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ORIGINAL ARTICLE

Physical, gravimetric and functional characterization of various milling fractions of popped gorgon nut (*Euryale ferox*)

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Abstract Studies were carried out on the milling characteristics to increase the usability of popped gorgon nut (*makhana*). It was conditioned to 6.2, 9.4 and 12.3% (db) moisture content and ground in a hammer mill at feed rates of 3, 6 and 9 kg/h. The differential screen analysis showed that increase in moisture content decreased the percent weight retained in the pan and produced more medium sized particles (0.592-0.157 mm). The Bond's work index, Kick's constant and average particle size increased but total surface area decreased with the increase of conditioning level. However, feed rate showed the antagonistic effect on these parameters. Various grinding characteristics were significantly affected either individually or in combination (interaction) by the conditioning level as well as the feed rate and could be well correlated in terms of Bond's work index, Kick's constant, total surface area, average particle size, effectiveness of milling and bulk density for popped *makhana*.

Keywords *Makhana* · Gorgon nut · Grinding · Sieve analysis · Surface area · Particle size

Introduction

Makhana is a popped kernel of gorgon nut, an aquatic plant cultivated in stagnant fresh water pools of North and Northeastern states of India. Its wild forms are also available in China, Japan and North America (Jha et al. 1991). It is a light, voluminous and nutritionally rich dry fruit (Gopalan et al. 1987) and is used as *kheer* (milk based sweet dish) and puddings. The edible part of the nut is starchy kernel, which is taken out by popping (Jha and Prasad 1996). Popping is a process of creating super heated water vapours within the conditioned nut. Heating and sudden release of pressure cause a volumetric expansion of the kernel termed as *Makhana*. It contains 12.8% moisture, 76.9% carbohydrates, 9.7% protein, 0.1% fat, 0.5% total minerals, 0.02% calcium, 0.9% phosphorus and 0.0014% iron (Gopalan et al. 1987). The variation in the quality of the product is mainly due to manual grinding that results into uncontrolled size reduction and particle distribution (Jha and Verma 2000). Size reduction of popped *makhana* may be a simple way to reduce the volume for low transportation cost to distance places for product development.

The sieve analysis, commonly known as the "gradation test" is a basic essential test to determine the gradation (distribution of aggregate particles by size within a given sample) and is a powerful quality control and quality acceptance tool. The particle size distribution during milling has been extensively studied for various agricultural materials like wheat (Irani and Fong 1961; Irani and Callis 1963; Kirylic and Michniewicz 1990; Walde et al. 2002), pea flour (Maaroufi et al. 2000), buckwheat (Steadman et al. 2001), wheat and barley straws, corn stover and switch grass (Mani et al. 2004) and lentil, cowpea, black gram, green gram and bengal gram (Indira and Bhattacharya 2006).

Scanty literature is available related to grinding and gravimetric characteristics of different sieve fractions of ground *makhana*. Keeping in view, the present work was undertaken to study the effect of varied conditioning levels and feed rate on the milling characteristics of popped

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Table 1 Physical characteristics of *makhana* before grinding

Conditioning level,% db	Thousand grain wt, g	Arithmetic mean diam, mm	Geometric mean diam, mm	Sphericity, %	Aspect ratio,%	Surface area, mm^2	Bulk density, kgm^{-3}
6.2	412.2^a	20.5^a	20.4^a	0.88^a	87.9^a	$1,304.9^a$	59.2^a
9.4	437.1^b	20.5^a	20.4^a	0.87^a	88.2^a	$1,308.3^b$	57.4^b
12.3	459.3^c	21.0^b	20.8^b	0.84^b	84.3^b	$1,352.9^c$	57.7^b

Means in same column with different superscripts are significantly different at $p \leq 0.05$, $n=2$

makhana in a commercial hammer mill. Such a study would help in understanding the particle size distribution in a commercial grinder. The knowledge about the gravimetric characteristics of various sieve fractions will also help in easy handling and application of ground *makhana*.

Materials and methods

Popped *makhana* was purchased from local market and cleaned manually by removing adhering foreign matter, immature and un-popped nuts, if any. The initial moisture content of the popped *makhana* was determined by hot air oven method (AOAC 1995). The samples were then conditioned to 6.2, 9.4 and 12.3% moisture levels (db) by drying in a cabinet dryer (Standard Instruments Corporation, Patiala, India) preset to 50°C. The average initial dimensions of *makhana* were calculated ($n=25$) using vernier caliper (Mitutoya, Japan) having least count of 0.02 mm, and was considered as the initial particle diameter (McCabe et al. 1993a, b).

