J. Agric. Engng Res. (1999) **72**, 145–150
Article No. jaer.1998.0356, available online at http://www.idealibrary.com on IDEAL

Physical and Hygroscopic Properties of Makhana

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(Received 17 November 1997; accepted in revised form 25 July 1998)

Makhana is the popped expanded kernel of the gorgon nut (*Euryale ferox*) and is used as a delicious food in India. Presently, it is sorted, graded and used as an ingredient of various ready-to-eat products. High volumetric expansion of makhana increases transport cost and makes it too expensive in distant places. Makhana thus requires further processing to get some value-added products of minimum volume. To develop any kind of product and mechanized system for their production, physical properties are required. Furthermore, since makhana is a seasonal and regional crop its storage conditions are also needed for keeping it appropriately at processing centres. Physical properties of makhana at moisture contents ranging from 5 to 20% (dry basis) and equilibrium moisture content at relative humidities ranging from 11·2 to 88% at temperature 30°C were determined using standard techniques. Physical properties were found to be: test weight (weight of 1000 makhana) 286 to 384 g; bulk density 56·5–84·6 kg/m^3; particle density 105–240·6 kg/m^3; porosity 29·4–48·9%; angle of repose 33–35·6°; and static coefficient of friction 0·596–0·82 and 0·493–0·684 on galvanized iron and stainless steel, respectively. The equilibrium moisture content of makhana was found to be between 11·5 and 58·9% (dry basis) within the ranges of variables studied.

Notation

D	diameter of heap at its base, mm
H	height of heap above the floor, mm
W_n	total weight acting normally to the sample in the plastic ring, g
W_t	total tangential weight (weight of hanging disc plus weight kept on it), g
ε	porosity, %
μ	coefficient of friction
ϕ	angle of repose, deg
ρ_b	bulk density, kg/m^3
ρ_p	particle density, kg/m^3

1. Introduction

Makhana is the popped expanded kernel of the gorgon nut (*Euryale ferox*)[1] which is a monotypic genus of the family Nymphaeaceae and is characterized by its hard seed coat (shell), black colour and round shape with a diameter ranging from about 4·5 to 15 mm (*Fig. 1*). It is grown in the stagnant fresh water pools of the North and Northeastern states of India. Wild populations are also found in China, Japan, Taiwan, and North America. Bihar, in India, is the leading state in its production and processing. The nuts are collected from the water and popped to remove the edible starchy kernel. Popping is the process of creating superheated vapour within the conditioned nut by heating the contained moisture and suddenly releasing the pressure to cause a volume expansion of the kernel. The expanded kernel of the nut obtained through this process is called makhana in India.

Presently, gorgon nuts are processed to obtain the makhana by the traditional method. Operations involved are drying, first roasting, tempering for 48–72 h, second roasting and popping.[2] The popped kernel (makhana), on average, contains[3] 12·8% moisture, 76.9% carbohydrates, 9·7% proteins, 0·1% fat, 0·5% minerals, 0·02% calcium, 0·9% phosphorous, and 0·0014% iron. Makhana, due to its rich nutritive value, is utilized for milk-based food preparations, like *kheer*, pudding, and in preparation of vegetables and curry. Salted and/or sweetened fried makhana is widely used as a snack.[4,5]

