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Effect of different grades on physical and mechanical properties of popped makhana

■ SANDEEP KUMAR* AND SATYA PRAKASH KUMAR[1]
Department of Food Engineering and Technology, National Institute of Food Technology Entrepreneurship and Management, Kundli, SONIPAT (HARYANA) INDIA
Email: prakash.kgp11@gmail.com
[1]Department of Basic and Applied Science,National Institute of Food Technology Entrepreneurship and Management, Kundli, SONIPAT (HARYANA) INDIA

*Author for Correspondence

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SUMMARY :

Makhana (*Euryale ferox*) is store house of the nutrition and commonly used as dry fruit in India. Makhana is mainly sold and marketed in the popped or puffed form. To develop any kind of mechanized system for processing the knowledge of physical and mechanical properties is desired. These properties will be useful for designing and development of processing equipment. The different physical and mechanical properties were determined at two moisture levels *i.e.* 4 per cent and 12 per cent using standard methods. As the moisture content increases the physical characteristics (Length, width, thickness, D_a and D_g) and gravimetric characteristics (sphericity, aspect ratio, surface area and volume) of all the grades increases linearly. The negative relation was observed with geometrical characteristics. Major variations were also observed in angle of repose and co-efficient of static friction at different grades and moisture levels. The result concludes that different grades and variation in the moisture level affects almost all the physical and mechanical properties significantly ($p<0.05$).

KEY WORDS : Makhana, Popped makhana, Physical properties, Mechanical properties

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Makhana (*Euryale ferox*) is known as important aquatic cash crop of India. It is an aquatic herb of family Nymphaeaceae and is characterized by its hard seed coat (shell), black in colour and round shape. It is also known as Gorgon nut or Fox nut. Makhana plant is considered as native of South-East Asia and China, but distributed to almost every part of the world. India and China are the only countries where makhana is cultivated as crop. In India it is mainly cultivated in the states of Bihar and some parts of eastern India (Mishra *et al.*, 2003). It is estimated that Bihar accounts for more than 80 per cent of total makhana production in the country. The total area under makhana cultivation in India is estimated to be 15000 ha. It yields 1,20,000 MT of makhana seeds, which after processing yields 40,000 MT of makhana pop. The estimated value of the production at farmers end is Rs. 250 crore and it generates revenue of Rs. 550 crore at traders level (N.R.C.M, 2003).

Makhana is a kind of hydrophyte used both as drug and food which exhibits much application and development prospect in the fields of medicine, food and economy. Makhana is the popped expanded kernel of the gorgon nut (Jha and Prasad, 1996). Popped makhana is one of the most common dry fruits utilized by the people due to low fat content, high contents of carbohydrates, protein and minerals. A lot of medicinal uses are recommended in the Indian and Chinese system of medicine. Makhana is recommended for treatment of diseases regarding respiratory, circulatory, digestive, excretory and reproductive systems.

In general, the post-harvest technology involves sun drying, size grading, pre-heating, popping, polishing, grading and packaging. Still entire system of makhana processing is manual as till date no successful machine has been developed for its processing. The processing is cumbersome, labour intensive and time consuming process and involves human drudgery to a great extent. The entire process is conventional, which is passed on to the generation from time immemorial. The natural distribution of these experts is limited to the some parts of north Bihar. Perhaps this is the only reason, that the processing of makhana is restricted to Bihar only (I.C.A.R, 2012). Makhana is mainly marketed as pop with limited value addition. In spite of being a nutritional, non-cereal and organic food, makhana sector continues to be relatively unexplored and underutilized. Makhana is graded into 4 to 5 grades based on size and light weight. Lower grade like murra and thurri are being sold at very low prices. It constitute about 15-20 per cent of the total popped makhana production.

Makhana has the ability to stand in competition to snacks like corn, oats and soya beans and thus, develop variety of products from makhana pop. However, the sector holds immense potential for value addition, product development and innovation, which would not only enhance livelihood of millions of fishermen but also bolster the economic health of the state and bring glory to this unexplored wonder crop called makhana. Food industries are eager to develop value-added products from makhana but the high transportation cost, due to the high volumetric expansion of makhana, make it an expensive. To explore the value addition of popped makhana and their product development the knowledge of engineering properties is desired. The engineering properties of the popped makhana will be useful for design and development of processing equipment. Very limited investigations have been made on the physical characteristics of puffed or popped makhana. Therefore, the present work was undertaken to examine physical and mechanical properties of different grades of popped gorgon nut at two different moisture levels in order to identify their properties and characteristics.