Grinding and differential sieve analysis Grinding studies were performed using a commercial hammer mill (Bells India Instrumentation, New Delhi) fitted with a single-phase motor (3 hp, 3,900 rpm). The samples (250 g) were ground at feed rates of 3, 6 and 9 kg/h. Sieve set of woven-wire cloth sieves (US standard sieves) of aperture size varying from 2.032-0.075 mm, having sieve diameter of 203 mm and height of 50 mm were used. A digital balance having least count of 0.001 g was used. The milling loss (%), moisture content and bulk density (loose and packed) of the ground material were determined before it was subjected to sieve analysis. The ground sample was placed on top of set of sieves and shaken until the weight of material on the smallest sieve reached equilibrium. The equilibrium was determined by inspecting and weighing at 5 min intervals after an initial sieving time of 10 min. If the weight on the smallest sieve containing any material changed by 0.2% or less of the total sample weight during a 5 min period the sieving process was considered complete at the onset of the previous period. The material collected on each sieve after 10 min shaking was weighed and packed separately in zip lock polythene bags (90 µm) and kept at ambient room temperature (27–30°C, 60–65% RH) for further analysis.

Determination of gravimetric, functional and grinding characteristics The bulk density (loose and packed) was determined for each sieve fraction (Singh et al. 2008). Sample was taken in a tared measuring cylinder and filled to a known volume for loose bulk density. However, for packed bulk density, the sample was tapped. The weight and volume were recorded 3 times. Weight of the sample was divided by its volume, which represented as bulk density (kgm^{-3}). Sample (2 g) was dispersed in 25 ml of

Table 2 Grinding and gravimetric characteristics of ground *makhana* before differential sieve analysis

Conditioning level,% db	Feed rate, kg/h	Milling loss,%	Moisture,% db	Loose bulk density, kgm^{-3}	Compact bulk density, kgm^{-3}
6.2	3	15.8^h	3.9^c	122.6^a	129.1^a
6.2	6	12.4^f	3.6^b	124.0^b	132.2^b
6.2	9	11.4^e	3.4^a	127.6^c	136.2^c
9.4	3	10.1^c	7.1^f	136.2^d	145.6^d
9.4	6	12.4^f	6.8^e	141.8^e	149.5^f
9.4	9	13.0^g	6.2^d	151.8^i	156.1^h
12.3	3	10.9^d	10.2^i	143.1^f	146.1^e
12.3	6	9.4^b	9.8^h	148.0^g	152.4^g
12.3	9	9.1^a	9.2^g	149.6^h	157.2^i

Means in same column with different superscripts are significantly different at $p \leq 0.05$, $n=2$

Table 3 Effect of conditioning level and feed rate on weight fractions (%) retained on various sieves after differential sieve analysis

Conditioning level,% db	Feed rate, kg/h	Sieve aperture, mm								
		2.032	1.405	0.954	0.592	0.500	0.296	0.157	0.075	Pan
6.2	3	2.7^{a}	3.1^{ab}	4.4^{d}	2.1^{a}	10.3^{f}	15.6^{e}	36.3^{e}	22.6^{h}	2.2^{d}
6.2	6	3.4^{e}	4.5^{c}	6.8^{g}	13.0^{f}	2.3^{d}	17.4^{f}	33.0^{d}	17.1^{d}	2.2^{e}
6.2	9	2.7^{a}	2.9^{ab}	3.6^{a}	8.5^{c}	2.2^{abc}	15.4^{d}	41.3^{i}	19.6^{e}	2.3^{f}
9.4	3	3.0^{b}	3.3^{b}	4.7^{e}	9.4^{e}	2.3^{bcd}	15.2^{b}	37.8^{g}	21.9^{g}	2.2^{c}
9.4	6	3.1^{c}	2.9^{ab}	4.1^{b}	8.3^{b}	2.1^{ab}	13.9^{a}	38.6^{h}	24.8^{i}	2.2^{c}
9.4	9	3.4^{f}	3.5^{d}	4.4^{c}	8.9^{d}	2.1^{ab}	15.3^{c}	36.9^{f}	21.3^{f}	2.2^{d}
12.3	3	5.8^{g}	6.1^{e}	9.8^{i}	19.4^{i}	2.4^{cd}	19.2^{h}	23.3^{a}	11.5^{b}	2.2^{a}
12.3	6	3.2^{d}	5.9^{a}	4.8^{f}	15.6^{g}	1.9^{a}	19.4^{i}	32.6^{c}	12.2^{c}	2.2^{b}
12.3	9	6.7^{h}	6.1^{e}	8.5^{h}	15.8^{h}	4.6^{e}	17.6^{g}	24.1^{b}	11.4^{a}	2.2^{b}

