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STUDY OF PHYSICO-CHEMICAL AND ENGINEERING PROPERTIES OF MAKHANA (*Euryale ferox*) FOR THE DEVELOPMENT OF MAKHANA POPPING MACHINE

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Abstract: Makhana (Euryale ferox.) is considered as a potential aquatic cash crop of India in general and North Bihar in particular. It is commonly known as Fox nut, Gorgon nut and Prickly water lily. It 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. Makhana is the popped expanded kernel of the gorgon nut and is used as a delicious food in India. Presently, it is sorted, graded and used as an ingredient of various ready-to-eat products. High volumetric expansion of makhana increases transport cost and makes it too expensive in distant places. Makhana thus requires further processing to get some value-added products of minimum volume. Since makhana is a seasonal and regional crop and its storage conditions are also needed for keeping it appropriately at processing centres. 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 stages of makhana were determined using standard techniques as well as proximate/chemical composition of makhana seeds has been analysed for the fabrication of Makhana popping machine. It was found that, raw makhana seeds have the moisture content in the range of 9.94 to 10.80 per cent (w.b). Protein content in makhana seeds ranged between 10.24 to 11.12 per cent the average fat content was 0.4 per cent in all the samples while makhana contained a good amount of fibre content 2.46 to 2.54 per cent and total ash content was 3.4 per cent observed in the three makhana samples. Physical and engineering properties were found to be: test weight (mean value of 100 makhana) 0.675 g; bulk density 637.80 kg/m^3; particle density 1155 kg/m^3; porosity 44.78%; angle of repose 21.1° to 22.1°; and static coefficient of friction 0·11 to 0·17 in sun mica sheet, copper sheet, mild steel, aluminium sheet, canvas sheet, wooden ply sheet and asbestos cement sheet.

Keywords: Makhana, Popping, Angle of Repose, Co-efficient of friction, Bulk density and porosity.

INTRODUCTION

Makhana (Euryale ferox) is an important aquatic crop, but is still neglected, probably because of lack of awareness among the rural masses in other parts of India than Bihar. In India, there are a lot of fallow wetlands, which remain unutilized round the year. In such case, Makhana cultivation may fetch more revenue to the poor masses. It only requires sincere efforts including dissemination of traditional knowledge as well as awareness to cultivate Makhana – a unique food resource.

Makhana is a main support for livelihood of the poor people. Makhana cultivated water bodies are also utilized along with fish culture. It is a perennial aquatic floating leaved herb, cultivated as a seasonal annual crop, which dies out after the fruits mature. The plant grows in fallow wetlands of standing shallow water of about 2.5 m depth and has rhizomatous stem. It was once distributed in India, covering a long range from Kashmir to Manipur alongside the Himalayan stretch from Northwest to far East. Now, its distribution has been confined within Bihar, along with adjacent states like Orissa, West Bengal, and Assam. It prefers tropical and sub-tropical climate, temperature between 20°C - 35°C, humidity between 50 percent - 90 percent and rainfall between 100 cm - 250 cm. Makhana is either eaten as raw puff or blended with vegetables, dal, etc. The seeds are edible after being processed and highly nutritious. It falls under one of the superior food qualities, which is reflected in its high amino acid index (89% - 93%) and arginine lysine /proline ratio (4.74 - 7.6). Caloric value (3.62 kcal/gm) is also remarkable as compared to staple foods. It has a prominent place in Indian dietary chart with medicinal values for respiratory, circulatory, digestive, renal and reproductive diseases. Commercially it is grown in Mithilanchal districts of Bihar comprising areas of Madhubani and Darbhanga. These areas accounts for 90 percent of estimated 75,000 tons of country's total annual production of makhana.

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.

MATERIALS AND METHODS

Sample preparation

For design and development of makhana popping machine first we have studied the physico-chemical and engineering properties of Makhana, Raw material was procured from local market of Saharsa and Purnea. The experiment was conducted in Agricultural Engineering department at Bihar Agricultural College, Sabour and Mandan Bharti Agriculture Collge, Saharasa. One lot of 2 kg of sample was cleaned, washed and graded according to average diameter and sphericity.

