Performance Evaluation of Rice Puffing Machine with LPG Heating System

ABSTRACT

Puffed rice is a popular and affordable breakfast cereal and snacks enjoyed worldwide. The traditional method of producing puffed rice is time-consuming and unhygienic. Hence, IGKV Raipur developed the rice puffing machine with LPG heating system for hygienic production of puffed rice. The developed rice puffing machine has greatly improved the efficiency and hygiene. The present study was focused on the performance evaluation of developed rice puffing machine using the IR-64 rice variety. The engineering and frictional properties of the rice were determined and the machine was evaluated at different temperatures and heating cylinder speeds. The optimized treatment of 210°C puffing temperature and 35 rpm heating cylinder speed yielded the highest puffing capacity (45 kg/hr), puffing efficiency (89.30%), and expansion ratio (346.00%). The cost of production per kg of puffed rice was calculated to be Rs. 41.50, with a benefit-cost ratio of 1.45:1. The rice puffing machine is recommended for small-scale entrepreneurs and start-up businesses in the puffed rice industry.

KEYWORDS: Rice puffing, puffed rice, performance evaluation, puffing efficiency, puffing capacity

1. INTRODUCTION

Rice, also known as paddy and scientifically named Oryza sativa L., is a highly significant food crop cultivated worldwide, ranking among the top three alongside wheat and maize. It belongs to the grass family (Germinaceae) and produces starchy seeds, making it the second-largest major cereal crop globally. Despite its cultivation in various regions and climates, a vast majority of the world's rice crop, around 90%, is grown and consumed in East, South-East, and South Asia. According to the USDA's Global rice production estimate for 2022-23, production is expected to reach 503.0 million tonnes, a slight decrease of 2% from the previous year, with global consumption and residual use projected to reach 517.2 million tonnes.(*www.usda.gov.in*)

Rice is a vital staple food for much of the world's population, particularly significant in Asia, with India contributing significantly to the global production and consumption of white rice around 111.76 million tonnes in 2021-22. Within India, Karnataka assumes a pivotal role in paddy production, with the Kalyana Karnataka (Seven districts of Northern Karnataka) region renowned as the state's rice bowl. Noteworthy productivity in districts like Raichur and Koppal underscores the region's significance, with productivity soaring to 4.28 tonnes per hectare during 2022-23 (www.agmarknet.gov.in)

The production of value added product like puffed rice fetches good market potential. Puffed rice is a popular snack food product in India and has been widely produced for centuries. Puffed rice provides less calories and nutrition compared to cooked rice, making it a better option for those who are considering losing weight. Puffed rice contains no cholesterol or sodium, making it suitable for everyone. Due to the absence of gluten, puffed rice can easily take over the place of bakery foods which are source of gluten and can cause discomfort especially in people with celiac disease. The nutritional status of puffed rice was found to be 76.92% of carbohydrate, 6.49% of protein, 0.94% of fat, 0.91% of dietary fibre and 0.46% of ash (Khan *et al.*, 2017).

Reliable figures on the volume of the puffed rice production in India are not available. But it has been estimated that about 10 per cent of rice is converted into puffed or rice snack food items. At present the puffed rice is made at cottage and semi-mechanized levels and mostly as a batch process (Nagaratna *et al.*, 2017). Puffed rice production in India is limited due to the labor-intensive process. Traditional methods are time-consuming, hindering large-scale production. Market demand for puffed rice remains high despite limited supply. Cottage-level production is primary method followed in India. The imperative to mechanize the puffing process for commercial production underscores the need for continuous, hygienic rice puffing technology.

IGKV, Raipur has developed the continuous type rice puffing machine with LPG heating system to overcome the limitations of traditional method of puffed rice production. The developed rice puffing machine has greatly improved the efficiency and hygiene. Puffing is a combined process of gelatinization of starch and expansion which is accomplished by exposing the grains to a high temperature for short time. Hence, the process may be called as high temperature short time process. This causes sudden heating and expansion of the moisture present in the inter-granular spaces of the starch granules in the form of vapour which results in puffing or expansion of the grains. (Parganiha *et al.*, 2022). Numerous varieties of paddy are grown in different parts of the state but, IR-64 variety is considered to be the best suited for raw milling before puffing.

In light of these considerations, the present study on "Performance Evaluation of Rice Puffing Machine" developed by IGKV Raipur was undertaken with the objectives of studying the engineering properties of the IR-64 rice variety and evaluating the performance of the rice puffing machine for the same variety.
This research endeavor aims to empower small and marginal farmers in paddy production catchment areas to transition towards puffed rice production, thereby enhancing profitability and market competitiveness. By embracing this technology, farmers and entrepreneurs stand to reap better returns while circumventing the challenges associated with traditional rice puffing practices.

2. MATERIALS AND METHODS

This section outlines the materials, instruments, techniques, and experimental procedures employed in the Conducted at the Department of Processing and Food Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Raichur, it provides a detailed description of the materials used for evaluating the performance of the rice puffing machine.