EXPERIMENTAL METHODS

Three kg of popped Makhana was procured from Darbhanga (Bihar) and bought to SLIET, Punjab for further experimental analysis. All the analysis was conducted in the department of FET, SLIET, Punjab. The Makhana was further divided into three grades according to average width and thickness at two different moisture levels *i.e.* 4 per cent and 12 per cent, respectively and all the physical and mechanical properties were determined accordingly. Moisture content of all the three grades was determined by AOAC (2000) methods.

Classification of grades :

Grade 1 (Fully Expanded) of width ≥15mm and thickness ≥14 mm.

Grade 2 (Fully Expanded) of width 8-14 mm and thickness 8-13 mm.

Grade 3 (Flattened and Irregular) of any width and thickness ≤9 mm.

For classifying the popped gorgon nut average diameter and thickness of each kernels were measured. Graded samples were packed separately in polyethylene bags, which were kept at room temperature until used in experiment to avoid any change in moisture content of the sample.

Size and shape :

To determine the size and shape of the popped gorgon nut, 100 popped gorgon nuts were selected at random from each grade, for conducting the experiment. For each individual kernel, three principal dimensions, namely length (L), width (W) and thickness (T) were measured using vernier caliper. Determination was reported in mm.

Geometric and arithmetic mean diameter :

The arithmetic mean diameter, Da and geometric mean diameter, Dg of popped kernels were calculated from the geometrical dimensions by formula given by Mohsenin, 1980; Bahnasawy, 2007.

$$D_a = \frac{X + Y + Z}{3}$$

$$D_g = (X.Y.Z)^{\frac{1}{3}}$$

where,

X = Length (L) in mm;

Y = Width (W) in mm;

Z = Thickness (T) in mm.

Both geometric and arithmetic mean diameter was expressed in mm.

Sphericity:

Sphericity of popped kernels was calculated by the following relationship (Mohsenin, 1980).

$$\varphi = \frac{(X.Y.Z)^{\frac{1}{3}}}{X} = \frac{D_g}{X}$$

where,

Dg = Geometrical mean diameter (mm);

X = length (L) in mm.

Aspect ratio :

The aspect ratio (Ra) was calculated as (Maduako and Faborode, 1990).

$$R_a = \frac{W}{L} \times 100$$

where,

L = Length (mm);

W = Width (mm).

Surface area and volume :

The surface area and volume of popped gorgon nut were determined using the following equations (Sacilik *et al.,* 2003).

$$S = \pi D_g^{\ 2}$$

$$V = \frac{\pi B^2 L^2}{6(2L - B)}$$

$$B = (WT)^{0.5}$$

where,

Dg = Geometrical mean diameter (mm);

L = Length (mm);

W = Width (mm);

T = Thickness.

The unit of surface area was reported as mm^2 and volume as cm^3.

Thousand kernel weight :

Thousand seed weight was determined by counting 100 popped kernels randomly from each grade and weighing them in an electronic balance (0.001) and then multiplied by 10 to give the mass of 1000 kernels. The results were expressed in gms.

Bulk density :

The bulk density is the ratio of the mass of the sample to its container volume. A tarred measuring cylinder was filled with the prepared sample to a known volume. Tapping during the filling was done to obtain uniform packaging and to minimize the wall effect, if any. The filled sample was weighed and the bulk density was calculated as calculated by Mohsenin (1980).

$$\text{Bulk density}\left(\frac{kg}{m^3}\right) = \frac{M}{V}$$

where,

M = mass of the sample (kg);

V = Volume of the filled sample (m^3).

True density :

The true density was measured by rapeseed displacement method. Rapeseed displacement method is a common method for measuring volumes of irregular solids. The true density of the sample is calculated as follows (Sahin and Sumnu, 2006).

$$\text{True density}\left(\frac{kg}{m^3}\right) = \frac{M}{V}$$

where,

W=Weight (kg);

V= Volume (m^3);

ρ= True density (kg/m^3).