Physical and Engineering Properties of Makhana Seeds

1. Size and shape indices

The makhana seeds, in terms of the three principal axial dimensions, that is length, breadth and thickness as the grain shape tester (K200, Japan) with an accuracy of 0.01 mm. The seed shape was also determined in terms of its geometric mean diameter, sphericity, roundness and aspect ratio. The geometric mean diameter (D_p) of the seed was calculated by using the following relationship (Mohsenin, 1970):

$$D_p = (LWT)^{1/3} \quad (1)$$

The degree of sphericity (Φ) was calculated using the following formula as described by (Mohsenin, 1970):

$$\Phi = \frac{(LWT)^{1/3}}{L} \times 100 \quad (2)$$

Where *L* is the length, *W* is the width and *T* is the thickness.

2. 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.

$$\text{Bulk density, } \rho_b = \frac{M}{V} \quad (3)$$

Where, ρ_b = Bulk density, M = Total mass of seed (g) and V = Total volume of grain (m^3)

3. True density

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/m3 by using the following formula (Tunde-Akintunde and Akintunde, 2007).

$$\text{True density, } \rho_t = \frac{Ms}{Vs} \qquad (4)$$

Where, Ms = mass of solid particle (Kg) and Vs = volume of solid particle (m^3)

4. Porosity (ε)

The porosity (ε) of bulk cereal was computed from the values of true density and bulk density using the relationship given by Mohsenin (1970) as follows:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (5)$$

Where, ρ_t = True density (Kg/m^3) ρ_b = Bulk density (Kg/m^3)

5. 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 non stretchable 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.

$$\mu = \frac{F}{W} \qquad (6)$$

Where,

μ = Coefficient of friction, W = force normal to surface of contact (N) and F = force of friction (N)

6. Hardness

Compressive strength of cereals grain was considered an important mechanical property in relation to seed breakage during extraction. The compressive strength of the cereal grain were measured by using Instron Universal Testing machine. The Instron machine consist of a rectangular plate, flat, clamps and digital display unit. The load cell was attached with the help of a flat and clamps to the vertically moving upper cross-head of the Instron machine. The base of the Instron machine was used as the base for placement of makhana seeds.

7. Angle of repose

To determine the emptying or dynamic angle of repose, a sunmica box of 300 × 300 × 300 mm, having a removable front panel was used. The box was filled with the sample, and then the front panel was quickly removed, allowing the seeds to flow and assume a natural slope. The angle of repose was calculated from the measurement of the maximum depth of the free surface of the sample and the diameter of the heap formed outside the container. All these experiments were replicated five times, unless stated otherwise, and the average values are reported at the set moisture content.

Proximate/Chemical Analysis of Makhana Seeds

The proximate analysis gives useful information about the material, particularly from nutritional and bio-chemical point of view. Following proximate constituents were analyzed.

1. Initial Moisture content

The moisture content of raw and popped makhana seeds was determined by standard oven drying method. About 10 g of representative sample was weighed and kept in oven at $105±2^0$ C for 24 hours. The dried samples were cooled in desicator to room temperature and then weighed using electronic balance and the moisture content of the material was expressed in wet and dry basis (Ranganna, 2002).

2. Ash content

The ash content of a foodstuff or cereal grain represents inorganic residue remaining after destruction of organic matter. It may not necessarily be exactly equivalent to the mineral matter as some losses may occur due to volatilization. Taking tare weight of three silica dishes (7-8 cm dia.). Weigh 2 gm of sample into each. Now ignite the dish and the contents on a Bunsen burner. Ash the material at not more than 525 ^{0}C for 4 to 6 hrs. Now cool the dishes and weigh. The difference in the weights gives the total ash content and is represented as percentage.