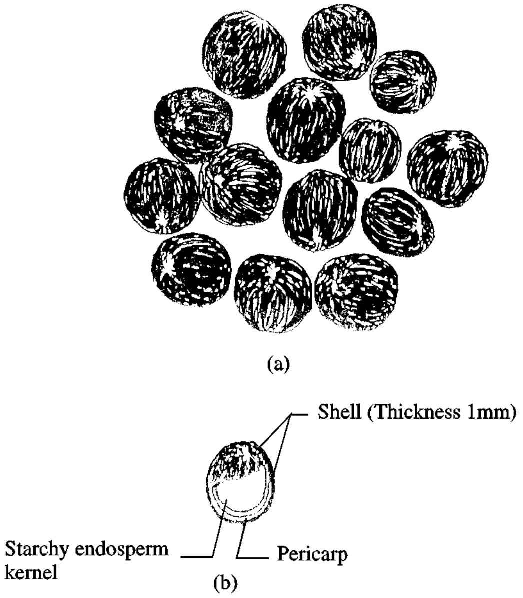

Fig. 1(a). Whole gorgon nuts (b) Detail of a gorgon nut

Makhana also has medicinal value and is used as an ingredient in preparation of indigenous tonics. In addition, it serves as a source of starch for textile industries.[6] Now makhana is being used as one of the ingradients of various ready-to-eat products. Food industries are eager to develop value-added products from makhana but the high transportation cost, due to the high volumetric expansion[1] of makhana, make it an expensive item in distant places. Thus, the food processing industries are searching for ways and means to process the makhana further to reduce its volume and add value. These could be achieved when proper machinery are developed for the purpose. Surprisingly, even average weight of individual makhana and the storage conditions are still not known. The objective of this investigation was, therefore, to determine the physical and hygroscopic properties of makhana at various moisture levels to be used for the design of: machinery for sorting, grading and size reduction; and drying and storage structures for storing makhana under different conditions for further processing.

2. Materials and methods

2.1. *Sample preparation*

Makhana was procured from the local market of Bhopal for the study. One 5 kg sample was divided into three grades according to average diameter and sphericity, and classified as grade 1 (large round and fully expanded) of diameter > 15 mm and sphericity $> 0{\cdot}8$, grade 2 (all irregular, flattened and overexpanded) of any diameter with sphericity $\leqslant 0{\cdot}8$, and grade 3 (small, round and partially expanded) of diameter $\leqslant 15$ mm and sphericity $> 0{\cdot}8$. For classifying the makhana, sphericity and diameter of individual makhana were measured. Sphericity was calculated as the ratio of geometric mean diameter to major diameter of makhana.[7] Limits of diameter and sphericity were based on a preliminary study of three prevailing grades of makhana in the market place.

Graded samples were air-dried to obtain a lower moisture level, whereas they were moistened by storage in a humidity-controlled chamber to obtain higher moisture levels. The moisture content of the sample was determined by keeping the sample in the hot-air oven[8] at 100 ± 2°C for 72 h and expressed in percent dry basis. The prepared samples of moisture contents 5, 10, 15 and 20%, packed separately in polyethylene bags, were kept in different desiccators at room temperature until used in experiments to avoid any change in moisture content of the sample. However, a few samples were also checked for their moisture content just before use.

2.2. *Physical properties*

Test weight, bulk density, particle density, porosity, angle of repose and static coefficient of friction on galvanized iron (GI) and stainless-steel (SS) surfaces at different moisture levels of the prepared samples were determined using standard techniques.[7] Experiments were replicated five times and the average values were reported.

2.2.1. *Test weight*

One thousand makhana from each sample were randomly selected and weighted on an digital electronic balance having an accuracy of 0·001 g. The average of the replicated values are reported.

2.2.2. *Bulk and particle density*

A measuring cylinder having an inner diameter of 106 mm and a length of 228 mm was filled with the prepared sample to a known volume. Tapping during filling was done to obtain uniform packing and to minimize the wall effect, if any. The filled sample was weighed and the bulk density of the material filling the cylinder was computed.

For determining the particle density, samples of five makhana from each grade were randomly selected for each replication. To ensure non-absorbance of the toluene by makhana, some of them were dipped into the toluene and the weight difference was found to be negligible. The particle volume of weighed makhana was then determined by the toluene displacement method in a measuring cylinder having graduation of 0·1 cm^3 and the particle density of the nut was computed.

2.2.3. *Porosity*

The porosity ε of the makhana of each grade was computed using the following formula and expressed in percent:

$$\varepsilon = (1 - \rho_b/\rho_p) \times 100 \qquad (1)$$

where ρ_b is the bulk density, and ρ_p is the particle density.