Porosity :

Porosity, ε (%) indicates the amount of pores in the bulk material (Mohsenin, 1980). The porosity of the kernels was calculated from the average values of bulk density and true density using the relationship.

$$\varepsilon(\%) = \left(1 - \frac{\rho_b}{\rho_s}\right) \times 100$$

where,
ρb = Bulk density (kg/m^3);
ρs = True density (kg/m^3).

Angle of repose :

The angle of repose indicates the cohesion among the individual units of a material. The higher the cohesion, higher is the angle of repose. In this method, a bottomless cylinder (9 cm diameter, 25 cm height) was used (Taser *et al.*, 2005 and Garnayak *et al.*, 2008). The cylinder was placed over a plain surface and popped kernels of gorgon nut were filled in. Tapping during filling was done to obtain uniform packing and to minimize the wall effect if any. The tube was slowly raised above the floor so that whole material could slide and form a natural slope. The height of heap above the floor and the diameter of the heap at its base were measured and the angle of repose (^{o}) was measured by following relations.

$$\Phi = \tan^{-1}\frac{2h}{D}$$

where,
Φ = angle of repose (°);
h = height of the pile (mm);
D = diameter of the pile (mm).

Co-efficient of static friction :

The static co-efficient of friction (μ) was determined for three structural materials namely glass, galvanized steel sheet and plywood. A plastic cylinder was placed on an adjustable tilting flat plate faced with the test surface and filled with the sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was inclined gradually, until the cylinder just started to slide down. The angle of tilt was noted from a graduated scale (Dutta *et al.*, 1988).

Rupture force :

The textural properties (hardness) of popped gorgon nut kernels were measured using a texture analyzer (TA.XT Plus™, Stable Microsystems, UK). A stainless steel cylindrical probe with P/75 mm diameter was used throughout. The load cell had a maximum capacity of 50 kg. A deformation strain of 80 per cent of the original length was applied. The seed hardness was defined as the peak force (maximum height of the force peak on the first compression cycle) of the texture profile curve and corresponded to the force required to deform or crush the seed. The measured force was expressed as the kg of force required to break the kernels. Twenyfive kernels were chosen as a representative for each experiment as variation in texture in individual grain is usually substantial (Gowen *et al.*, 2007). During texture analysis, the orientation of each kernel was kept uniform on the platform of the texture analyzer.

EXPERIMENTAL FINDINGS AND ANALYSIS

The findings of the present study as well as relevant discussion have been presented under following heads :

Physical characteristics :

Physical characteristics of the three different grades of popped makhana at 4 per cent and 12 per cent moisture level were analyzed and presented in Table 1. Linear dimensions are important in determining aperture size in design of grain handling machinery (Al Mahasneh and Rababah, 2007). The geometrical characteristics in terms of length and width was found maximum for grade 3 and minimum for grade 2 for different grades of popped makhana at different moisture level. The variation in length of different grades may be due to the smaller size, flattened and irregular length of the popped makhana. The length and width varied significantly ($p<0.05$) among all the grades. The thickness of grade 1 was found

Table 1 : Physical characteristics of different grades of popped makhana

Parameters	Moisture content					
	4 %			12 %		
	Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
Length X (mm)	$18.10^b \pm 1.19$	$14.80^c \pm 0.91$	$20.70^a \pm 3.26$	$18.70^b \pm 1.56$	$15.10^c \pm 1.10$	$20.90^a \pm 3.54$
Width Y (mm)	$16.10^b \pm 1.19$	$12.50^c \pm 0.84$	$18.90^a \pm 2.80$	$16.50^b \pm 1.35$	$12.70^c \pm 1.10$	$19^a \pm 3.54$
Thickness Z (mm)	$15.20^a \pm 1.13$	$11.60^b \pm 1.26$	$7.6^c \pm 1.34$	$15.60^a \pm 1.26$	$11.80^b \pm 1.47$	$7.90^c \pm 1.19$
Arithmetic diameter D_a (mm)	$16.40^a \pm 1.02$	$12.96^c \pm 0.57$	$15.73^a \pm 1.97$	$16.93^a \pm 1.29$	$13.19^c \pm 0.68$	$15.94^a \pm 2.03$
Geometric diameter D_g (mm)	$16.35^a \pm 1.03$	$12.87^c \pm 0.57$	$14.29^b \pm 1.65$	$16.87^a \pm 1.28$	$13.08^c \pm 0.68$	$14.54^b \pm 1.55$

