PHYSICAL AND AERODYNAMIC PROPERTIES OF MAKHANA

S.N. JHA

Dairy Engineering Division
National Dairy Research Institute
Karnal-132 001, INDIA

AND

R.P. KACHRU

Indian Council of Agricultural Research
Krishi Bhavan, New Delhi-110 001, INDIA

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ABSTRACT

Makhana is a popped kernel of gorgon nut (Euryale ferox) *and is considered a delicious food item in India. It is, presently, sorted, graded and processed manually. To develop any kind of mechanized system for these purposes, physical data are required and thus, 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 5 to 20% (dry basis). The data were used to develop correlation equations that predict these physical properties as a function of moisture content of makhana. The spatial dimensions and aerodynamic properties were also determined. The average diameter of makhana varied between 18.4 mm to 12.4 mm with the sphericity between 0.581 to 0.967; and other physical properties varied quadratically with moisture content. The terminal velocity and drag coefficient of makhana at 8% moisture content (dry basis) varied between 4.48 to 6.10 m/s and 0.62 to 1.06, respectively.*

INTRODUCTION

The gorgon nut (Euryale ferox), a seed of an aquatic herb, is grown in the stagnant fresh water pools of the northern and north-eastern states of India. Its wild populations are also found in China, Japan, the former Soviet Union, and North America (Jha *et al.* 1991). It is characterized by its hard seed coat (shell), black color and round shape with a diameter ranging from 4.5 mm to 14.5 mm (Jha and Prasad 1993).

The edible part of the nut is its starchy kernel which cannot be separate easily from the raw nut. It is, therefore, popped manually by the tradition method (Jha and Prasad 1990) as any other method of popping is not in practice Popping is the process of creating superheated water vapor within the cond tioned nut by heating the contained moisture, and suddenly releasing the pressu to cause a volumetric expansion of the kernel. The expanded kernel of the nu obtained through this process is the popped kernel and known as makhana India.

The makhana contains (g/100g) 12.8 moisture, 76.9 carbohydrates, 9 proteins, 0.1 fat, 0.5 total minerals, 0.02 calcium, 0.9 phosphorous, and 0.001 iron (Gopalan *et al.* 1987). Makhana is used for milk based food preparation such as 'kheer', pudding etc. and preparations of vegetables and curry, due its rich nutritive value. Fried makhana with salt or sugar is widely prepared a snack. Makhana has medicinal value and is used as an ingredient in prepar tion of indigenous tonics (Jha *et al.* 1991; Perry 1980). It also serves as a sour of starch for textile industries (Lakhmani 1978) and determination of its essenti amino acid index and chemical score indicated that it is nutritionally comparab with fish (Jha *et al.* 1991). These days makhana is being used by food indus as an ingredient of ready-to-eat products.

Due to its high volumetric expansion ratio, i.e. up to 25 (Jha 1993), transportation for marketing from one place to another is too costly, whi raises the cost of makhana many folds in distant markets. Makhana process and industrialists are also seeking to develop some value added products fr makhana. A gorgon nut processing machine has been developed (Jha 19 which needs an attachment for the separation of popped kernel and seed c (shell) of the nut.

Presently, no information is available on any engineering properties of popped kernel in the literature. The main objective of this investigation therefore to determine the physical and aerodynamic properties of makhana correlate some of them with moisture content and grade of the sample.

MATERIALS AND METHODS

Sample Preparation

Makhana popped by the existing traditional method was procured from market for the study. One lot of 2 kg of sample was separated into three gr according to average diameter and sphericity, and categorized as grade 1 if diameter is greater than 15 mm and the sphericity is greater than 0.8; gra regardless of the diameter provided the sphericity is less than 0.8; and gra if the diameter is less than 15 mm and the sphericity is greater than 0.8. Gr samples were either air dried or moistened by keeping in a humidity contr oven to obtain the required moisture levels. The entire range of possible moisture content, i.e., 5 to 20%, of makhana was investigated. The moisture content was determined by keeping the sample in hot air oven at 100 ± 2C for 72 h (Hall 1970) and expressed in per cent dry basis. The prepared samples were kept in desiccators filled with salt solutions of the appropriate concentration at room temperature to maintain a particular moisture content before using them for the experiments.