2.1. Specifications of rice puffing machine

The rice puffing machine, developed by IGKV Raipur (Chhattisgarh) was procured as shown in Plate 1. For evaluating the performance for the IR-64 rice variety.

The specifications of Machine:

- Continuous type with sand or salt as the heating medium
- Capacity of puffing machine: 50 -75 kg per hour
- Heating system: LPG with two burners, capable of reaching 250-300°C
- Roasting and puffing parts made of 2-3 mm mild steel
- Equipped with temperature indicator, speed controller, vibrated feeding system, and 1 hp electric motor
- Inbuilt recirculation of heating media
- Claimed puffing efficiency: 98%

2.2. Procurement of raw materials

The rice variety IR-64 was obtained from Karnataka State Seed Corporation Ltd, Raichur. The other materials required for the puffing process such as sand, baking soda, table salt, and LPG cylinders were sourced from the local market.

2.3. Conditioning of raw rice

Conditioning of milled rice before puffing is crucial for production quality puffed rice. It involves a hydrothermal treatment to eliminate air voids within the rice kernel and maintain optimum moisture content. The process flowchart for rice conditioning is presented in Fig.1.

Plate 1. Rice puffing machine developed by IGKV Raipur

Process flow chart for conditioning of raw rice

Raw rice (10.50 % M.C)

↓

Adding water (350 ml, 1 kg), table salt (60 g) and baking soda (5 g) mixing thoroughly so as to obtain moisture content of conditioned rice of having M.C 23.9±0.1623 %, respectively (w.b.)

↓

Drying in shade for 9 hours and heaping overnight (tempering)

Fig.1. Conditioning of raw rice before puffing

2.3. Performance evaluation of rice puffing machine

The machine parameters like speed and temperature of heating cylinder are crucial for getting good quality puffed rice, hence based on previous reviews these two variables were selected for performance evaluation of the rice puffing machine. The raw rice was conditioned using the process mentioned in Fig.1. The different parameters considered for performance evaluation of the rice puffing machine are given below.

Table 1 Variables considered for performance evaluation of rice puffing machine

Sl. No.	Variables	Levels	Treatments
1	Puffing temperature, °C	3	200, 210 and 220
2	Speed of heating cylinder, (rpm)	3	30, 35 and 40

Statistical design: FCRD

Treatments combination: 3×3×3

Replication: 3

Table 2. Treatment combinations for performance evaluation of rice puffing machine

Treatments	Puffing temperature (PT) (°C)	Speed of heating cylinder (SHC) (rpm)
T_1	200	30
T_2		35
T_3		40
T_4	210	30
T_5		35
T_6		40
T_7	220	30
T_8		35
T_9		40

T_1 – 200ºC PT and 30 rpm SHC

T_2 – 200ºC PT and 35 rpm SHC

T_3 – 200ºC PT and 40 rpm SHC

T_4 – 210ºC PT and 30 rpm SHC

T_5 – 210ºC PT and 35 rpm SHC

T_6 – 210ºC PT and 40 rpm SHC

T_7 – 220ºC PT and 30 rpm SHC

T_8 – 220ºC PT and 35 rpm SHC

T_9 – 220ºC PT and 40 rpm SHC

PT – Puffing temperature (ºC)

SHC - Speed of heating cylinder(rpm)

Plate 2. Conditioned rice (IR-64)

2.4. Observations to be taken

- Engineering properties of rice (Variety-IR-64)
- Puffing yield
- Expansion ratio
- Puffing capacity

2.4.1. Moisture content

The moisture content of raw and conditioned rice was determined by AOAC method (AOAC, 2016: 988.05)

2.4.2. Shape and size

The shape and size of the product is an important parameter that affects conveying characteristics of solid materials. The shape of the raw and conditioned rice was determined by measuring the longitudinal land lateral dimension using the digital vernier caliper having a least count of 0.01 mm. The dimensions were compared with the shapes as described in the standard chart (Mohsenin, 1986). The average size of raw and conditioned rice was calculated from randomly selected 100 rice grains in terms of their linear dimensions such as length, width and thickness.

2.4.3. Geometric mean diameter

Geometric mean diameter is the cube root of product of three semi-axes of rice grain. Three major principle axes of raw and conditioned rice grains of variety IR-64 were measured with the help of a digital vernier calliper having least count of 0.01 mm. The geometric mean diameter (Dg) of the samples was calculated by using the following relationship (Masoumi and Tabil, 2003)

$$D_g = (LWT)^{1/3} \quad \dots (2.1)$$

Where,

Dg= Geometric mean diameter of rice grain, mm
L= Length of rice grain, mm
W= Width of rice grain, mm
T= Thickness of rice grain, mm

2.4.4. Arithmetic mean diameter

Arithmetic mean diameter of raw and conditioned rice grain was calculated by using the following equation (Mohsenin, 1986).