Mean ±S.D. with different superscripts in a row differ significantly ($p<0.05$) (n=20)

maximum followed by grade 2 and minimum for grade 3. The difference in the result of grade 3 was due to flatness of popped makhana at all the moisture levels. The difference was found significant ($p<0.05$) among all the grades. The arithmetic diameter of grade 1 was found maximum followed by grade 3 and minimum for grade 2 at all moisture levels. The arithmetic mean diameter and effective mean diameter is useful in determining the diameter of sieve holes (Simonyan *et al.*, 2007). The arithmetic mean diameter has direct relation with dimension of kernels. The variation in the result was due to larger dimension of popped makhana and different grades. Jha and Sharma (2010) reported the arithmetic mean diameter of popped makhana at different conditioning levels from 20.5 to 21 mm. The geometric mean diameter was found maximum for grade 1 followed by grade 3 and minimum for grade 2 at all moisture levels. Jha and Sharma (2010) reported the geometric diameter of popped makhana at different conditioning levels from 20.4 to 20.8 mm. The variation in the result might be due to larger dimension of popped makhana and grades. Significant difference ($p<0.05$) was found in the results among all the grades of samples. As the moisture content increased the three linear dimensions of all the grades of popped makhana increased due to the swelling of the seeds. Similar findings were also reported by Al-Mahasneh and Rababah (2007) for green wheat.

Geometrical characteristics :

Geometrical characteristics of the three different grades at 4 per cent and 12 per cent moisture level were analyzed and presented in Table 2. Sphericity of the grade 1 was found maximum followed by grade 2 and minimum for grade 3. As there was increase in the moisture level in popped makhana, there was slight decrease in the sphericity. The higher value of sphericity means kernels are closer to the shape of a sphere. Similar results have been reported by Jha and Sharma (2010) as 0.88 per cent to 0.84 per cent for popped makhana. The low sphericity value thus suggests that the popped makhana tend towards a hemispherical shape (Omobuwajo *et al.*, 2000). The width to length ratio of grade 3 was maximum followed by grade 1 and minimum for grade 2. Jha and Sharma (2010) reported the aspect ratio of popped makhana in the range from 87.9 per cent to 84.3 per cent at difference conditioning levels. The highest value of surface area was reported for grade 1 followed by grade 3 and minimum for grade 2. The difference in the results might be due to difference in geometrical characteristics. The surface area is a relevant tool in determining the shape of the kernels. This will actually be an indication of the way the popped makhana will behave on oscillating surfaces during processing (Alonge and Adigun, 1999). Higher surface area results (1352.9 mm^2 to 1304.9 mm^2) have been reported by Jha and Sharma (2010) for popped makhana. There was significant difference ($p<0.05$) in the surface area among all the grades. The highest value of volume was reported for grade 1 followed by grade 3 and minimum for grade 2. The surface area and volume increased with increase in moisture content. This is because they are dependent on the three linear dimensions, which were observed to be increase. These properties are useful in the hydrodynamic separation and transportation of grains and seeds (Tunde-Akintunde and Akintunde, 2007).

Gravimetric characteristics :

Gravimetric characteristics of the three different grades at 4 per cent and 12 per cent moisture level were analyzed and presented in Table 3. The weight of food grains is an important parameter to be used in the design of cleaning grains using aerodynamic forces (Oje and Ugbor, 1991). The 1000 kernel weight of grade 1 was reported highest followed by grade 3 and lowest for grade 2 irrespective of moisture content. The difference in the result was due to different dimensional characteristics

Table 2 : Geometric characteristics of different grades of popped makhana

Parameters	Moisture content					
	4 %			12 %		
	Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
Sphericity Φ (%)	$0.91^{a}\pm0.03$	$0.87^{a}\pm0.04$	$0.69^{b}\pm0.07$	$0.90^{a}\pm0.02$	$0.86^{a}\pm0.04$	$0.69^{b}\pm0.07$
Aspect ratio R_a (%)	$89.99^{ab}\pm4.17$	$84.67^{bcd}\pm 6.58$	$91.86^{a}\pm9.77$	$88.36^{ad}\pm4.36$	$84.36^{bcd}\pm8.05$	$89.30^{ac}\pm7.72$
Surface area S (mm^2)	$843.12^{a}\pm104.01$	$521.37^{c}\pm47.07$	$649.67^{b}\pm150.22$	$899.04^{a}\pm134.15$	$539.14^{c}\pm56.60$	$671.39^{b}\pm144.87$
Volume V (cm^3)	$2.06^{a}\pm0.40$	$0.94^{b}\pm0.13$	$1.12^{b}\pm0.37$	$2.23^{a}\pm0.49$	$0.99^{b}\pm0.16$	$1.18^{b}\pm0.36$