Physical Properties

The spatial dimensions at initial moisture content of 8%; and test weight (weight of 1000 makhana), bulk density, true 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 (Mohsenin 1980). Experiments were replicated 20 times in case of spatial dimensions and sphericity; and 5 times for other properties.

Spatial Dimensions

Length, breath, and thickness of randomly selected 20 makhana of each grade were measured using a micrometer having a least count of 0.01 mm. The diameter was taken as the mean of the three linear dimensions and the projected or frontal area, A_p, was computed using the following expressions (Mohsenin 1980):

$$A_p = (p/4)L_l L_s \quad (1)$$

Sphericity

The sphericity of an object expresses the shape character of the solid relative to that of a sphere of the same volume. It is therefore 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:

$$\text{Sphericity} = (abc)^{1/3}/a \quad (2)$$

Bulk and True Density

Bulk density of makhana was determined by using a closed bottom cylinder of inner diameter 106 mm and length 228 mm and a digital electronic balance.

The cylinder was filled with the prepared sample and was tapped during filling to obtain uniform packing and to minimize the wall effect, if any. The filled sample was weighed using an electronic digital balance. The bulk density of the material filled in cylinder was computed. For determining the true density (particle density), samples of 5 makhana from each grade were randomly selected. The true volume and weight of each makhana were determined by the toluene displacement method and an electronic digital balance, respectively, and the true density of the nut was computed.

Porosity

The porosity or packing factor, ϵ, of makhana of each grade was computed using the following formula and expressed in percent.

$$\epsilon = (\tau - \rho) \times 100/\tau \qquad (3)$$

Angle of Repose

For determination of angle of repose of makhana, a cylinder having inner diameter and length of 106 mm and 220 mm, respectively, was filled and slowly raised above the glass floor so that the 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 measuring scale and the angle of repose, Ø, of the makhana was computed using the following expression:

$$Ø = \tan^{-1}(2H/D) \qquad (4)$$

Coefficient of Friction

The coefficient of friction of makhana was determined on two surfaces: galvanized iron (GI) and stainless steel (SS) sheets. A table-top set-up was made which consisted of a bottomless plastic cylinder with a small thickness having height and diameter of 85 and 80 mm, respectively. The middle of the cylinder 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. The weight of the samples and the disc connected to the string, W_n, were initially taken and then plastic cylinder was kept on horizontal position on GI or SS sheet. The plastic cylinder was filled and weights were added to the hanging disc in small amounts until the ring filled with the makhana began to slide on the surface. The total weight, W_t, required to slide the cylinder on metal surface was recorded and the coefficient of friction, μ, was computed by the expression:

$$\mu = W_f/W_n \quad (5)$$

The spatial dimensions of makhana were measured at 8% moisture content; whereas other physical properties were determined at 5, 10, 15 and 20% (db) moisture content. Data were analyzed and five equations, viz., quadratic, linear, power, exponential and logarithmic, were evaluated to give the best fit.

Aerodynamic Properties

Aerodynamic properties, such as terminal velocity was determined experimentally; whereas drag coefficient, resistance coefficient and Reynolds number were computed from the terminal velocity, frontal area, diameter, particle density and weight of makhana, and mass density and absolute viscosity of the air.

Terminal Velocity

Terminal velocity was determined using relationship between time and displacement of the object (Bilanski *et al.* 1962). Experiments were conducted to determine the time of fall of different grades of makhana from different heights. A small room was selected and sealed completely to render it air-tight, and it was vacated for some time to ensure the condition of still air. Different heights, up to 6 m at 1 m intervals in the middle of room, were marked by means of a measuring tape. Makhana was dropped from each marked height and the time of fall was recorded using a digital electronic stop watch. The loss of moisture from makhana during its fall, if any, was neglected. The experiment was replicated 10 times for each height and grade of makhana. The average time of fall for each height and grade of makhana was computed and plotted (Fig. 1). If the height of fall is sufficient for the makhana to reach its terminal velocity, the time-displacement curve becomes linear when such velocity is attained (Mohsenin 1980). The terminal velocity of makhana was then taken as the slope of linear portion of the curve.