$$D_a = \frac{(L+W+T)}{3} \quad \dots (2.2)$$

Where,

Da = Arithmetic mean diameter of rice grain, mm
L= Length of rice grain, mm
W= Width of rice grain, mm
T= Thickness of rice grain, mm

2.4.5 Surface area

The surface area of raw and conditioned rice was determined by analogy with a sphere of same geometric mean diameter using the following relationship (Mohsenin, 1986).

$$S = \pi(D_g)^2 \quad \dots (2.3)$$

Where,

S= Surface area of rice grain, mm^2
Dg= Geometric mean diameter of rice grain, mm

2.4.6. Unit volume

The unit volume of raw and conditioned rice grain was calculated by using the following equation (Wani *et al.*, 2014). A unit of volume is a unit of measuring volume or capacity, the extent of an object or space in three dimensions. Units of capacity may be used to specify the volume of fluids or bulk goods.

$$V = \frac{(L\times W\times T)}{6} \qquad \ldots (2.4)$$

Where,

V = Unit volume of rice grain, mm^3
L= Length of rice grain, mm
W = Width of rice grain, mm
T= Thickness of rice grain, mm

2.4.7. Bulk Density

The bulk density of the agricultural material such as grains plays an important role in many applications such as design of grain hoppers and storage structures (Heridarbeigi *et al.*, 2009). The bulk density of raw and conditioned rice of variety IR-64 was determined by using a container of known volume. The container was weighed using electronic balance. The bulk density was calculated by using the following formula (Mohsenin, 1986).

$$\text{Bulk Density (kg m }^{3}) = \frac{\text{Wieght of Rice (kg)}}{\text{Volume of Rice including Pore Space } (m^3)} \qquad \ldots (2.5)$$

2.4.8. Puffing yield

Puffing yield in terms of puffed rice and un-puffed from the sample after puffing were separated by hand picking and weighed. Puffing yield was determined by considering the proportion of puffed grains in the sample (Maisont and Narkrugsa, 2009). The puffing yield was expressed as percentage.

$$\text{Puffing Yield (\%)} = \frac{\text{Weight of Puffed grains (g)}}{\text{Weight of the grain feed (g)}} \times 100 \qquad \ldots (2.6)$$

2.4.9. Expansion ratio

The expansion ratio of puffed rice was calculated by measuring the total volume of raw and puffed rice as per the method suggested by Maisont and Narkrugsa (2009). Known quantity of raw and puffed rice was measured using beaker of known volume. Expansion ratio was calculated by using following equation.

$$\text{Expansion ratio (\%)} = \frac{\text{Volume of sample after puffing}}{\text{Volume of sample before puffing}} \times 100 \qquad \ldots (2.7)$$

2.4.10. Puffing capacity

Puffing capacity of the rice puffing machine is defined as the rate at which puffing takes place at unit time. It usually varies with the speed of heating mesh and the feed rate (Taheri *et al*.,2017). The equation used for calculation of puffing capacity is given below,

$$\text{Puffing Capacity}\ (\frac{kg}{h}) = \frac{\text{Weight of feed (kg)}}{\text{Time taken for puffing (h)}} \times 100 \qquad \ldots (2.8)$$

2.4. 11. True density

The apparatus used for measuring the true density of raw and conditioned rice consisted of a 100 ml measuring jar and a weighing balance. Fifty ml of toluene was taken in a measuring jar. A known weight (10 g) of rice was poured into the measuring jar and rise in the toluene level was recorded as the true volume of the rice grains without void space. The true density of rice grain was calculated by using the following formula (Mohsenin, 1986).

$$\text{True density}\ (kg\ m^{-3}) - \frac{\text{Wieght og rice (kg)}}{\text{Change in volume of toluene}\ (m^3)} \qquad \ldots (2.9)$$

2.4. 12. Porosity

The porosity is the percentage of volume of voids in the test sample at given moisture content. The porosity of rice and conditioned rice was calculated as the ratio of the difference in true and bulk densities to the true density value and expressed in percentage and it was calculated by using the following equation (Mohsenin, 1986).

$$\text{Porosity} = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad \ldots (2.10)$$

Where,

ε = Porosity of rice grain, %

ρt = True density of rice grain, kg m^{-3}

ρb = Bulk density of rice grain, kg m^{-3}

2.4. 13. Thousand grain weight

The weight of 1000 raw and conditioned rice grains were determined by measuring the weight of randomly taken 100 grains by using an electronic balance and then multiplying by 10 to obtain the weight of 1000 raw and conditioned rice (Dhake *et al.*, 2017).

