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Influence of moisture content and grade on engineering properties of makhana

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ABSTRACT

Makhana (Euryale ferox Salisb.) is one of the most common dry fruits utilized by the people due to low fat content, high contents of carbohydrates, protein, minerals and other medicinal significance. For the purpose of developing any kind of mechanized system for sorting, grading and manual processing, different engineering properties like test weight, bulk density, true density, porosity, angle of repose and coefficient of friction of different grades of makhana were determined using standard techniques at moisture contents ranging from 20 to 60% (dry basis). Increase in moisture content was found to increase the linear dimensions, mass of 100 seeds, bulk density, true density, angle of repose, and coefficient of friction while porosity decreased with increase in moisture content. Coefficient of friction was found to increase as moisture content increased from 0.298–0.414, 0.420–0.517 and 0.524–0.639 respectively on glass, wooden and mild steel sheet structural surfaces. Angle of repose showed an increasing trend with increase in moisture content. The study concludes that grade and changes in moisture content significantly (P<0.05) affected most of the engineering properties determined.

Keywords: Makhana, Gorgon nut, Moisture content, Grade, Engineering property

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INTRODUCTION

Makhana (*Euryale ferox* Salisb.) is considered as a potential aquatic cash crop of India in general and Bihar in particular. It is commonly known as Fox nut, Gorgon nut and Prickly water lily. Commercially it is grown in Mithilanchal districts of state Bihar comprising areas of Madhubani and Darbhanga. These areas accounts for 90% of estimated 75,000 tons of country's total annual production of makhana. Besides India, this unique crop is grown in China, Nepal and Bangladesh. Botanically, it is an aquatic, stem less and prickly herb with short and thick rootstock and it belongs to nymphaeceae family. The economic part of makhana is the popped expanded kernel which is used as a delicious food. The edible part of the nut is its starchy kernel which cannot be separated easily from the raw nut. It is therefore popped, manually by the traditional methods (Jha and Prasad 1990) as there is a lack of scientific methods of popping. Popping is the process of creating superheated water vapour within the conditioned nut by heating the contained moisture, and suddenly releasing the pressure to cause a volumetric expansion of the kernel. The expanded kernel of the nut obtained through this process is known as makhana in India (Jha and Prasad 1998). Due to low fat content, high content of carbohydrate, protein and minerals, it is one of the most common dry fruits utilized by the people. The calorific value of raw seeds (362 kcal/100g) and puffed seeds (328 kcal/100g) lie close to staple foods like wheat, rice, other cereals(Bilgrami et al.1983).Besides nutritional value makhana is also recommended in the Indian and Chinese system of medicine in the treatment of respiratory, circulatory, digestive, excretory and reproductive systems disorder.

In order to be able to reap the maximum benefits from breeding and agronomical improvement in the field of makhana cultivation there is the need for the development of processing equipment and techniques to add value to makhana. Knowledge of engineering properties of agricultural materials and their dependence on the moisture content are needed to adequately design appropriate equipment and systems for various agricultural operations such as planting, harvesting and post harvest operations for agricultural crops (Asoegwu et al. 2006). Such basic information should be of value not only to engineers but also to food scientists and processors who may exploit these properties and find new uses (Mohsenin 1986). Though the information on physical properties for many food grains is available, the information of these properties for makhana at various moisture levels is scarce and hence this study was undertaken with the objective to determine the engineering properties of makhana and Correlate them with moisture content and grade of the sample.

MATERIALS AND METHODS

Sample preparation

For studying the engineering properties of Makhana, its procurement was done from local market. One lot of 3 kg of sample was separated into three grades according to average diameter and sphericity as shown in Table 1.

Moisture content

To obtain the desired moisture levels (20 to 60%), graded samples were either air dried or moistened, as per the case, by keeping them in a humidity controlled oven. The prepared samples were kept in desiccators filled with salt solutions of the appropriate concentration at room temperature to maintain particular moisture content before using them for the experiments. The initial moisture content of the seeds was determined using methods described by Dutta et al. (1988).

12g of sample was weighed in a previously weighed moisture box using digital electronic, top pan balance. Three replications were taken for each sample. The weighed seed sample was kept in the hot oven for 24 hours at 102^0C. Seed lots of different initial moisture content was obtained either by adding pre-calculated amount of water for mixing with seeds or by drying the seed lots to reduce the moisture. After oven drying, samples were removed from oven and kept for 15 minutes in an airtight dessicator for moisture equilibrium. Final weights were taken on digital electronic balance and loss of moisture was calculated as average moisture content of sample on dry basis by using following formulae.