The diameter chosen for calculation of Reynolds number was the average of the three linear dimensions. The projected or frontal area assumed for computation of drag coefficient was based on the two largest dimensions L_1 and L_2 as in Eq. (1).

The drag coefficient, C, Reynolds number, Nr, and resistance coefficient, k were computed from the expressions reported by Mohsenin (1980), thus:

$$C = 2W(\rho_p - \rho_f)/(A_p \rho_p \rho_f V_t^2) \tag{6}$$

$$Nr = \rho_f V_t d/\eta_f \tag{7}$$

$$k = W/V_t^2 \tag{8}$$

The aerodynamic properties were determined at 8% moisture content (db) of makhana which will be useful in design of its separator because it is the expected moisture content just after popping of gorgon nut.

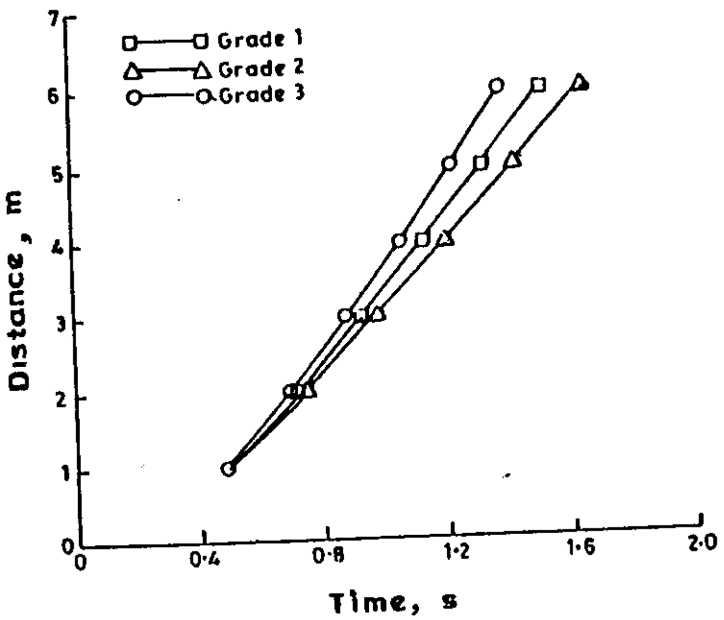

FIG. 1. DISTANCE-TIME RELATIONSHIP OF POPPED KERNEL OF GORGON NUT (MAKHANA)

RESULTS AND DISCUSSION

Physical Properties

The length, breadth and thickness of grade 1 makhana vary between 16.55 to 25.25 mm, 15.31 to 20.54 mm, and 11.18 to 20.02 mm, respectively, whereas; the corresponding values for grade 2 were found to be 16.34 to 30.24 mm, 11.52 to 24.55 mm, and 4.24 to 18.35 mm. The length, breadth and thickness of third grade makhana vary between 10.34 to 17.41, 9.02 to 16.52, and 8.46 to 13.05 mm, respectively (Table 1). The average of the dimensions, except thickness, of grade 2 makhana is higher than that of grade 1 makhana,