2.4. 14. Angle of repose

Flow ability of material is usually measured using the angle of repose (a measure of the internal friction between grains) that is useful in the design of hoppers (Mohmoud *et al.*, 2009). The angle of repose is the angle between base and slope of the cone formed on a free vertical fall of raw and conditioned rice onto a horizontal plane. It was determined by following the procedure as described by Sahay and Singh (2012). The height and diameter of rice and conditioned rice heaped in natural piles was noted, and the angle of repose was calculated using the following formula.

$$\text{Angle of Repose } (\varphi) = \tan^{-1}\left[\frac{2H}{D}\right] \quad \ldots (2.11)$$

Where,

φ= Angle of repose, degrees

H= Height of heap of rice grain, mm

D= Diameter of heap of rice grain, m

2.4. 15.Coefficient of internal friction

Coefficient of internal friction is the friction between the grain mass of kernels against each other. The coefficient of internal friction was measured by using a table provided with change able surfaces. A box of size 75 mm × 75 mm × 95 mm tied by a cord, passing over pulley was attached to a pan. The changeable surface was filled with rice and conditioned rice. The weight (W_1) was put into pan until the empty box started to slide on rice surface. Later, the empty box was filled with known weight of sample (W) and again the weight was put into pan to cause sliding. The weight (W_2) required to slide the filled box on the rice surface was recorded (Mohsenin, 1986). The coefficient of internal friction was calculated using the following equation.

$$\text{Coefficient of internal friction} = \frac{W_2 - W_1}{W} \quad \ldots (2.12)$$

Where,

W_1 = Weight to cause sliding of empty box, kg

W_2 = Weight to cause sliding of filled box, kg

W= Weight of rice inside the box, kg

2.4. 16.Coefficient of external friction

Coefficient of external friction is the sliding stress between the grain and the horizontal plane against the wall. The coefficient of external friction was measured by using a table provided with changeable surfaces.The box of size 75 mm × 75 mm × 95 mm was tied by cord passing over the pulley and a pan was attached to the cord. The weight (W_1) was put into pan until the empty box started to slide. Later, the box was filled with known weight of sample (W) and again the weight was put into the pan to cause the box to slide. The weight (W_2) required to slide the filled box was recorded (Mohsenin, 1986).

$$\text{Coefficient of external friction} = \frac{W_2 - W_1}{W} \quad \ldots (2.13)$$

Where,

W_1 = Weight to cause sliding of empty box, kg

W_2 = Weight to cause sliding of filled box, kg

W= Weight of rice inside box, kg

2.4. 17.Colour

Colour is an important attribute because it is usually the first property that consumers observe. It is one of the most important quality acceptances for products, which reflects sensation to the human eye. The roasted products are usually darker in colour, but darker colour does not mean better quality. Too dark may imply that the product is over roasted. The advantage is that this parameter can be visually determined for assessing product quality (Satishkumar et al., 2015). Hunter's lab colourimeter (Premier colour scan, Colour Flex EZ; Mumbai, India) was used for the measurement of colour of raw and puffed rice. The colour was measured by using CIELAB scale at a 10° observer with D-65 illuminant. It works on the principle of focusing the light and measuring the energy reflected from the sample across the entire visible spectrum. It provides a reading in terms of L*, a* and b* where luminance (L*) forms the vertical axis, which indicates whiteness (+) to darkness (-). Similarly, a* indicates redness (+) to greenness (-) and b* indicates yellowness (+) to blueness (-) (Manjula and Ramachandra, 2014). The instrument was calibrated using black and white tiles provided with the instrument. The raw and puffed rice samples were filled in the sample cup. The deviation of the colour of the sample to the standard was also observed and recorded.

2.5. Economics of puffed rice production

One of the main important parameters influencing the profitability of operation is the cost of the machine. There are two types of machinery costs, *viz.*, fixed and variable costs. Fixed costs depend on how long a machine is owned rather than how much it is used. It includes depreciation, interest, shelter and insurance. Variable costs are also called as operational costs. It includes repair and maintenance, power consumption and labour costs. The total machine cost of the machine was calculated by taking into consideration of materials used and labour charges

3. RESULTS AND DISCUSSION

The section presents the results of the research work undertaken entitled "Performance Evaluation of Rice Puffing Machine". It discusses the findings regarding the engineering properties of raw and conditioned rice, as well as the performance evaluation of the rice puffing machine.

3.1. Engineering properties of the rice (IR-64)

The moisture content, physical properties such as linear dimensions (length, width and thickness) geometric mean diameter, arithmetic mean diameter, surface area, unit volume, thousand grain weight, bulk density, true density and porosity, frictional properties such as angle of repose and coefficient of internal and external friction were measured for raw and conditioned rice at moisture content *viz.*, 10.50±0.1699% and 23.9±0.1623% (w.b.). The engineering properties of raw rice and conditioned rice are presented in Table 3

Table 3.Engineering properties of raw and conditioned rice

SI.No.	Parameters	Raw rice	Conditioned Rice
Physical properties			
1	Moisture content (%) (w.b.)	10.5±0.17	23.9±0.16
2	Length (mm)	6.71±0.22	6.87±0.26
3	Width (mm)	2.02±0.13	2.06±0.17
4	Thickness (mm)	1.80±0.01	1.92±0.02
5	Geometric mean diameter (mm)	2.89±0.11	3.00±0.10
6	Arithmetic mean diameter (mm)	3.50±0.11	3.61±0.13
7	Surface area(mm^2)	26.24±2.19	28.29±1.75
8	Unit volume (mm^3)	4.03±0.49	4.07±0.48