The moisture content, m, wet basis.

$$m = \frac{Wm}{Wm + Wd} \times 100$$

Where,
W_m = weight of moisture
W_d = weight of dry material

The moisture content, M, dry basis.

$$M = \frac{Wm}{Wd} \times 100$$

Size and Shape

The triaxial dimensions such as length (a), breadth (b) and thickness(c) of raw and dried makhana seeds were determined by taking five samples of each class using vernier calliper having a least count of 0.001mm. The samples were divided into three classes based upon their largest linear dimensions i.e. small (<9mm), medium (9mm to 11mm) and large(>11mm). The averages of three intercepts were calculated. The shape of seed was determined by calculating sphericity.

Sphericity

Sphericity of an object is defined as a ratio of the diameter of a sphere of the same volume as the object to the diameter of the smallest circumscribing sphere. The sphericity is also calculated as the ratio of geometric mean diameter of the object to the major diameter (Mohsenin 1980). The largest intercept, a, second largest intercept, b, normal to 'a' and the third intercept, c, normal to both 'a' and 'b' were measured (Mohsenin 1980), and the sphericity was computed using the following expression:

$$\text{Sphericity} = \frac{(abc)^{\frac{1}{3}}}{a}$$

Where,
a = longest intercept,
b = longest intercept normal to a, and
c = longest intercept normal to a and b

Angle of repose
To measure the angle of repose a wooden box full of makhana seeds was mounted on a tilting top drafting apparatus (Jha 1993). The upper part of apparatus was fitted with glass on which wooden box with seeds was mounted. The apparatus top was tilted till the wooden box full of seeds started moving over the inclined surface. At this point the reading on vertical scale (H_h) as well as horizontal length (D_h) was recorded. This process was repeated four times and every time the reading of vertical scale and horizontal distance was recorded. The angle of inclination Ø was measured which gave the angle of repose of the makhana seeds.

$$\text{Angle of repose } (\varnothing) = \tan^{-1}\frac{H_h}{D_h}$$

Where,
Ø = angle of repose in, degree;
H_h = vertical height of scale;
D_h = horizontal distance of apparatus

Coefficient of friction
A tilting top drafting apparatus was used and makhana seeds of known weight were filled in the hollow wooden box. The box was kept on the surface in such a way so that seeds were in contact with the surface. The middle of the box was tied with a nonstretchable string and connected to a plastic disc having minimum weight. A pulley having minimum friction 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. Different weights from a weight box were kept on the pan till the wooden box in the seeds just starts sliding. This is the condition where frictional force is nullified and motion starts. This process was repeated thrice for each surface (Dutta et al. 1988; Suthar and Das 1996). As the coefficient of friction varies with characteristics of the surface, three different surfaces namely, wooden, glass and mild steel sheet were used.

$$\boldsymbol{\mu} = \frac{F}{W}$$

Where,
μ = Coefficient of friction
W = force normal to surface of contact
F = force of friction

Bulk density
Bulk density was measured using the AOAC method, in which a cylinder of inner diameter 106 mm and length 228 mm was filled with makhana seeds. The excess seeds were removed and the weight recorded. The bulk density was then calculated as the ratio of makhana weight to the volume occupied (Omobuwajo et al.1999). The bulk density was calculated using formula.

$$\rho_b = \frac{M}{V}$$

Where,
ρ_b = Bulk density
M = Total mass of grain
V = Total volume of grain

True density
The true density of the makhana seeds were obtained using the method described by Tunde-Akintunde and Akintunde (2007). Seeds of known weight were taken and known volume of Toluene was put into measuring cylinder and reading was recorded. After that the known weight of seed taken was put into the measuring cylinder

and the reading of the volume raised in the cylinder was recorded. In order to determine the volume of seed the initial recorded reading of the cylinder was subtracted from the later recorded reading. Finally the true density was calculated in forms of kg/m^3 by using the following formula.

$$\rho = \frac{M_S}{V_S}$$

Where,
M_s = mass of solid particle
V_s = volume of solid particle
ρ = True Density

Porosity
Porosity was calculated from the relationship between bulk (ρ_b) and true (ρ_t) density according to Mohsenin (1986).

$$p = \frac{1 - \rho_b}{\rho_t}$$

RESULTS AND DISCUSSION

The effect of grade and moisture content on some engineering properties of makhana has been presented in Table 2. The effect of grade and moisture content on the physical dimensions of the gorgon nut seed was significant ($P<0.05$). The length breadth and thickness of large grade makhana varies between 11.82 to 12.43 mm, 11.44 to 12.22 mm and 11.01 to 11.65 mm respectively, whereas the corresponding values for medium grade was found to be 10.55 to 10.93mm, 9.60 to 9.92 mm, and 9.38 to 9.75 mm. The length, breadth and thickness of small grade makhana vary between 8.79 to 8.99 mm, 8.10 to 8.21mm and 7.69 to 8.02 mm respectively (Table 2). The findings are in tune with the reports of Al-Mahasneh and Rababah (2007). for green wheat, Aydin (2002). for grains hazelnuts, Calisir et al. (2005). for rapeseed, and Tunde-Akintunde and Akintunde (2007). for sesame seeds. Linear dimensions are important in determining aperture size in design of grain handing machinery (Al-mahasneh and Rababah 2007).