Means in same column with different superscripts are significantly different at $p \leq 0.05$, $n=2$

distilled water. The contents were mixed 6 times using vortex shaker for 30 min and then centrifuged (Eltek MP-400R, Electrocraft, Mumbai, India) at 5,000 rpm for 15 min. The supernatant was carefully decanted and the contents of the tube were allowed to drain at a 45^{o} angle for 20 min and then weighed. Average gain in weight was expressed as water absorption capacity (Singh et al. 2008).

The surface area of the particles was required to measure the grinding effectiveness which was the ratio of the surface area of the final product after grinding to that of the raw material.

$$\text{Grinding effectiveness} = \frac{\text{Surface area after grinding}}{\text{Surface area before grinding}} \quad (1)$$

The surface area was calculated by measuring the volume of 50 popped *makhana* using rapeseed displacement method. From the volume of one *makhana*, its diameter and hence the surface area was calculated (Velu et al. 2006). The surface area of the final product obtained from one *makhana* was calculated as follows;

$$\textit{Weight of one particle} = (4/3)\,\pi\,(D_2/2)^3\,\rho \quad (2)$$

$$\text{Number of particles (N)} = \frac{\text{Weight of one grain}}{\text{Weight of one particle}} \quad (3)$$

$$\text{Surface area after grinding} = 4\,\pi\,(D_2\,/2)^2\,N \quad (4)$$

Based on the mass fractions, the average final particle size (D_2) was calculated using the following relationship;

$$\text{Average particle size } (D_2) = \sum_{i=1}^{n} \Phi_i\, d_i \quad (5)$$

where p = density of particles, d_i = aperture size of mesh, Φ_i = differential weight fraction of particles passing through aperture size d_i.

Table 4 Effect of conditioning level and feed rate on loose bulk density of various sieve fractions

Conditioning level,% db	Feed rate, kg/h	Sieve aperture, mm								
		2.032	1.405	0.954	0.592	0.500	0.296	0.157	0.075	Pan
6.2	3	46.6^{a}	69.0^{f}	59.0^{a}	63.1^{c}	68.5^{b}	97.8^{g}	133.7^{i}	193.9^{h}	199.2^{h}
6.2	6	58.0^{e}	49.3^{a}	59.8^{b}	62.2^{b}	78.9^{ab}	71.3^{a}	95.2^{a}	186.4^{d}	198.5^{f}
6.2	9	58.2^{e}	61.5^{d}	67.9^{e}	77.1^{f}	76.1^{ab}	88.1^{d}	122.9^{e}	191.6^{f}	192.5^{b}
9.4	3	52.6^{c}	53.2^{b}	64.0^{c}	60.2^{a}	62.0^{a}	96.1^{f}	115.7^{c}	182.4^{b}	197.2^{e}
9.4	6	57.2^{d}	59.5^{c}	66.3^{d}	78.5^{g}	75.6^{ab}	72.4^{b}	116.0^{d}	183.6^{c}	193.2^{c}
9.4	9	51.7^{b}	59.8^{c}	69.4^{g}	68.0^{d}	69.8^{ab}	85.2^{c}	131.1^{g}	195.8^{i}	198.5^{g}
12.3	3	57.2^{d}	65.1^{e}	68.6^{f}	70.6^{e}	69.8^{ab}	91.6^{e}	128.2^{f}	192.2^{g}	199.5^{i}
12.3	6	61.2^{f}	73.9^{g}	87.4^{i}	82.6^{h}	78.5^{ab}	112.3^{h}	114.8^{b}	191.1^{e}	189.9^{a}
12.3	9	62.3^{g}	72.1^{h}	79.5^{h}	90.7^{i}	68.3^{ab}	$118.^{i}$	131.2^{h}	181.8^{a}	195.6^{d}

Means in same column with different superscripts are significantly different at $p \leq 0.05$, $n=2$