19	Bulk density (kg m^{-3})	722.37±2.59	700.89±1.10
10	True density (kg m^{-3})	1195±1.20	1236±1.48
11	Porosity (%)	39.5±0.18	43.2±0.11
12	Thousand grain weight (g)	17.92±0.41	21.50±0.22
13	Shape	Oval	Oval
Frictional properties			
14	Angle of repose (°)	32.82±0.48	34.36±0.45
15	Coefficient of internal friction	0.59±0.01	0.60±0.01
16	Coefficient of external friction	0.46±0.01	0.49±0.02

3.1.1. Moisture content

The mean values of moisture content (w.b.) for raw and conditioned rice of variety IR-64 are presented in Table 3 and the values were found to be 10.50±0.1699% for raw rice and 23.9±0.1623% for conditioned rice. The increase in moisture content after conditioning was due to the addition of water during conditioning process of the raw rice. The moisture content of 10 to 14% was observed by Kibar et al. (2010) for Osmancik-97 variety of rice.

3.1.2. Physical properties of raw and conditioned rice

The physical properties of raw and conditioned rice were determined and presented in the Table 3. From the table it is observed that, the shape of raw and conditioned rice was found to be oval. the average values of linear dimensions *viz.*, length, width and thickness of raw and conditioned rice were found to be 6.71±0.2188, 2.02±0.1345 and 1.80±0.0991 mm of raw rice 6.87±0.26, 2.06±0.17 and 1.92±0.020 mm for rice having moisture content of 23.90±0.16%. The mean values of geometric mean diameter were found to be 2.89±0.11 mm for raw rice and 3.00±0.10 mm for conditioned rice with moisture content of 23.90±0.16% respectively. 3.50±0.11 mm for raw rice and 3.61±0.13 mm for conditioned rice after having moisture contents of 23.90±0.16%. The surface area of raw rice was found to be 26.24±2.19 mm^2 and 28.29±1.75 mm^2 for conditioned rice after having moisture content of 23.90±0.16%. Mean value of unit volume of raw rice were found to be 4.03±0.49 m^3 at 10.50±0.17% moisture content and for conditioned rice at 23.90±0.16% moisture content, it was found to be 4.07±0.48 mm^3. The bulk density values were found to be 722.37±2.59 kg m^{-3} for raw rice and 700.89±1.10 kg m^{-3} for conditioned rice at 23.90±0.16%

moisture content. The porosity values were found to be 39.5±0.18% for raw rice and 43.2±0.11% for conditioned rice. The numerical mean values of thousand grain weight of raw and conditioned rice were found to be 17.92±0.41 g and 21.50±0.22 g, respectively. The angle of repose of raw rice was found to be 32.82±0.48° of raw rice having moisture content of 10.50±0.17% and it was 34.36±0.45° for conditioned rice having moisture content of 23.90±0.16%.

The coefficient of internal friction was found to be0.59±0.01for raw rice, and 0.60±0.01 for conditioned rice having moisture content of 10.50±0.17% and 23.9±0.16%, respectively. The average values of coefficient of external friction were found to be 0.46±0.01 for raw rice, 0.49±0.02.

3.1.3. Performance evaluation of rice puffing machine

As explained in the methodology, a digital temperature recorder present in the rice puffing machine it will helps to adjust and vary the levels of temperature from minimum 200°C to a maximum 220°C at different heating cylinder speeds between 30 to 40 rpm. The conditioned rice having initial moisture content of 23.90±0.16% was used for performance evaluation of rice puffing machine.

The performance of the rice puffing machine was evaluated in terms of, puffing efficiency, expansion ratio and puffing capacity. The experiment was conducted with three puffing temperatures (200, 210 and 220°C), three heating cylinder speeds (30, 35 and 40 rpm) and moisture content of rice (23.90±0.16%). A sample size of 5 kg of conditioned rice was taken for each experiment and replicated thrice.

The puffing efficiency, puffing capacity of puffing machine and expansion ratio of puffed rice was calculated by using the equation 3.21, 3.23 and 3.22, respectively. The values of the puffing efficiency, expansion ratio and puffing capacity are given in Table 4 respectively.

3.2. Effect of puffing temperature and heating cylinder speed on quantity of puffed rice during performance evaluation of rice puffing machine

The effect of puffing temperature and speed of heating cylinder on the quantity of puffed rice during performance evaluation is shown in Table 4. It is evident that from table 4, the quantity of puffed rice obtained is varied from 3.80±0.03 to 4.46±0.04 kg at different puffing temperatures (200, 210 and 220°C) and heating cylinder speeds (30, 35 and 40 rpm).