2.2.4. *Angle of repose*

For the determination of the angle of repose of makhana, a tube (inner diameter 106 mm and height 220 mm) was kept vertically on a horizontal crystal glass floor and filled with the sample. Tapping during filling was done to obtain uniform packing and to minimize the wall effect, if any. The tube was slowly raised above the glass floor so that whole material could slide and form a heap. The height above the floor H and the diameter of the heap D at its base were measured with the help of a measuring scale and the angle of repose of the makhana ϕ was computed using the following expression:

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

2.2.5. *Coefficient of static friction*

The coefficient of static friction of makhana was determined on two surfaces, galvanized iron (GI) and stainless-steel (SS) sheets. A table-top arrangement[5] was made which consisted of a plastic ring with a small thickness having height and diameter of 85 and 80 mm, respectively, connected to a hanging weight carrier by means of a string which passed over a pulley of minimum friction at one of the table. The diameter of ring was selected to ensure that the total contact area of makhana, with a horizontal surface large enough to resist the force applied tangentially by sliding the whole mass rather than rolling was sufficient to be measured easily. The weight of the sample, W_n, and of the weight-carrier connected to the string were measured and then the plastic ring was positioned on a horizontal GI or SS sheet. The plastic ring was filled and raised slightly above the floor to eliminate the effect of the rim of plastic ring in the value of static coefficient of friction. Weights were then added to the hanging disc in small amounts until the ring filled with the makhana began to slide on the surface. The total weight required to slide the cylinder on the metal surface W_t was recorded and the coefficient of static friction was computed by the expression:

$$\mu = W_t/W_n \qquad (3)$$

All the physical properties were determined shortly after preparation of samples of 5, 10, 15, and 20% (d.b.) moisture content of three grades of makhana and the data were plotted.

2.3. *Hygroscopic properties*

Equilibrium moisture contents of different grades of makhana were determined by the stationary method[8] at various relative humidities at 30°C. Saturated solutions of different chemicals were prepared in different desiccators for maintaining the desired levels of relative humidities. The chemicals used were lithium chloride (LiCl), potassium acetate (CH_3 COOK), magnesium chloride ($MgCl_2$), potassium carbonate (K_2CO_3), sodium nitrite ($NaNO_2$), sodium chloride (NaCl) and barium chloride ($BaCl_2 \cdot 2H_2O$) for maintaining the relative humidities of 11·2, 22, 32·4, 43·6, 63·3, 75·6 and 88%, respectively[8] at 30°C. Levels of relative humidilites in the desiccators were verified before keeping the experimental samples in them.

Makhana, 10–15 in number of each grade, were randomly selected and weighed by an digital electronic balance. The weighed sample of known moisture content was then kept on a wire mesh in different desiccators having different relative humidities. The brims of the desiccators were greased and closed completely by their lids so that there was no air passage from or to the desiccators to keep the levels of relative humidity constant during the experiment. All desiccators were kept at one place and ensured that they were not disturbed. Weights of the samples were recorded at 24 h intervals until three identical consecutive readings were obtained.

During the experiment, mould growth on some samples at 88% relative humidity was observed after a few weeks and these samples were discarded. The experiment at this relative humidity was repeated and weight of the sample was again recorded regularly until mould growth started. The moisture content of each sample of constant weight was determined and reported as the equilibrium moisture content of makhana.

The experiment was replicated thrice and the average values with their standard deviations are reported.