Table 5 Effect of conditioning level and feed rate on compact bulk density of various sieve fractions

Conditioning level,% db	Feed rate, Kg/h	Sieve aperture, mm								
		2.032	1.405	0.954	0.592	0.500	0.296	0.157	0.075	Pan
6.2	3	53.5^{h}	73.8^{g}	64.7^{b}	69.8^{b}	75.6^{b}	106.2^{f}	144.9^{d}	254.9^{b}	248.9^{b}
6.2	6	64.8^{b}	53.0^{a}	60.5^{a}	68.0^{a}	79.5^{d}	83.8^{b}	114.8^{a}	248.5^{a}	248.7^{a}
6.2	9	64.1^{f}	68.1^{f}	75.8^{f}	85.7^{f}	74.6^{a}	98.4^{d}	145.6^{e}	258.3^{d}	254.2^{d}
9.4	3	54.4^{c}	58.0^{b}	72.9^{e}	71.2^{c}	74.5^{a}	105.7^{e}	146.9^{f}	256.5^{c}	254.1^{d}
9.4	6	57.2^{d}	59.5^{c}	69.3^{d}	84.8^{e}	76.2^{c}	77.7^{a}	134.7^{c}	259.6^{e}	254.1^{d}
9.4	9	50.2^{a}	59.8^{d}	76.5^{g}	75.0^{d}	74.6^{a}	90.0^{c}	155.2^{h}	269.2^{g}	254.2^{d}
12.3	3	69.6^{i}	66.3^{e}	68.6^{c}	75.3^{d}	75.4^{b}	106.9^{g}	150.9^{g}	258.1^{d}	252.0^{c}
12.3	6	63.8^{e}	76.2^{h}	95.5^{i}	87.6^{g}	76.1^{c}	125.0^{h}	121.8^{b}	272.9^{h}	254.1^{d}
12.3	9	66.3^{g}	74.2^{i}	84.3^{h}	95.7^{h}	75.1^{b}	130.3^{i}	151.1^{g}	262.5^{f}	254.2^{d}

Means in same columns with different superscripts are significantly different at $p \leq 0.05$, $n=2$

The grinding energy per unit weight E in kWh/kg was calculated by noting the wattage of the hammer mill, time of grinding and the feed rate. Based on the particle sizes (initial and final) and the energy in kWh required to grind a unit weight of material, the Bond's work index (W_i) and Kick's constant (K_k) were calculated as;

$$E = K_K \ln (D_1/D_2) \quad (6)$$

$$E = 0.3162\, W_i \left[\frac{1}{\sqrt{D_2}} - \frac{1}{\sqrt{D_1}}\right] \quad (7)$$

where D_1 = particle size before grinding, D_2 = particle size after grinding.

The constant in Eq. 6 is the slope of curve plotted for energy against logarithmic value of ratio of initial and final particle size and is known as Kick's constant (K_k). It gives the idea of specific energy used to grind the material, which is directly proportional to the size reduction ratio. The Bond's work index (W_i) in Eq. 7 is the gross energy requirement in kWh per ton of feed needed to reduce a very large feed to such a size that 80% of the product passes through 100 μm sieve.

Statistical analysis The analysis of variance test was carried out ($n=2$) using SPSS 7.5 software and statistical procedures described by Gomez and Gomez (1984) to examine the effect of conditioning level and feed rate ($p \leq 0.05$) on the grinding characteristics of popped *makhana*. The results were compared with Duncan's multiple range test. The Pearson's correlation coefficients among various grinding characteristics were calculated using MS Excel

Table 6 Effect of conditioning level and feed rate on water absorption capacity (%) of various sieve fractions