Among different variables, the maximum quantity of puffed rice 4.46±0.04 kg was observed at 210°C puffing temperature and 35 rpm heating cylinder speed. The lowest quantity (3.80±0.03 kg) of puffed rice was recorded at 200°C puffing temperature and heating cylinder speed of 30 rpm. The reason for higher yield at 210°C puffing temperature and 35 rpm heating cylinder speed might be due to optimum conditions required for puffing operation. The present findings were in accordance with the results quoted by Basavaraj *et.al.*(2015) who stated the optimum temperature for getting good quality puffed rice as 240-250°C using sand roasting method at the moisture content of 31%.

3.3. Effect of puffing temperature and heating cylinder speed on puffing efficiency of rice puffing machine

The effect of puffing temperature and speed of heating cylinder on puffing efficiency during performance evaluation is shown in Table 4.It is noticed that from table 4, the puffing efficiency of the puffing machine varied from 76.00±0.54 to 89.30±0.32% with different puffing temperatures (200, 210 and 220°C) at different heating cylinder speeds (30, 35 and 40 rpm). Among different variables, the puffing efficiency was the maximum (89.30±0.32%) at 210°C temperature and at 35 rpm heating cylinder. The least (76.00±0.54%) puffing efficiency was recorded at 200°C puffing temperature and at 30 rpm heating cylinder speed. Similar results were obtained by Maisont and Narkrugsa (2010) who concluded that as the moisture content increased from 10 to 13%, the puffing efficiency also got increased. Whereas, further increase in moisture content from 16 to 19% the puffing efficiency decreased significantly. This might be due to the higher moisture in the grains loosen the inter locking in the husk and endosperm (lemma-palea), which resulted in insufficient internals team pressure being maintained to cause puffing.

3.4. Effect of puffing temperature and cylinder speed on puffing capacity of rice puffing machine

The effect of puffing temperature and speed of heating cylinder on puffing capacity of the puffing machine is shown in Table 4. It is seen that from table 4, the puffing capacity of rice puffing machine varied from 35.25±0.43 to 45.00±0.43 kg h^{-1} at different puffing temperatures (200, 210 and 220°C), different heating cylinder speeds (30, 35 and 40 rpm). Among the different treatments, the puffing capacity was the maximum (45.00±0.43 kg h^{-1}) at 210°C puffing temperature and 35 rpm speed of heating cylinder. As the speed of heating cylinder increased, the puffing capacity also increased. The next best puffing capacity (43.50±1.07 kg h^{-1}) obtained at 210°C puffing temperature and 40 rpm heating cylinder speed. The least puffing capacity (35.25±0.43 kg h^{-1}) was recorded at puffing temperature of 200°C and heating cylinder speed of 30 rpm. The increased puffing capacity at higher heating cylinder speed might be due to lesser residence time during puffing operation. It could also be noted that, the puffing efficiency got reduced at higher speed due to less residence time.

Plate.3. Puffed Rice

200°C at 30 rpm **210°C at 35 rpm** **220°C at 30 rpm**

Plate.4. Puffed rice packets

Table 4. Effect of puffing temperature and speed of heating cylinder on performance rice puffing machine

Treatments	Puffing quantity (kg)		Puffed rice (%)	Un puffed rice (%)	Puffing efficiency (%)	Puffing capacity (kg h^{-1})	Time of puffing for 5 kg rice (min)	Expansion ratio (%)
	Puffed rice	Un puffed rice						
T_1	3.80±0.03	1.20±0.03	76.00±0.54	24.00±0.42	76.00±0.54	35.25±0.3	8.51±0.56	267.50±0.56
T_2	4.06±0.01	0.93±0.01	81.37±0.33	18.63±0.19	81.37±0.33	37.75±0.62	7.95±0.16	269.50±0.16
T_3	3.93±0.02	1.06±0.02	78.70±0.32	21.30±0.31	78.70±0.32	40.25±1.0	7.45±0.47	266.00±0.47
T_4	4.26±0.02	0.74±0.02	85.20±0.32	14.80±0.46	85.20±0.32	39.75±0.42	7.55±0.13	333.33±0.13
T_5	4.46±0.04	0.53±0.02	89.30±0.32	10.70±0.30	89.30±0.32	45.00±0.32	6.66±0.37	346.00±0.37
T_6	4.34±0.04	0.65±0.02	86.90±0.41	13.10±0.45	86.90±0.41	43.50±0.42	6.70±0.22	344.80±0.22
T_7	3.92±0.02	1.07±0.03	78.50±0.63	21.50±0.55	78.50±0.63	39.00±0.42	7.69±0.13	197.50±0.13
T_8	4.23±0.02	0.77±0.02	84.60±0.43	15.40±0.25	84.60±0.44	41.25±0.66	7.27±0.93	207.50±0.93
T_9	4.09±0.02	0.90±0.01	81.90±0.24	18.10±0.30	81.90±0.24	40.00±0.42	7.50±0.07	200.00±0.07
Mean	4.12	0.87	82.50	17.50	82.50	40.19	7.48	270.24
SE(m)±	0.02	0.01	0.21	0.19	0.21	0.42	0.18	0.72
CD	0.05	0.03	0.60	0.57	0.60	0.96	0.23	2.11