Test weight
The values of test weight of 100 seeds, each for large, medium and small at 60% moisture content were found to be 82.6g, 65.6g and 42.5 g respectively which were significantly higher than the test weight at lower moisture content. The lower test weight of smaller seeds at the same moisture was obviously due to their smaller size. Similar results were reported by Tunde-Akintunde and Akintunde (2007). for sesame seeds.

Bulk density
An increasing trend of bulk density with moisture range (20 - 60% db) was observed (Table 2). At higher moisture levels, highest bulk density was exhibited by smaller grade makhana followed by medium and large grade. The increasing nature of bulk density with moisture content was due to the proportionate increase in weight with moisture content may be more than that of the volume (Jha and Kachru 1998). It is evident that bulk density increased with moisture content but decreased with size of seeds. This trend may be due to the fact that proportionate increase in weight with moisture content was more than that in volume and better packing ability of the smaller seeds.

True density
The true density increases with increase in moisture content (Table 2). The true density of smaller seeds was found to be more than that of the larger ones which indicates that the smaller was heavier than the larger one for a given volume and moisture content. The bulk density was lower than that of true density because the air space in grain bulk increases the volume while the weight is the same.

Porosity
Porosity value decreased with increase in moisture content (Table 2). It was higher for large grades followed by medium and small grades, irrespective of moisture contents. In all the grades porosity was highest at 20% moisture content. A linear decrease in porosity with increase in pumpkin seed moisture content was reported by (Joshi et al. 1993). However, Singh and Goswami (1996). found the porosity of cumin seed to increase with grain moisture content.

Angle of repose
The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of the granular material to a horizontal plane. It showed an increasing trend with moisture content (Table 3) because of its

higher projected area which may increase the internal friction of the material. Compared to all the grades the angle of repose is highest of medium grade makhana seeds.

Co efficient of friction

The coefficient of friction increased with moisture content and grade of makhana (Table 4). The coefficient of friction on mild steel sheet is higher than wooden surface and lowest for glass surface which may be caused by the higher roughness of the mild steel sheet. As the moisture content increased, the static coefficient of friction against the selected surfaces increased. The same increase was observed for sunflower seeds and millet by Gupta and Das (2000). and Baryeh (2002). The possible reason for this may be the fact that an increase in moisture content increased the cohesion between the seeds, thus increasing the friction, the seed experiences during its flow/movement on the respective surfaces (Balasuramanian and Vismanathan 2010).

Sphericity

Sphericity of makhana varies between 0.967 to 0.969 mm, 0.930 to 0.931 mm and 0.932 to 0.934 mm for large, medium and small grade, respectively. This reveals that the medium and small are almost of spherical shape, whereas; large grade is relatively flat. The flatness arises from the fact that some of makhana seeds get compressed when the hot roasted seeds are struck by a wooden hammer to break their shells for popping. The dimension of small grade is lowest because of its partial expansion and due to the smaller size of the seeds.

The effect of variety was significant ($P<0.05$) for all the mechanical properties. Also the interactive effect of variety and moisture content on the parameters was significant ($P<0.05$). The correlations between grain moisture content, physical dimension and engineering properties are presented in Table 5. Significant ($P<0.05$) strong engineering correlations existed between grain moisture content and bulk density and true density while a significant ($P<0.05$) negative correlations was found between grain moisture content and porosity. Sphericity, mass of 100 seeds, length, breadth, thickness and bulk density showed significant ($P<0.05$) positive correlations with length, breadth, thickness, angle of repose, bulk density; but negatively correlated with porosity.

Table 1 Classification of makhana seeds according to different grades

Grade	Average diameter	Sphericity
Large	>11mm	>0.8
Medium	Not considered	>0.8
Smaller	<9 mm	>0.8

Table 2 Effect of grade and moisture content on the engineering properties of makhana