Mean ±S.D. with different superscripts in a row differ significantly ($p<0.05$) (n=20)

and grading system of popped makhana. The difference in the result is due to different dimensional characteristics of popped makhana and as the moisture content increased in the nut, the mass of the nut also increased because it absorbed moisture as it is more hygroscopic. Higher 1000 kernel weight results (459.3 g to 412.2 g) were reported by Jha and Sharma (2010). The bulk density value was reported highest for grade 2 followed by grade 3 and lowest for grade 1 for all the moisture level. The difference was due to differences in the volume occupied by the nut and mass of the nut. The similar trend in result for bulk density was reported by (Jha, 1999) of different grades of popped makhana with varying moisture content. The difference in the results was found significant ($p<0.05$) among all the grades. The true density value was reported highest for grade 2 followed by grade 3 and lowest for grade 1 at all the moisture level. Since grade 2 size was smaller than other two grades, more unit of kernels were entering into the container volume compared with unit of popped makhana resulting to a higher bulk and true density. Increase in true density with moisture content has been reported by Gupta and Das (1997) for sunflower and Altuntas and Yildiz (2007) for faba bean, respectively. The result was found significantly different ($p<0.05$) among all the grades. The porosity value was reported highest for grade 3 followed by grade 1 and lowest for grade 2 at different moisture level. The difference in the result of porosity was due to different bulk and true density of different grades of popped gorgon makhana because it has direct relation with both the density.

Frictional properties :

Frictional properties such as angle of repose and static co-efficient of friction on different surface at 4 per cent and 12 per cent moisture level are presented in Table 4. The angle of repose reported at 4 per cent and 12 per cent moisture level of grade 3 was highest followed by grade 1 and lowest for grade 2. This phenomenon is imperative in the food grain processing, particularly in the designing of the hopper for milling equipment. The grade 3 has highest angle of repose because cohesion forces between kernels and the wall are stronger and higher projected area due to flatness and irregularity in shape which may increase the internal friction of the material irrespective of the moisture level. Similar trends were also reported by Jha (1999) of different grades of popped makhana with varying moisture content. With respect to increase in moisture level minor increase in the angle of repose was observed. The high value of the angle of repose may be due to the large size of the grains and their relatively rough surface which prevent sliding of the grains on one another easily (Tunde-Akintunde and Akintunde, 2007). Significant difference ($p<0.05$) was found in the angle of repose of various grades of makhana.

Table 3 : Gravimetric characteristics of different grades of popped makhana

Parameters	Moisture content					
	4 %			12 %		
	Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
1000 kernel weight (g)	325.60^{b}±4.50	271.60^{e}±8.08	285.4^{de}±14.87	355.54^{a}±18.33	296.68^{cd}±9.23	315.42^{bc}±31.31
Bulk density ρ_b (kg/m^3)	68.18^{d}± 1.02	136.05^{a}±1.85	89.13^{b}± 0.67	72.81^{c}±1.29	138.29^{a}±5.57	91.40^{b}±2.07
True density ρ_s (kg/m^3)	135.22^{c}±1.67	239.63^{a}±1.21	203.49^{b}± 1.24	142.92^{c}±4.37	243.03^{a}±15.03	206.93^{b}±8.31
Porosity ε (%)	49.56^{b}± 1.29	43.22^{c}± 0.57	56.19^{a}± 0.39	48.99^{b}±2.35	42.96^{c}±3.42	55.77^{a}±1.97

Mean ±S.D. with different superscripts in a row differ significantly ($p<0.05$) (n=5)