3. Fat content

Fat soluble material in a food or cereal is extracted from an oven dried sample using a soxhlet extraction apparatus**.** The ether is evaporated and the residue weighed. The ether extract or crude fat of a food represents, besides the true fat (triglycerides), other materials such as phospholipids, sterols, essential oils, fat soluble pigments, etc. extractable with ether. Water-soluble materials are not extracted since the sample has been thoroughly dried prior to extraction with anhydrous ether.

$$(\%)\text{Fat} = \frac{\text{Wt. of the fat soluble material}}{\text{Wt. of the sample}} \times 100 \qquad (7)$$

4. Protein content

Determination of protein content or Nitrogen content is estimated by Kjeldahl method which is based on the determination of the amount of reduced nitrogen (NH_2 and NH) present in the sample. The various nitrogenous compounds are converted into ammonium sulphate by boiling with conc. H_2SO_4. The ammonium sulphate formed is decomposed with an alkali (NaOH), and the ammonia liberated is absorbed in excess of neutral boric acid solution and titrated with standard acid.

$$N_2\ (\%) = \frac{(\text{sample titre - blank titre}) \times \text{N of HCl} \times 14 \times \text{vol. made up} \times 100}{(\text{Aliqout}) \times \text{Wt. of the sample taken} \times 1000}$$

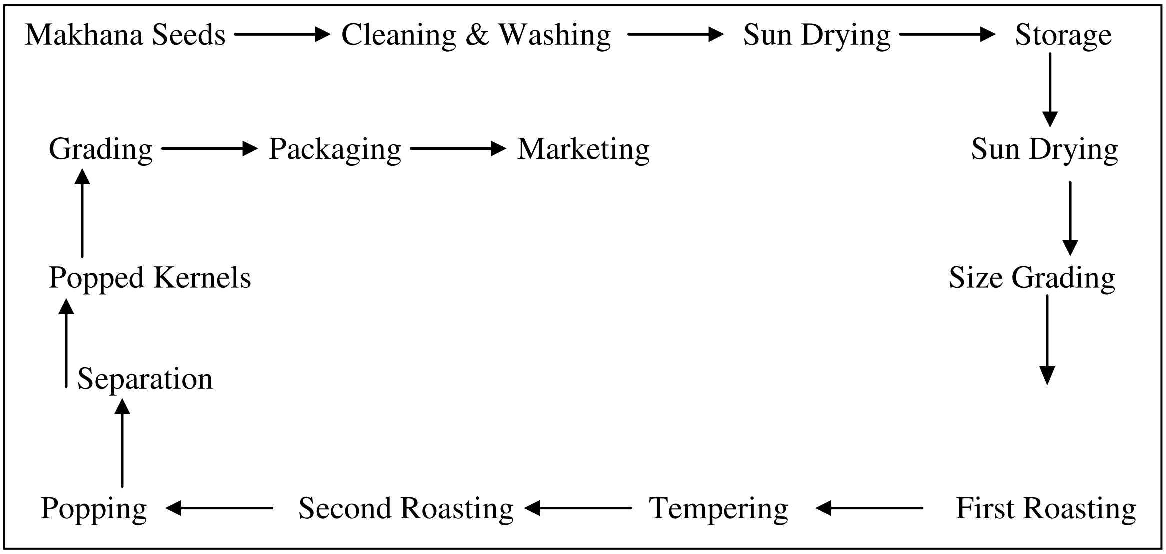
$$\text{Protein } (\%) = N_2\ (\%) \times 6.25 \qquad (8)$$

5. Crude fibre content

Crude fibre consists largely of cellulose lignin (97 %) plus some mineral matter. It represents only 60-80 % of the cellulose and 4-6 % of lignin. Commonly used in quality & quantity. Extract 2g of ground material with ether to remove fat (Initial Boiling temp. 35.38 ^{0}C and final temp. 52 ^{0}C). After extraction with ether boil 2g of dried material with 200 ml of H_2SO_4 for 30 min. with bumping chips. Then filter through muslin and wash with boiling water until washing are no longer acidic. Then boil with 200 ml of NaOH solution for 30 min. Filter through muslin cloth and wash with 25 ml of boiling 1.25 % H_2SO_4 3.25 ml portion of H_2O and 25 ml OH. Remove the residue and transfer to ashing dish (w_1). Drying the residue for 2 hour at 130 ^{0}C. Cool the dish in desicator and weigh (w_2) and ignite it for 30 min. at 600 ^{0}C then cool in a desicator and weigh (w_3).