3. Results and discussion

3.1. *Physical properties*

The test weight increases with moisture content as expected (*Fig. 2*). The increase in bulk and particle densities with moisture content (*Figs 3* and *4*) is because of increase in weight proportional to moisture content

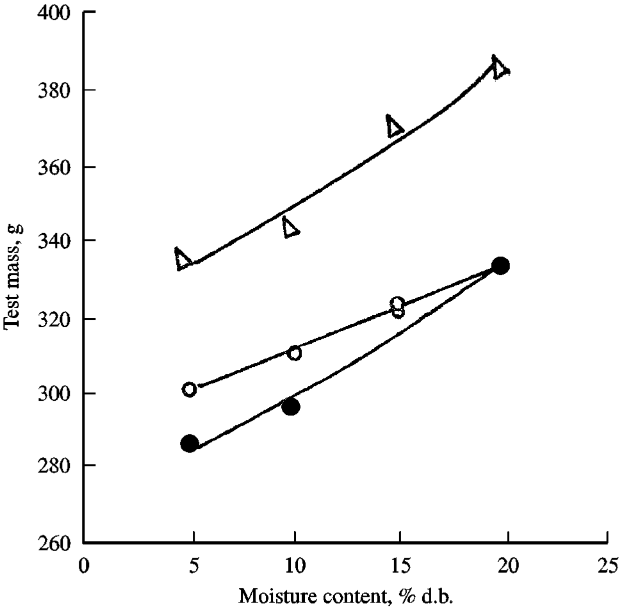

Fig. 2. Variation of test weight with moisture content of makhana: Δ, grade 1; ●, grade 2; ○, grade 3

which is more than that in the volume. However, the porosity (*Fig. 5*) was not found to follow any specific trend. The increase in angle of repose with moisture content (*Fig. 6*) may be due to an increase in the internal friction with the moisture content.

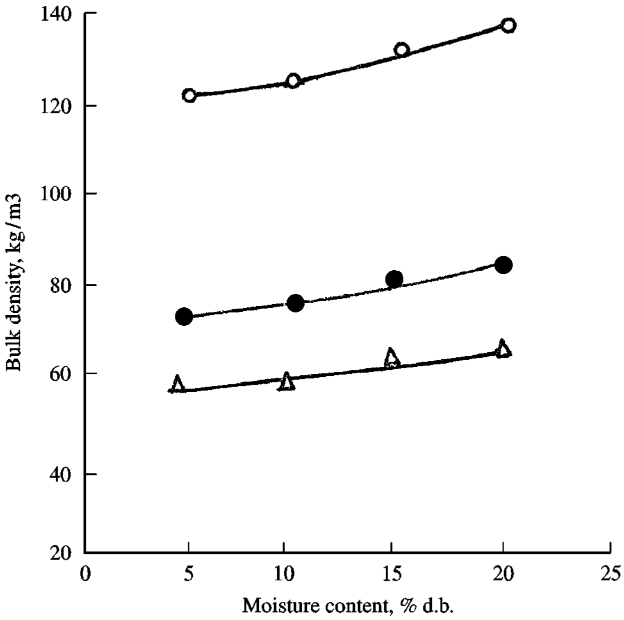

Fig. 3. Variation of bulk density with moisture content of makhana: Δ, grade 1; ●, grade 2; ○, grade 3

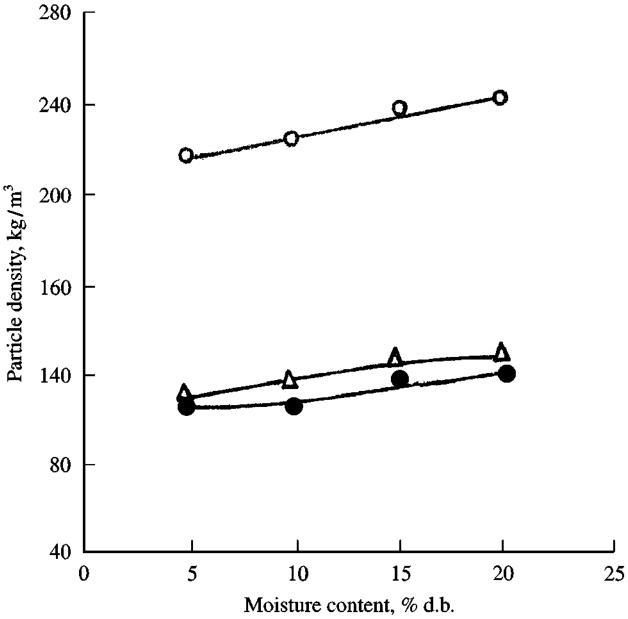

Fig. 4. Variation of particle density with moisture content of makhana: Δ, grade 1; ●, grade 2; ○, grade 3