Conditioning level,% db	Feed rate, kg/h	Sieve aperture, mm								
		2.032	1.405	0.954	0.592	0.500	0.296	0.157	0.075	Pan
6.2	3	146.8^{h}	235.4^{g}	238.0^{h}	230.0^{d}	429.5^{a}	440.4^{g}	553.8^{g}	613.6^{g}	626.9^{h}
6.2	6	146.3^{g}	240.1^{h}	236.7^{g}	259.2^{h}	437.0^{a}	446.3^{h}	565.8^{h}	632.9^{h}	629.2^{i}
6.2	9	148.6^{i}	251.4^{i}	245.2^{i}	276.4^{i}	443.2^{a}	449.5^{i}	578.7^{i}	633.9^{i}	625.4^{g}
9.4	3	135.5^{d}	211.0^{d}	208.3^{d}	253.9^{f}	400.8^{a}	434.2^{f}	523.3^{d}	598.6^{d}	577.2^{e}
9.4	6	137.2^{e}	217.6^{e}	211.6^{e}	253.8^{e}	417.2^{a}	428.0^{e}	534.5^{e}	601.7^{e}	574.4^{d}
9.4	9	140.9^{f}	221.9^{f}	217.6^{f}	256.3^{g}	418.0^{a}	428.5^{d}	544.2^{f}	613.0^{f}	572.4^{c}
12.3	3	127.6^{c}	139.1^{a}	176.2^{b}	191.6^{a}	398.6^{a}	397.9^{b}	499.0^{a}	577.2^{a}	564.6^{a}
12.3	6	122.3^{b}	139.9^{b}	181.4^{c}	196.4^{b}	409.7^{a}	388.3^{a}	516.4^{b}	581.6^{b}	567.2^{b}
12.3	9	117.3^{a}	153.1^{c}	160.1^{a}	201.9^{c}	416.2^{a}	403.2^{c}	522.7^{c}	591.8^{c}	580.7^{f}

Means in same columns with different superscripts are significantly different at $p \leq 0.05$, $n=2$

Table 7 Effect of conditioning level and feed rate on various milling characteristics of *makhana*

Conditioning level,% db	Feed rate, kg/h	Bonds work index, $kwhkg^{-1}$	Kicks constant, $kwhkg^{-1}$	Total surface area, mm	Average particle size, mm	Grinding Effectiveness*
6.2	3	1.76^{f}	0.19^{c}	31.25^{d}	0.43^{b}	36.51^{d}
6.2	6	0.88^{c}	0.09^{b}	33.04^{f}	0.41^{a}	38.59^{b}
6.2	9	0.59^{a}	0.06^{a}	35.14^{h}	0.42^{a}	41.04^{e}
9.4	3	1.83^{g}	0.19^{c}	32.11^{e}	0.44^{c}	37.51^{d}
9.4	6	1.01^{e}	0.09^{b}	32.91^{e}	0.42^{a}	38.45^{b}
9.4	9	0.61^{a}	0.06^{a}	34.82^{f}	0.43^{d}	40.67^{c}
12.3	3	2.34^{h}	0.21^{d}	24.45^{a}	0.66^{e}	28.57^{a}
12.3	6	0.97^{d}	0.09^{b}	28.75^{b}	0.68^{f}	33.58^{b}
12.3	9	0.78^{b}	0.07^{a}	30.37^{c}	0.67^{f}	35.48^{c}

Means in same column with different superscripts are significantly different at $p \leq 0.05$, $n=2$, * = No units

(Sharma et al. 2009) (Microsoft Corp., Redmond, WA, USA).

Results and discussion

Physical characteristics of whole popped makhana The initial moisture content of popped *makhana* was 12.7% (db). The *makhana* was conditioned to 6.2, 9.4 and 12.3% moisture content (db). The thousand *makhana* weight, geometric mean diameter, arithmetic mean diameter, sphericity, aspect ratio, surface area of 50 *makhana* grains and bulk density of popped *makhana* varied between 412.2–459.3 g, 20.5–21.0 mm, 20.4–20.8 mm, 0.84–0.88%, 84.3–87.9, 1,304.9–1,352.9 mm^2 and 56.4–59.2 kgm^{-3}, respectively (Table 1). Jha (1998, 1999) also reported similar trends of physical properties for various grades of popped *makhana* at different moisture levels.

Grinding studies Grinding and gravimetric characteristics of ground material were recorded before it was subjected to sieve analysis. Milling loss was higher at lower moisture level and decreased with an increase of moisture content as well as the feed rate (Table 2). The loss at lower moisture content might be due the formation of more fine powdered material that gets easily lost in the form of dust particles during the grinding process. There was a loss in final moisture content of the ground material that ranged from 3.4 to 9.2% db. The loss was more apparent at higher feed rate. That may be due to higher evaporation due to rise in temperature as a result of more friction among the feed particles of ground material. The bulk density of the material was measured at this range of moisture content (as such basis). The loose and compact bulk density increased from 122.5–151.7 and 129.1–157.2 kgm^{-3}, respectively with the increase of feed rate but decreased with the conditioning level (Table 2). Zhao et al. (2009) also observed similar variations in functional properties of ginger powder fractions as a function of particle size.