$$(\%)\ \text{Crude Fibre} = \frac{\{(w2 - w1) - (w3 - w1)\}}{\text{Wt. of the sample}} \times 100 \qquad (9)$$

Table 1- Flow Chart for Makhana Popping/Processing



RESULTS AND DISCUSSIONS

Physical/Engineering Properties of Makhana seeds

Physical and engineering properties of makhana seeds have been evaluated for the purpose of designing suitable equipment for the makhana popping machine. Since, popping of makhana seeds is not a continuous process, so before popping makhana seeds is cleaned and washed then, seeds is dried for the storage at a suitable moisture content and then it is graded before first and second roasting. Then finally popping occurs after second roasting then grading and separation of popped kernels occurs before packaging and marketing. Table 3 shows all the physical properties of makhana seeds, which was calculated samples for 100 observation and tabulated. Table 4 and 5 shows the engineering properties of raw makhana seeds and these values was good acceptable for designing of makhana popping machine.

Chemical/Proximate composition of Makhana seeds

Three samples of makhana were procured from the local market to study their proximate composition. Small variations were observed in the different parameters analyzed. These may be due to environmental differences like soil, water, and air.

Table 2- Proximate composition of Raw Makhana Seeds

Raw Makhana	M.C (%,w.b)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)	Crude Fibre (%)
Sample A	10.80	10.54	0.392	3.424	72.37	2.47
Sample B	11.75	11.12	0.418	3.416	70.84	2.46
Sample C	09.94	10.24	0.408	3.394	73.48	2.54

Moisture content was found lowest in sample C which may be due to the variation in environmental conditions and cultivation practices. Protein content in makhana ranged between 10.24 to 11.12 per cent. The estimated content was found to be lower than reported earlier. The fat content of all the three samples were comparable to each other. In the present study, a fat content of 0.4 per cent was observed; while the reported values were quite lower (0.1 per cent). Approximately, 3.4 per cent total ash content was observed in the three makhana samples. Makhana contained a good amount of fibre content (2.46 to 2.54 per cent).

Table 3. Physical properties of Makhana Seeds

Physical Property	Number of Observations	Mean Value
Length, mm	100	12.40
Width, mm	100	12.10
Thickness, mm	100	11.73
Geometrical mean diameter, mm	100	12.10
Sphericity,	100	0.917
True density, Kg/m^3	100	1155.00
Bulk density, Kg/m^3	100	637.80
Porosity, %	100	44.78
Seed Weight, g	100	0.675

Table 4. Angle of Repose and Hardness of Makhana seeds at different stages.

Treatment	Moisture Content, (% d.b)	Angle of Repose, Degree	Hardness (N/mm^2)
Raw Makhana	60.00	22.10	402.10
Dried Makhana	33.00	21.70	471.50
Pre heated Makhana	25.74	21.40	567.16
Roasted Makhana	11.50	21.10	683.59

Table 5. Co-efficient of friction of Makhana Seeds (25.74 %, d.b)

Components	External friction
Sun mica sheet	0.11
Copper sheet	0.11
Mild Sheet	0.12
Aluminum sheet	0.14
Canvas Sheet	0.15
Wooden play sheet	0.16
Asbestos cement sheet	0.17
Internal Friction (Seed to Seed)	0.17

Conclusion

The following conclusions were drawn from this investigation i.e for the fabrication of Makhana popping machine, the physico-chemical properties and engineering properties of makhana seeds has been analysed and found that raw makhana seeds have the moisture content in the range of 9.94 to 10.80 per cent (w.b). Protein content in makhana seeds ranged between 10.24 to 11.12 per cent. The fat content of raw makhana seeds has been observed in the range of 0.39 to 0.4 per cent in all the samples while 3.4 per cent total ash content was observed in the three makhana samples. Makhana contained a good amount of fibre content 2.46 to 2.54 per cent. Physical and engineering properties were found to be: test weight (mean value of 100 makhana) 0.675 g; bulk density 637.80 kg/m^3; particle density 1155 kg/m^3; porosity 44.78 percent; angle of repose 21.1° to 22.1°; and static coefficient of friction 0·11 to 0·17 in different metal sheet.

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