The test weight and porosity of grade 1 makhana were found to be highest followed by grade 3 makhana (*Figs 2* and *5*). The lowest test weight and particle density of grade 2 makhana may be due to its over-expansion during popping. Over-expanded makhana

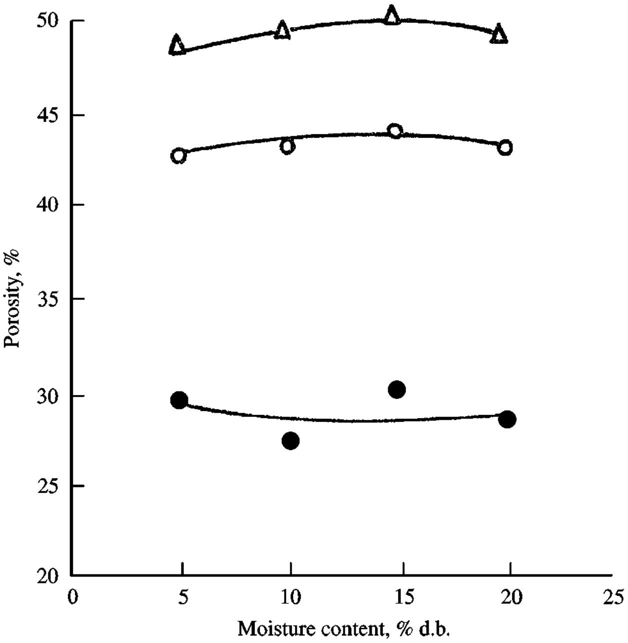

Fig. 5. Variation of porosity with moisture content of makhana: Δ, grade 1; ●, grade 2; ○, grade 3

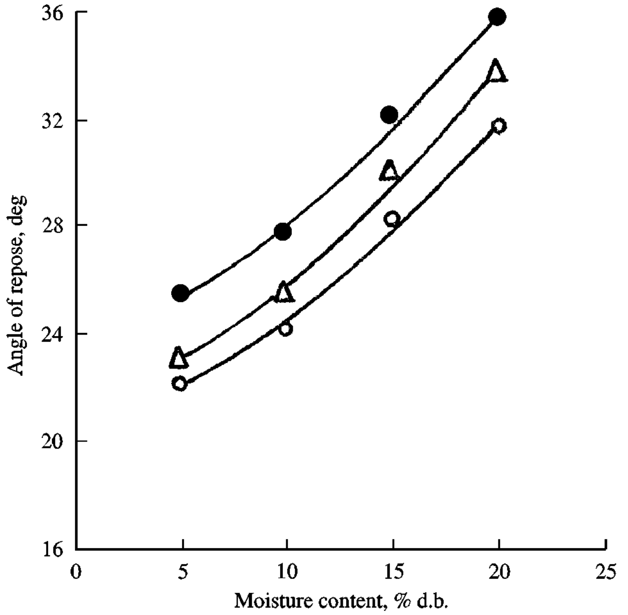

Fig. 6. Variation of angle of repose with moisture content of makhana: Δ, grade 1; ●, grade 2; ○, grade 3