3.5. Effect of puffing temperature and heating cylinder speed on expansion ratio of puffed rice

The effect of puffing temperature and speed of heating cylinder on expansion ratio of puffed rice during performance evaluation is shown in Table 4. It is evident that from table 4, the expansion ratio of puffed rice varied from 197.50±0.14 to 346.00±0.38% with different puffing temperatures of 200, 210 and 220°C, heating cylinder speeds of 30, 35 and 40 rpm. Among different variables, the maximum expansion ratio of 346.00±0.38% was observed at 210°C puffing temperature and 35 rpm heating cylinder speed. The least (197.50±0.14%) expansion ratio was recorded at the puffing temperature of 220°C and at 30 rpm speed of heating cylinder. Similar results were obtained by Maisont and Narkrugsa (2010) on the effect of moisture content on expansion ratio, where expansion ratio values were increased as the moisture content increased from 10 to 13% while treating at 800 W microwave heating.

3.6. Proximate composition of raw and puffed rice

The proximate composition and colour values of the raw rice and puffed rice are given in the Table 5. From it is inferred that, the moisture content, crude protein, crude fat, crude fibre contents have decreased after puffing and total ash and carbohydrate content increased after puffing. The colour values of raw rice and puffed rice had a significant difference due to high temperature treatment and conditioning given to rice led to change in *L**, *a** and *b** values from 59.26±0.45, 3.45±0.16 and 20.53±0.36 to 73.33±0.64, 2.36±0.06 and 17.92±0.58, respectively.

Table 5. Proximate composition of raw rice and puffed rice

Sl. No.	Parameters	Raw rice	Puffed rice
1	Moisture content (%)	10.5±0.17	3.00±0.11
2	Crude protein (%)	7.69±0.16	7.13±0.04
3	Crude fat (%)	1.78±0.07	1.31±0.03
4	Crude fibre (%)	1.45±0.11	1.73±0.02
5	Total ash (%)	0.67±0.03	3.16±0.04
6	Carbohydrates (%)	77.91±0.47	83.67±0.07
7	Colour values L* a* B*	59.26±0.45, 3.45±0.17, 20.53±0.36	73.53±0.64, 2.36±0.06, 17.92±0.59

3.7. Economics of puffed rice production

The cost estimation for the rice puffing machine was calculated as per the standard procedure (Ojha and Michael, 2003). The total operating cost of puffing machine per annum was Rs. 37, 90, 00/-. The total production cost of the puffed rice per annum was Rs. 39, 48,000/-, expected returns per the year Rs. 64, 80,000/- with a benefit (b): cost (c) ratio of 1.45: 1 and payback period of 2.24 year

Conclusion

The present study emphasized the importance of optimizing operational parameters such as moisture content, puffing temperature, and heating cylinder speed for effective rice puffing. The engineering properties determined for raw and conditioned rice showed that moisture content of 23.90±0.16% resulted in larger rice grain size (6.87±0.26 mm) grain. The shape of the grains was oval for raw and conditioned rice. The performance of the rice puffing machine was evaluated in terms of puffing efficiency, expansion ratio and puffing capacity with the popular rice variety IR-64.

The highest puffing efficiency (89%), puffing capacity (45 Kg/h) and expansion ratio (346 %) were found in the optimized **treatment with 210 °C puffing temperature and 35 rpm cylinder speed. The benefit cost ratio was worked out to be 1.45.** These findings provide valuable insights for improving rice puffing efficiency and enhancing product quality in the food industry. The rice puffing machine is recommended for small-scale entrepreneurs and start-up businesses in the puffed rice industry.

REFERENCES

Anonymous, 2022-2023, www.usda.gov.in of United States Department of Agriculture Economics and Statistics, GOI.

Anonymous, 2022-2023, www.agmarket.gov.in of Ministry of Agriculture.

Anonymous, 2022-2023, (https://raitamitra.karnataka.gov.in) of Ministry of Agriculture, GOK.

AOAC, 1990, Official methods of analysis, 15th edition. *Association of official Analytical Chemists*, Arlington, VA.

AOAC, G., 2016, Official methods of analysis of AOAC International. Rockville, MD: AOAC International, ISBN: 978-0-935584-87-5.

Ashwini, M. V., Robinson, P. and Sameer, S., 2016, Design and fabrication of domestic puffed rice making machine. *International Journal of Engineering Research, Science, and Technology*, 5(8): 428-432.

Bhatt, H. K. and Joshi, D. C., 2014, Standardization of pretreatments for production of ready-to-puff Rice using microwave energy. *Journal of Grain Processing and Storage*, 1(2): 47-53.

Bhattacharyya, M. K. and Bhattacharyya, M., 2016, Development of an innovative eco-friendly rice puffing machine for modernizing a traditional cottage industry. *African Journal of Science, Technology, Innovation and Development*, 8(5): 371-376.