Grade	Moisture Content (%)	Sphericity	Length (mm)	Breadth (mm)	Thickness (mm)	Test weight (g/100)	Bulk density (kg/m³)	True density (kg/m³)	Porosity (%)
Large (L)	20	0.967	11.82	11.44	11.06	58.8	507.26	1101.9	53.96
	30	0.967	11.82	11.49	11.01	51.4	622.86	1157.3	46.17
	40	0.969	12.43	12.06	11.65	60.2	697.32	1231.2	43.36
	50	0.969	12.43	12.22	11.49	73.5	726.12	1249.5	43.4
	60	0.969	12.43	12.16	11.55	82.6	751.66	1253.2	40
Medium (M)	20	0.93	10.61	9.67	9.38	51.1	535.86	1140.2	53
	30	0.93	10.61	9.6	9.45	53.3	659.24	1212.6	45.6
	40	0.931	10.93	9.92	9.72	59.2	731.54	1270.5	42.4
	50	0.931	10.93	9.89	9.75	61	757.14	1278.8	40.8
	60	0.932	10.55	9.6	9.4	65.6	788.74	1289.4	38.82
Small (S)	20	0.932	8.79	8.13	7.69	33.6	574.2	1168.5	50.9
	30	0.933	8.99	8.21	8.02	37.2	686.3	1243.9	44.9
	40	0.934	8.91	8.1	8.01	38.5	756.4	1283.8	41.08
	50	0.934	8.91	8.21	7.89	40.99	796.7	1292.2	38.34
	60	0.935	8.79	8.13	7.79	42.5	811.4	1299.6	37.36
Mean	40.00	0.94	10.60	9.92	9.59	53.97	693.52	1231.51	44.01
Standard deviation	14.64	0.02	1.42	1.59	1.48	13.95	95.44	62.15	5.19
SE	3.78	0.00	0.37	0.41	0.38	3.60	24.64	16.05	1.34
CV	36.60	1.87	13.37	16.05	15.44	25.86	13.76	5.05	11.79
P of grades	a	a	a	a	a	a	a	a	a
P of initial moisture content	a	a	a	a	a	a	a	a	a
P of grade X initial moisture content	a	a	a	a	a	a	a	a	a

[a] *Significantly different ($P<0.05$)*

Table 3 Effect of grade and moisture content on the mechanical properties of makhana

Grade	Moisture Content (%)	Angle of repose(°)	Coefficient of friction		
			Glass surface	Wooden surface	Mild steel sheet
Large (L)	20	21.35	0.364	0.472	0.577
	30	21.75	0.376	0.481	0.59
	40	22.26	0.389	0.492	0.61
	50	22.44	0.397	0.501	0.615
	60	22.56	0.414	0.517	0.644
Medium (M)	20	22.76	0.309	0.426	0.568
	30	23.95	0.326	0.441	0.584
	40	25.48	0.352	0.472	0.606
	50	25.52	0.378	0.486	0.624
	60	26.65	0.392	0.497	0.639
Small (S)	20	0	0.298	0.42	0.524
	30	0	0.311	0.441	0.533
	40	0	0.323	0.472	0.544
	50	0	0.349	0.486	0.551
	60	0	0.361	0.497	0.558
Mean	40.00	15.65	0.36	0.47	0.58
Standard deviation	14.64	11.55	0.04	0.03	0.04
SE	3.78	2.98	0.01	0.01	0.01
CV	36.60	73.79	10.09	6.11	6.51
P of grades	a	a	a	a	a
P of initial moisture content	a	a	a	a	a
P of grade X initial moisture content	a	a	a	a	a

[a] Significantly different (P<0.05)

Table 4 Correlation coefficients between different engineering properties of makhana

		Physical properties				Engineering properties				
	Moisture content	**Sphericity**	**Length**	**Breadth**	**Thickness**	**Test weight**	**Bulk density**	**True density**	**Porosity**	**Angle of repose**
Moisture content	1									
Sphericity	0.050	1.000								
Length	0.067	0.785[a]	1.000							
Breadth	0.071	0.870[a]	0.988[a]	1.000						
Thickness	0.062	0.839[a]	0.995[a]	0.996[a]	1.000					
Test weight	0.448	0.575[b]	0.861[a]	0.832[a]	0.836[a]	1.000				
Bulk density	0.910[a]	-0.192	-0.201	-0.206	-0.204	0.146	1.000			
True density	0.840[a]	-0.332	-0.302	-0.321	-0.314	0.059	0.979[a]	1.000		
Porosity	-0.917[a]	0.138	0.161	0.163	0.160	-0.164	-0.992[a]	-0.949[a]	1.000	
Angle of repose	0.053	0.347	0.840[a]	0.751[a]	0.789[a]	0.803[a]	-0.173	-0.227	0.147	1

[a] Correlation is significant at the 0.01 level (2-tailed)
[b] Correlation is significant at the 0.05 level (2-tailed)

CONCLUSION

The effect of grade and moisture content on some engineering properties of makhana seeds was reported. The linear dimensions, mass of 100 seeds, bulk density, true density, angle of repose and coefficient of friction increased with increase in grain moisture content irrespective of grades. Static coefficient of friction increased on glass surface, wooden surface and mild steel sheet as moisture content increased. The different engineering properties of the makhana seeds were significantly affected by grade and moisture content. The knowledge gained from this study may be utilized in design and development of machines for sorting, grading and processing of makhana.

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