TABLE 1.
SPATIAL DIMENSIONS OF POPPED KERNEL OF GORGON NUT

Grade of Sample		Length (mm)	Breadth (mm)	Thickness (mm)	Average diameter (mm)	Frontal Area (mm^2)	Sphericity (fraction)
1	Max.#	25.26	20.54	20.02	21.21	400.99	0.967
	Min.	16.55	15.31	11.18	15.28	201.73	0.802
	Ave.	20.59	18.02	15.12	17.91	282.95	0.866
	Sd.	2.24	1.68	2.00	1.55	51.24	0.054
2	Max.	30.24	24.55	18.36	23.93	569.41	0.789
	Min.	16.34	11.52	4.24	12.66	148.02	0.581
	Ave.	23.64	18.69	11.52	18.39	366.31	0.727
	sd.	4.03	5.29	3.39	3.53	120.74	0.060
3	Max.	17.41	16.52	13.05	14.66	220.96	0.900
	Min.	10.34	9.02	8.46	9.20	73.25	0.804
	Ave.	15.04	13.51	10.37	12.44	161.86	0.851
	Sd.	1.84	1.89	1.29	2.77	38.55	0.026

#Max.-Maximum, Min.-Minimum, Ave.-Average, Sd.-Standard deviation

but sphericity is lowest among the three grades. The standard deviation is highest for all the dimensions of grade 2 makhana (Table 1). This indicates that variation in dimensions of grade 2 makhana is maximum. Sphericity of makhana varies between 0.802 to 0.967, 0.581 to 0.789 and 0.804 to 0.92 for grade 1, grade 2 and grade 3, respectively. This reveals that the grade 1 and 3 are almost of spherical shape, whereas; grade 2 is relatively flat. The flatness arises from the fact that some of makhana get compressed when the hot roasted nuts are struck by a wooden hammer to break their shells for popping. The dimensions of grade 3 are lowest because of its partial expansion and/or due to the smaller size of the nut.

Among the five equations, viz., quadratic, linear, power, logarithmic, and exponential, tested for the best fit of the data, the quadratic form of the equation was found to be the best for all the physical properties as given below through Eq. (9-29) with their correlation coefficients:

Test weight:

$$TW_1 = 319.188 + 2.599M + 0.035M^2 \quad r=0.987 \qquad (9)$$

$$TW_2 = 270.748 + 2.63M + 0.026M^2 \quad r=0.979 \qquad (10)$$

$$TW_3 = 289.218 + 2.144M + 0.001M^2 \quad r=0.9952 \qquad (11)$$

Bulk density:

$$\rho_1 = 54.927 + 0.201M + 0.016M^2 \quad r=0.9919 \qquad (12)$$

$$\rho_2 = 69.507 + 0.504M + 0.013M^2 \quad r=0.996 \qquad (13)$$

$$\rho_3 = 119.011 + 0.385M + 0.027M^2 \quad r=0.997 \qquad (14)$$

True density:

$$\tau_1 = 104.321 + 1.457M - 0.011M^2 \quad r=0.994 \qquad (15)$$

$$\tau_2 = 101.745 + 0.440M + 0.022M^2 \quad r=0.963 \qquad (16)$$

$$\tau_3 = 207.578 + 1.718M - 0.002M^2 \quad r=0.9957 \qquad (17)$$

Porosity:

$$\epsilon_1 = 46.092 + 0.538M - 0.0197M^2 \quad r=0.964 \qquad (18)$$

$$\epsilon_2 = 29.66 - 0.178M + 0.007M^2 \quad r=0.179 \qquad (19)$$

$$\epsilon_3 = 41.135 + 0.368M - 0.014M^2 \quad r=0.847 \qquad (20)$$

Angle of repose:

$$\varnothing_1 = 20.783 + 0.362M + 0.014M^2 \quad r=0.997 \tag{21}$$

$$\varnothing_2 = 23.367 + 0.314M + 0.015M^2 \quad r= 0.997 \tag{22}$$

$$\varnothing_3 = 20.139 + 0.28M + 0.015M^2 \quad r=0.996 \tag{23}$$

Coefficient of friction on GI sheet

$$\mu_1 = 0.495 + 0.029M - 0.0006M^2 \quad r=0.999 \tag{24}$$

$$\mu_2 = 0.524 + 0.015M - 0.0002M^2 \quad r=0.991 \tag{25}$$

$$\mu_3 = 0.482 + 0.018M - 0.0003M^2 \quad r=0.999 \tag{26}$$

Coefficient of friction on SS sheet

$$\mu_1 = 0.389 + 0.028M + 0.0007M^2 \quad r=0.999 \tag{27}$$

$$\mu_2 = 0.393 + 0.023M - 0.0005M^2 \quad r=0.9999 \tag{28}$$

$$\mu_3 = 0.398 + 0.0169M - 0.0003M^2 \quad r=0.999 \tag{29}$$

In general, all the physical properties increased with moisture content (Fig. 2-4 and 6-7) but porosity of grade 1 and 3 makhana increased up to 15% moisture content only beyond which it declined. The porosity of grade 2 makhana failed to follow any specific trend (Fig. 5) and thus yielded a very poor correlation with moisture (Eq. 19). Similar trends are also reported for these physical properties of gorgon nut (Jha and Prasad 1993).