Biswal, S., Mohapatra, S. R. and Panda, M. K., 2017, Designing and development of a portable rice puffing machine. *International Journal of Latest Trends in Engineering and Technology*, 8(1): 140-147.

Chandrasekhar, P. R. and Chattopadhyay, P. K., 1991, Rice puffing in relation to its varietal characteristics and processing conditions. *Journal of Food Process Engineering*, 14(4): 261-277.

Kamaraddi, V. and Prakash, J., 2015, Assessment of suitability of selected rice varieties for production of expanded rice. *Cogent Food and Agriculture*, 1(1): 1112675.

Khaled M.H., Abd El Salam, Ahmed M., Shaalan, and Medhat A.E. El-Dalil M A., 2015, Popping properties of rice as influenced by cultivars, temperature and time of popping. *Alexenderia Exch.J. Food Properties*, 36(4): 358-363.

Kumar, L.A.L.I.T., Mishra, N., Patel, S., Khokhar, D. and Lakra, A.N.I.T.A., 2017, Rice puffing characteristics of some selected varieties. *Trends in Biosciences*, 10(30): 6263-6267.

Maisont, S. and Narkrugsa, W., 2009, Effects of some physicochemical properties of paddy rice varieties on puffing qualities by microwave "original". *Agriculture and Natural Resources*, 43(3): 566-575.

Marihonnappanavara, S., Jayraj, P., Nagaratna, P. and Ramappa, K.T., 2017, Performance Evaluation of Small-Scale Rice Puffing Machine. *International Journal of Current Microbiology and Applied Sciences.* 6(8): 3531-3536.

Mishra, G., Joshi, D.C. and Panda, B.K., 2014, Popping and puffing of cereal grains: a review. *Journal of grain processing and storage*, 1(2): 34-46.

Mohamad Gesudaraj, Udaykumar Nidoni, Vasudevan. S, N., Beladhadi, R. V., Sharangouda, H., 2012, unpublished Thesis. Development and performance evaluation of dehusker for foxtail millet. Department of PFE, CAE, UAS, Raichur.

Nagaratna, P., Poornima., Marihonappanavara, S. and Ramappa, K.T., 2017, Design and development of small-scale rice puffing machine *International Journal of Current*

Microbiology and Applied Sciences, 6(8): 2954-2961.

Parganiha, D., Patel, S., Naik, R.K., Khokhar, D., Mishra, N.K. and Pisalkar, P.S. (2022), Puffing characteristics of three test varieties of parboiled milled rice. Journal of Food Science and Technology, 59(1): 234-245.

Raviteja, G., Shrinivas, D., Ramappa, K. T. and Sharanagouda, H., 2015, Performance evaluation of manual and mechanical rice puffing machines. *International Journal of Agricultural Science and Research (IJASR),* 5(5): 333-342

Raviteja, G., Shrinivas, D., Ramappa, K. T. and Sharanagouda, H., 2015, Comparative study of manual and mechanical rice puffing methods. *International Journal of Agricultural Science and Research (IJASR),* 5(5): 209-216.

Swarnakar, A. K., Mohapatra, M. and Das, S. K., 2022, A review on processes, mechanisms, and quality influencing parameters for puffing and popping of grains. *Journal of Food Processing and Preservation*, 46(10): 16891.

Taheri, M. R. Y., Ghassemzadeh, H. R., Ranjbar, S. F., Vahed, M. M. and Gazor, H. R., 2017, Design construction and performance evaluation of an innovative hybrid fluidized bed-infrared chickpea roaster. *Biological Forum – An International Journal,*9(2): 92-101.

Tavanandi, H.A., Das, A.K., Venkateshmurthy, K. and Raghavarao, K. S. M. S., 2021, Design and development of a machine for continuous popping and puffing of grains. *Journal of Food Science and Technology*, *58*: 1703-1714.

Tiwari, V. K., Varsha, D. H. L. and Sharma., 2017, A note on the studies of physical properties of brown rice. *International Journal of Scientific Development and Research*. 2(1): 1-4.

Vengaiah, P. C., Srivastav, P. P. and Majumdar, G. C., 2015, Design related physical properties of major cereals. Research paper *Biosci is Journal of Global Biosciences*, *4*(1): 1910-1914.

Villareal, C. P. and Juliano, B. O., 1987, Varietal differences in quality characteristics of puffed rices. *Cereal Chem*, 64(4): 337-342.

Wani, I. A., Sogi, D. S., Wani, A. A. and Gill, B. S., 2017, Physical and cooking characteristics of some Indian kidney bean (Phaseolus vulgaris L.) cultivars. *Journal of the Saudi Society of Agricultural Sciences*, 16(1): 7-15.

Zubair, M. A., Rahman, M. S., Islam, M. S., Abedin, M. Z. and Sikder, M. A., 2015, A comparative study of the proximate composition of selected Rice varieties in Tangail, Bangladesh. *Journal of Environmental Science and Natural Resources*, 8(2): 97-102.