Percent fractions retained It is clear from Table 3 that as the moisture content of the material increased, more medium size (0.59-0.16 mm) particles produced during grinding. However, contrary to this statement, the feed rate had significant positive effect i.e. more finer particles were produced. This could be attributed to higher friction produced among the feed particles due to sufficient filling of grinding cavity with the feed during grinding process with the increased feed rate. The results were in compliance

Table 8 Pearson's correlation coefficients among various grinding and gravimetric characteristics

	BWI	KC	TSA	APS	GE	ML	MC	LBD
KC	0.987*							
TSA	-0.705	-0.617						
APS	0.216	0.113	-0.892*					
GE	-0.705	-0.617	0.998*	-0.809				
ML	0.099	0.176	0.334	-0.672	0.334			
MC	0.269	0.149	-0.727	0.870*	-0.727	-0.741		
LBD	-0.166	-0.274	-0.276	0.591	-0.276	-0.565	0.812	
CBD	-0.238	-0.339	-0.170	0.528	-0.170	-0.622	0.876*	0.983*

BWI Bond's work index, *KC* Kicks constant, *TSA* Total surface area, *APS* Average particle size, *GE* Grinding effectiveness, *ML* Milling loss, *MC* moisture content, *LBD* Loose bulk density, *CBD* Compact bulk density

* = Significant at $p \leq 0.05$

with the results reported by Jha and Verma (1999) for popped *makhana* milled at different moisture content and grinding time.

Gravimetric characteristics The loose bulk density ranged between 46.8 and 199.5 kgm^{-3} (Table 4). However, the compact bulk density varied from 53.5 to 254.1 kgm^{-3} among the entire sieve fractions (Table 5). The compact bulk density showed slight variations with the treatments, as compared to loose bulk density, within the same particle range. Similar observations for ginger powder fractions have also been reported by Zhao et al. (2009).

Functional characteristics Water absorption capacity tends to increase with the decrease of the particle size (Table 6). This might be attributed to the absorption of more water by the particles due to increased surface area. Jha and Verma (1999) reported similar observations for the milk absorption characteristics of *makhana* for varied particle sizes. However, the water absorption capacity increased with the increase of feed rate within the same particle range. The residual final moisture retained after the grinding process might be one of the reasons for increase in the water absorption capacity of the ground material (Table 2).

Effect of treatments on various grinding characteristics Bond's work index and Kick's constant which are the measures of energy uptake, increased with the conditioning level (Table 7). However, the same parameters declined with the increase of feed rate. This might be attributed to comparatively less grinding time taken to grind the unit feed with the increase of feed rate. However, with the increase of conditioning level, the material became tougher, resulted in more consumption of energy and hence the increase in Bond's work index and Kick's constant. The total surface area decreased with the increase of conditioning level. The average particle size increased with the conditioning level but decreased with the feed rate. This was due to higher moisture level that leads to reduced grinding and thus less formation of fine material. The effectiveness of milling showed slight variation between moisture ranges of 6.2 and 9.4% (db) but thereafter, it decreased drastically at higher moisture range of 12.3% (db). Similar observations were reported by Indira and Bhattacharya (2006) for different legumes and Velu et al. (2006) for microwave dried maize grains. Jha and Verma (1999) also observed during grinding of popped *makhana* that mass fraction retained in pan decreased with the increase in moisture level.

Correlation among various grinding characteristics The correlation data (Table 8) shows that various grinding characteristics for the popped *makhana* could be well correlated in terms of Bond's work index, Kick's constant, total surface area, average particle size, effectiveness of milling and bulk density. Thus, it is apparent that variations in independent variables (conditioning level and feed rate) either individually or in combination (interactions) significantly influenced the measured parameters.

Conclusion

The conditioning level and feed rate affect the grinding as well as gravimetric characteristics significantly. More fine particles and less medium size particles (0.592-0.157 mm) were produced at lower conditioning level and higher feed rate. With the increase in conditioning level, the energy consumption for the grinding process increased, but with the increase in feed rate it declined. Variation in conditioning level as well as feed rate either individually or in combination (interaction) influenced grinding process significantly and the same could be done without roasting. Thus, an energy intensive operation (roasting) may be eliminated from the grinding process of *makhana*.

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