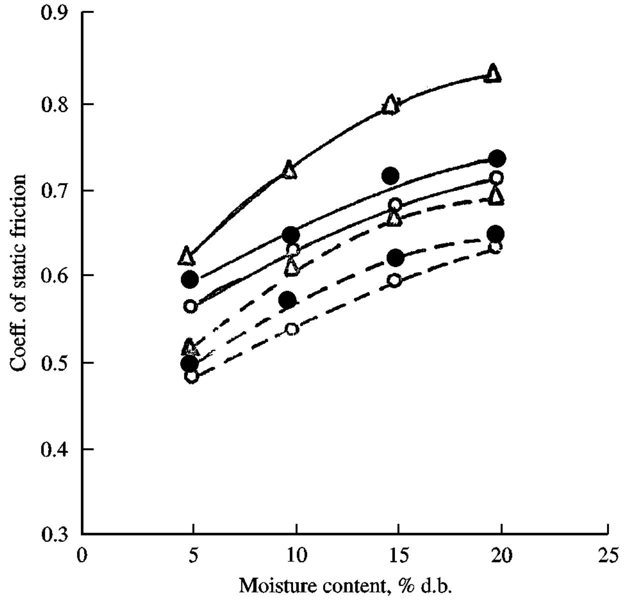

Fig. 7. Variation of coefficient of friction with moisture content of makhana and metal surfaces: Δ, grade 1; ●, grade 2; ○, grade 3; ——— on galvanised iron; --- on stainless steel

usually consists of a fractured surface with more porous structure, more irregular shape and lighter weight. The bulk density decreased with grade of makhana. This may be due to the fact that the grade 1 makhana consists of fully expanded kernels with high expansion ratio which restricts their packing ability; while the corresponding packing characteristics of grade 2, although lighter than grade 1, probably increase considerably due to its flatness/irregularity in shape. Grade 3 makhana however, is, partially expanded and smaller in size, so it may have maximum packing ability.

The angle of repose is highest for grade 2 makhana (*Fig. 6*) mainly because of its higher projected area due to flatness and irregularity in shape which may increase the internal friction of the material. The coefficient of static friction increased with moisture content and higher grade of makhana (*Fig. 7*). An increased moisture content and higher grade may result in an increase in adhesion characteristics and roughness of the surface of makhana, respectively. The coefficient of friction on GI sheet is higher than that on the SS sheet. More roughness of the GI sheet and SS may be the cause of this.

3.2. *Hygroscopic property*

Equilibrium moisture content for grades 1, 2, and 3 makhana varies between 11·5–50·6% (d.b.), 12·6–55·1% (d.b)., and 16–58·9% (d.b.), respectively, for relative humidities in between 11·2 and 88% at 30°C (Table 1). The table shows that the equilibrium moisture content of makhana increases with increase in relative humidity which is an established fact for grain[9] also. The equilibrium moisture content of makhana at each relative humidity decreases with increase in its grade (Table 1). This may be due to a difference in structure of different grades of makhana which may have an effect on moisture absorption and holding capacity.

4. Conclusions

1. Test weight, bulk density, particle density, porosity, angle of repose, and static coefficient of friction of makhana on galvanized iron and stainless steel were found to be in the range of 286–384 g, 56·5–84·6 kg/m^3, 105–240·6 kg/m^3, 29·4–48·9%, 22–35·6°, 0·596–0·82 and 0·493–0·684, respectively. These properties, except porosity increased with increase in moisture content. Porosity did not follow any well-defined trend.
2. The equilibrium moisture content of higher grade makhana was found to be lower than that of the smaller grade. The values range between 11·5 and 58·9% in relative humidities from 11·2 to 88% at a temperature 30°C.

Table 1
Equilibrium moisture content of makhana

Grade of makhana	*Equilibrium moisture content (%) d.b.*						
	Relative humidity (%) at 30°C						
	11·2	*22·0*	*32·4*	*43·6*	*63·3*	*75·6*	*88·0*
1	11·5 (1·6)*	20·5 (1·1)	30·2 (1·3)	37·8 (1·7)	41·3 (1·5)	43·4 (1·7)	50·6 (1·8)
2	12·6 (1·4)	23·2 (1·2)	33·7 (1·6)	39·8 (1·3)	45·0 (1·4)	47·8 (1·5)	55·1 (1·3)
3	16·9 (1·5)	28·7 (1·4)	37·9 (1·4)	43·5 (1·1)	48·3 (1·6)	52·2 (1·9)	58·9 (1·5)

* Figures in parentheses indicate standard deviation.

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