were selected which were obtained after drying, preheating and roasting of the nut. The results were analysed according to the multiple regression method (Snedecor and Cochran 1967). Coefficients of each term of the regression equations were subjected to F-test at 5% level of significance.

Coefficient of cubical thermal expansion : The method to determine the coefficient of cubical thermal expansion of gorgon nut kernel and shell was based on the standard ASTM test D864-52 for plastics (ASTM 1968).

Results and Discussion

Moisture diffusivity : The results of the moisture diffusivity of gorgon nut and kernel are presented in Table 1. It is evident that the moisture diffusivities

TABLE 1. MOISTURE DIFFUSIVITY OF GORGON NUT AND ITS KERNEL

Treatment No.	Temperature	Gorgon nuts		Kernels	
		Moisture content	Moisture diffusivity	Moisture content	Moisture diffusivity
	°C	%, db	$m^2/min \times 10^{-7}$	%, db	$m^2/min \times 10^{-7}$
1	200	60.2	5.11	48.6	4.87
2.	200	33.7	4.08	33.5	4.28
3	200	25.9	3.88	15.3	3.59
4	300	60.2	5.66	48.6	5.72
5	300	33.7	4.78	33.4	5.20
6	300	25.9	4.39	15.3	4.29
7	400	60.2	6.28	48.6	6.57
8	400	33.7	5.29	33.4	6.11
9	400	25.9	4.78	15.3	4.83

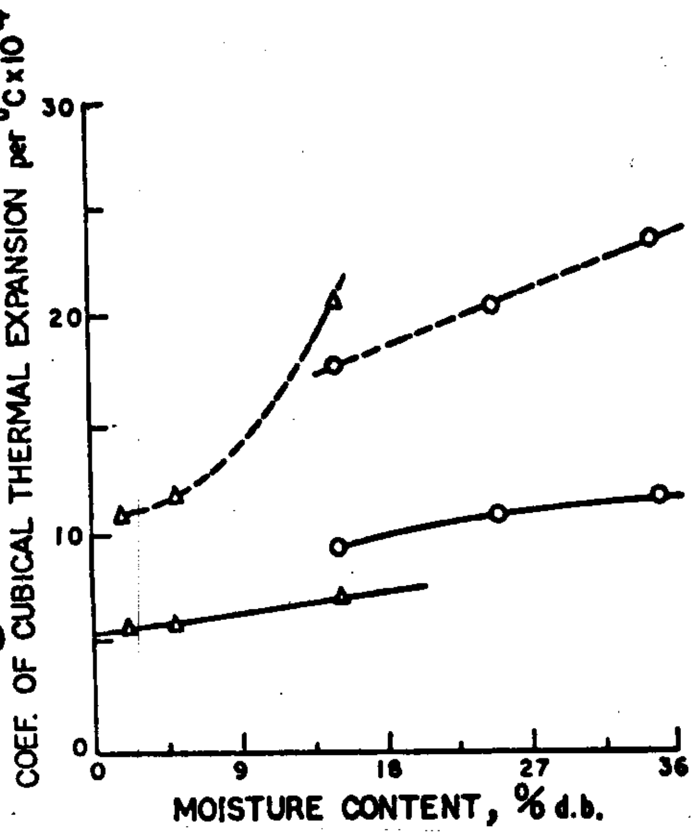

Fig. 1. Effect of moisture content and temperature on coefficient of cubical thermal expansion of gorgon nut kernel and shell, O—O kernel; Δ——Δ shell; —— 31-66°C; - - - 66-96°C

of the nut and the kernel increase with increase in moisture content and temperature. The multiple regression analysis of results showed that the coefficients containing all the moisture and quadratic terms in the equation for nut, and the coefficients of second order terms for moisture as well as temperature of the equation in case of kernel, were not found significant at 5% level and thus, those terms were omitted from the final equations. The final regression equations for the nut and the kernel with best fit having the correlation coefficients of 0.997 for both the cases were :-

$$D_n = 1.22\times10^{-7} + 6.77\times10^{-10}T \quad \dots (3)$$

$$D_k = 1.22\times10^{-7} + 5.88\times10^{-9}M + 7.32\times10^{-10}T \quad \dots (4)$$

Where, D_n and D_k are moisture diffusivity of the gorgon nut and the kernel, respectively (m^2min^{-1}), M is moisture content of the sample (% db), and T is the temperature of the sample (°C).

Coefficient of cubical thermal expansion : Coefficient of cubical thermal expansion of the kernel and shell are plotted with moisture content in Fig 1. Coefficients of cubical thermal expansion of both kernel and shell are much higher beyond a transition temperature of 66°C. The coefficient of cubical thermal expansion of the shell increases rapidly above 5% moisture content and 66 to 96°C temperature range and exceeds the value of the kernel at about 15% moisture content. But, in actual roasting operation of the gorgon nut, moisture content of the shell would never exceed beyond 5% and that of the kernel in the range of 15 to 33%. In the above range of moisture content, the coefficient of cubical thermal expansion of the kernel is much higher than that of the shell. This indicates that the nut is subjected to not only the internal pressure build up within the nut due to thermal processing, but also to the mechanical pressure exerted by the kernel on the shell due to higher rate of cubical thermal expansion.

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