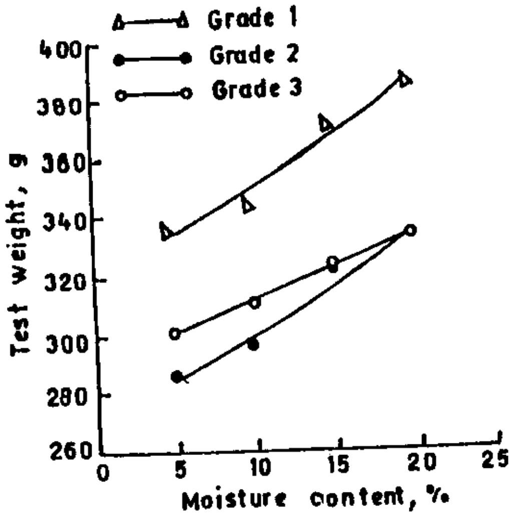

FIG. 2. VARIATION OF TEST WEIGHT WITH MOISTURE CONTENT OF MAKHANA

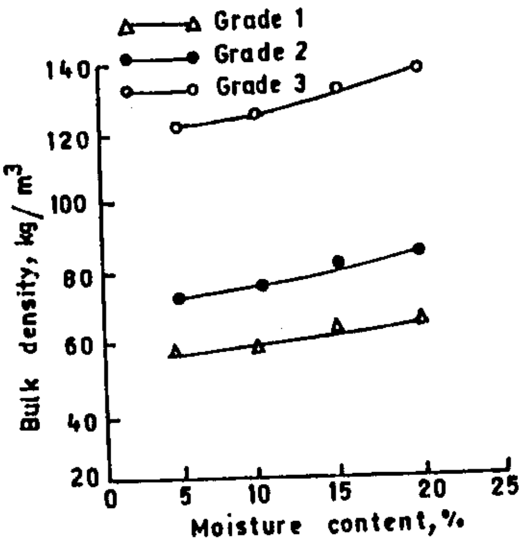

FIG. 3. VARIATION OF BULK DENSITY WITH MOISTURE CONTENT OF MAKHANA

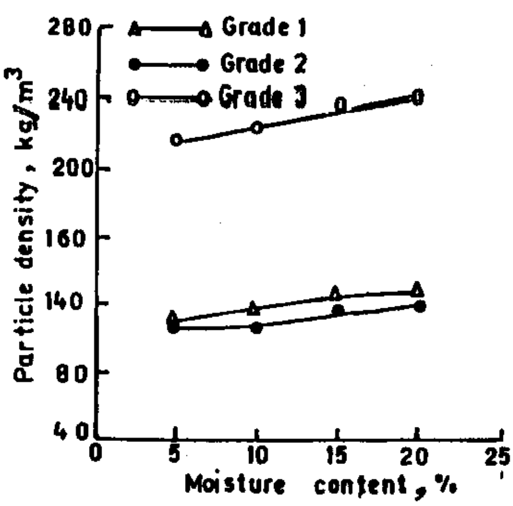

FIG. 4. VARIATION OF PARTICLE DENSITY WITH MOISTURE CONTENT OF MAKHANA

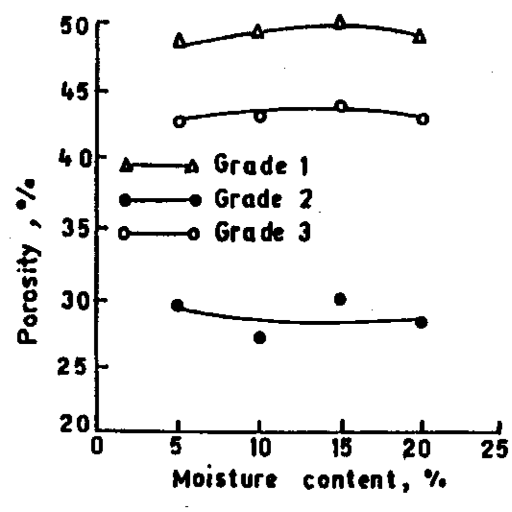

FIG. 5. VARIATION OF POROSITY WITH MOISTURE CONTENT OF MAKHANA

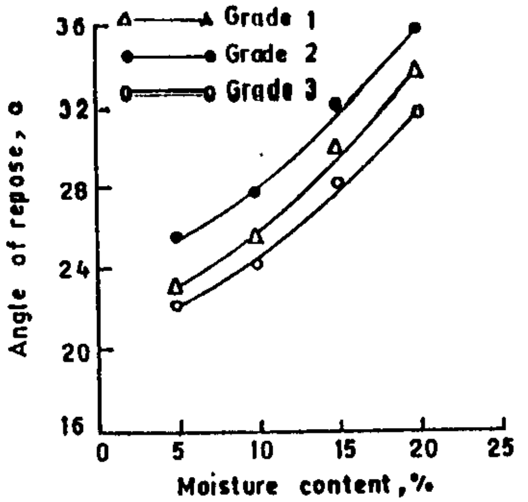

FIG. 6. VARIATION OF ANGLE OF REPOSE WITH MOISTURE CONTENT OF MAKHANA

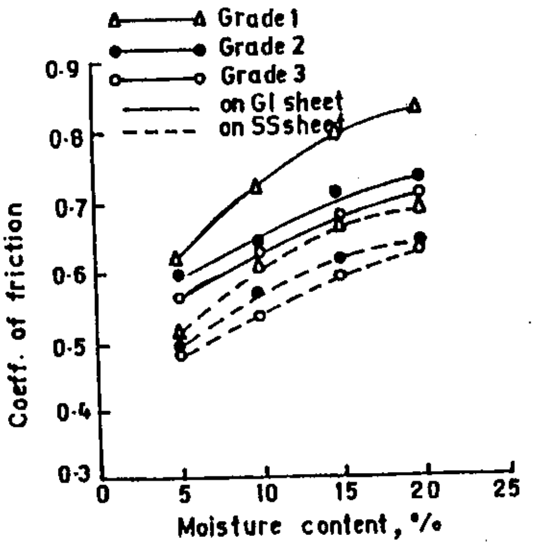

FIG. 7. VARIATION OF COEFFICIENT OF FRICTION WITH MOISTURE CONTENT OF MAKHANA AND METAL SURFACES

The increasing nature of bulk and true densities with moisture content is because of the proportionate increase in weight with moisture content may be more than that of the volume. Increase in angle of repose with moisture content may be due to increase in internal friction. The test weight, particle density, and porosity of grade 1 makhana were found to be highest followed by grade 3 makhana (Fig. 2, 4 and 5). The lowest test weight, true density and porosity of grade 2 makhana may be due to its flatness in shape. Bulk density decreased with grade of makhana (Fig. 3). This may be due to the fact that the higher grade consists of larger sizes of makhana having higher values of sphericity which reduces the packing ability.