Table 4 : Frictional characteristics of different grades of popped makhana

Parameters	Moisture content					
	4 %			12 %		
	Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
Angle of repose	25.64^{bc}±0.62	23.85^{cd}±0.42	31.17^{a}±0.68	27.13^{b}±1.83	25.29^{bd}±0.96	32.17^{a}±3.15
Co-efficient of static friction						
Glass	0.42^{cd}±0.01	0.40^{d}±0.01	0.52^{a}±0.01	0.46^{b}±0.02	0.43^{c}±0.02	0.54^{a}±0.02
Galvanized steel	0.30^{d}±0.01	0.35^{bc}±0.01	0.42^{a}±0.01	0.34^{c}±0.02	0.38^{b}±0.02	0.44^{a}±0.02
Plywood (Parallel)	0.40^{d}±0.03	0.44^{c}±0.02	0.56^{a}±0.01	0.45^{bc}±0.01	0.48^{b}±0.02	0.59^{a}±0.01
Plywood (Perpendicular)	0.54^{d}±0.02	0.59^{c}±0.01	0.65^{a}±0.01	0.58^{c}±0.01	0.62^{b}±0.01	0.67^{a}±0.02

Mean ±S.D. with different superscripts in a row differ significantly ($p<0.05$) (n=5)

Co-efficient of static friction of different grades on various surfaces showed that static friction on plywood in perpendicular arrangement is higher than other surfaces and static friction on galvanized iron is the lowest at both the moisture levels. The static friction on glass surface at 4 per cent moisture level was reported highest for grade 3 followed by grade 1 and lowest for grade 2. Same trend were also reported at 12 per cent moisture level. The static co-efficient of friction on galvanized iron surface at 4 per cent moisture level was reported highest for grade 3 followed by grade 2 and lowest for grade 1. The same trend *i.e.* highest value for grade 3 and lowest for grade 1 was found for other two materials *i.e.* plywood in parallel and plywood in perpendicular arrangement. Significant difference ($p<0.05$) was found in the co-efficient of static friction values of all the three grades at both the moisture level *i.e.* 4 per cent and 12 per cent. The static co-efficient of friction on glass at 12 per cent moisture level was reported highest for grade 3 followed by grade 2 and lowest for grade 1. The reported value for co-efficient of static friction in this study was lower than reported by Jha, 1999 of different grades of popped makhana with varying moisture content. As the moisture content increased, the static co-efficient of friction against the selected surfaces increased. The same increasing trend was observed for sunflower seeds (Gupta and Das, 2000) and for millets (Baryeh, 2002). This may be due to the fact that an increase in moisture content increased the cohesion between the seeds, thus increasing the friction the seed experiences during its flow or movement on the respective surfaces (Balasubramanian and Vismanathan, 2010). The highest value reported for grade 3 might be due to an increase in adhesion characteristics, roughness and flatness of the surface of popped makhana. The co-efficient of friction on plywood in perpendicular arrangement is higher than that of others. More roughness of the plywood in perpendicular arrangement may be the reason. The frictional properties are moisture dependent and as the moisture content increased in the sample, the change in the frictional properties was seen.

Rupture force :

The rupture force of different grades of popped gorgon nut at 4 per cent moisture level is presented in Fig 1. The rupture force at 12 per cent moisture was not determined because it was hygroscopic in nature and had not been crushed. The rupture force was highest for grade 2 followed by grade 3 and lowest for grade 1. The highest rupture force for grade 2 was due to compactness of internal structure of unpopped kernels. The deshelling efficiency is subject of rupture force. Therefore, sample classification and fractioning the seeds according to geometry or unit mass are essential, because wrong classification might allow small seeds pass uncracked through the deshelling equipment and larger seeds might be broken into small fragments instead of being deshelled as observed in other seeds and grains (Ashes and Peck, 1978).

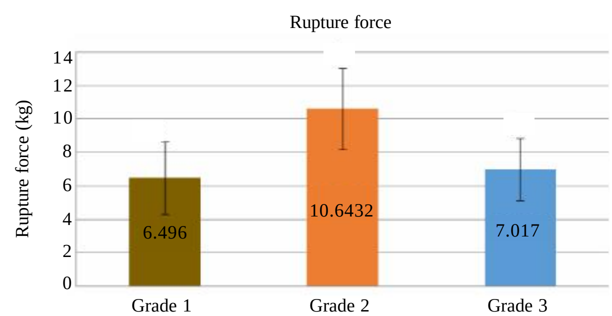

Fig. 1 : Rupture force of different grades of popped makhana

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