The angle of repose is highest for grade 2 makhana (Fig. 6) mainly because of its higher projected area which may increase the internal friction of the material. The coefficient of friction increased with moisture content and grade of makhana (Fig. 7). Increased moisture content and grade may result in increase of adhesion characteristics and roughness of the surface of makhana, respectively. The coefficient of friction on GI sheet is higher than that of the SS sheet which may be caused by the higher roughness of GI sheet than stainless steel.

Aerodynamic Properties

The terminal velocity and drag coefficient of makhana increased with ratio of weight to projected area; whereas Reynolds number and resistance coefficient did not follow any trend (Table 2). The terminal velocity of grade 2 makhana was found to be lowest (4.5 m/s); whereas it was highest for grade 3 (6.1 m/s) and 5.1 m/s for grade 1 makhana. These trends are due to the fact that the ratio of weight to projected area is in the same order. This shows that the grade 2

TABLE 2.
AERODYNAMIC PROPERTIES OF POPPED KERNEL OF GORGON NUT

Grade* of sample	Weight (kg)x10^3	Ratio of weight to projected area (kg m^{-2})	Terminal velocity (m s^{-1})	Reynold's number	Drag coefficient	Resistance Coefficient (kgs^2m^{-2})x10^5
1	0.387	1.112	5.16	300	0.72	1.46
2	0.222	0.732	4.48	238	0.62	1.10
3	0.396	2.293	6.10	248	1.06	1.06

* Moisture content of sample was 8 %

makhana is lightest in weight. The Reynolds number was found to be highest (300) for grade 1 makhana followed by grade 3. This indicates that the makhana having higher sphericity may cause more turbulence in air during its movement. The resistance coefficient increases with increase in grade of makhana perhaps because more surface area of higher grade of makhana was into contact with air and resisting its velocity. The aerodynamic properties of makhana or of similar materials are not available in literature for comparison. However, the values of Reynolds number and drag coefficient of grade 1 and 3 makhana are near to those reported for spherical bodies (Mohsenin 1980). The terminal velocity of grade 1 and 2 makhana, respectively was found to be near to that of alfalfa and flax; whereas this value for grade 3 falls between that of small and large oats (Bilanski *et al.* 1962).

CONCLUSIONS

The average diameter of makhana varied between 18.4 mm to 12.4 mm with sphericity ranging between 0.58 to 0.97. The test weight, bulk density, true density, porosity, angle of repose and coefficient of friction of makhana varied quadratically with moisture content. These physical data may be utilized in design and development of machines for sorting, grading and processing of makhana; and the developed correlation would greatly help in estimating these properties at desired moisture content within the range of study. The terminal velocity and drag coefficient of grade 2 makhana at 8% moisture content were lowest, 4.48 m/s and 0.62, respectively; whereas these values were found to be the highest for grade 3 (6.1 m/s and 1.06) at the same moisture content. The resistance coefficient of makhana varies between 1.06×10^{-5} to 1.46×10^{-5} kgs^2/m^2 at 8% moisture content. These aerodynamic properties may directly be used in design of pneumatic separator and grader for makhana.

NOMENCLATURE

A Area, m^2
a Longest intercept, mm
b Longest intercept normal to a, mm
C Drag coefficient, dimensionless
c Longest intercept normal to a and b, mm
D Diameter of heap, m
d Diameter of makhana, m
H Height of heap, m
K Resistance coefficient, kgs^2m^{-2}
L Linear dimensions, mm
M Moisture content, % (dry basis)

Nr Reynolds number, dimensionless
r Correlation coefficient, dimensionless
TW Test weight, g
V Velocity, ms^{-1}
W Weight, kg

Greek Letters

ϵ Porosity, %
Ø Angle of repose, °
τ True (particle) density, kgm^{-3}
ρ Bulk density, kg m^{-3}
μ Coefficient of friction, fraction
η Absolute viscosity

Subscript

f fluid (air)
l largest
p projected, particle
n normal
s second largest
t tangential, terminal
1 grade 1 makhana
2 grade 2 makhana
3 grade 3 makhana

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