

# Optimization of Operational Parameters in a Cyclone Type Pneumatic Rice Polisher

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## Abstract

A pneumatic rice polishing system has been developed to minimize broken content ( $B_p$ ) and maximize the degree of polishing ( $D_p$ ). This polisher consists of a metallic cyclone coated with hard abrasive material, a blower, a collection system. Brown rice is feed vertically at the rate of 1.5 kg/min that flows towards the abrasive cyclone through horizontal air flow at 72.2 m/s. Experiments were carried out at different moisture content (M) and grit size of abrasive material (E) at fixed number of passes. Degree of polishing and broken content varied with both M and E. System showed  $D_p$  from  $4.224 \pm 0.02\%$  (13% M and 60 E) to  $13.250 \pm 0.56\%$  (12% M and 36 E) whereas  $B_p$  from  $2.146 \pm 0.14\%$  (10% M and 60 E) to  $49.717 \pm 2.64\%$  (13% M and 36 E). Effect of M and E and their square were found significant ( $p < 0.05$  and  $p < 0.01$ ) on  $D_p$  and  $B_p$ . Optimum values of  $D_p$  and  $B_p$  were achieved at 100 E and 11.70% M (wet basis) respectively with a value of 10.359% and 0.476%.

**Keywords:** Pneumatic polishing system; Degree of polishing; Broken content; Rice; Moisture content

**Abbreviations:** Cm: Centimeter; dia: Diameter; M: Meter; min: Minute; mm: Millimeter; S: Second; wb: Wet Basis

## Introduction

Rice (*Oryza sativa*) is the staple food of almost half of the world population. Asia accounts for 92% of world's rice production. India is the second largest rice growing country in the world [1]. Rice is the main source of nutrition for majority (65%) of people in India. Thus, rice milling becomes the largest agro-based industry in India. Polishing of brown rice is necessary to improve cooking quality, digestibility, and extension of storage period. Ideally, polishing should be within 5% to 6% of the weight of brown rice. However, commercially excessive polishing (10% to 12%) with removal of deeper starchy endosperm layer is a common practice because of consumer preference with white shiny grains. Most of the nutrients such as dietary fibers, essential amino acids, minerals, proteins and vitamins (B & E) present in the outer layers of the kernel and the germ are removed during polishing, which considerably reduces the nutritional value of rice. This result in loss of beneficial dietary fiber, large yields of broken (20% to 50%) and less oil content in the resultant bran mixed with starchy endosperm fraction [2]. Polishing is the most energy intensive operation among all other operations in rice milling process [3]. The major part of the supplied energy in polishing gets converted into heat energy; rises grain temperature significantly that leads to induce fissure development and ultimately cracking of the grain. Generally, two types of rice polishers are used—friction type and abrasion type. Friction type machines have metallic polishing rollers, which remove bran by inter-grain friction under relatively high pressure while the abrasion type polishers accomplish it by cutting of surface layers of grain by sharp edges of abrasive particles, such as carborundum, at relatively low pressure. Both operations involve high shearing action on the rice kernels under high pressure (5000-10000 Pa), involving inter-granular attrition and high rate friction with abrasive surface [4]. Large amount of the input energy to polishers is utilized for its moving parts to overcome friction and inertial forces, resulting high specific energy consumption. The moving parts of these heavy rollers also suffer excessive wear and tear that leads to high maintenance cost.

Prakash et al. [5] developed a horizontal abrasive pipe pneumatic rice polisher without any moving part and with negligible thermal and

compressive stresses, was found successful in carrying out control level of polishing of rice grains with yield of broken as low as 8.52% compared to 20% in laboratory abrasive polisher. Restriction of flow with the formation of dunes; large pressure drop with excessive friction in the pipe are some of the drawbacks of this system. To overcome this, a new technique of cyclone type pneumatic rice polishing system has been developed. In this new technique of rice polishing, the modification of cyclone separator has been tried. The inner surface of the cyclone separator is lined with abrasive surface (Caborundum grit size 100, 60 and 36, Concord, India). Mixture of air and rice particles enters tangentially into the system near the top of the cylindrical section. The grains follow swirling path inside the polisher and come in contact with the hard-abrasive emery surface and get polished. The mixture of bran and milled rice was collected at the bottom of the polisher. The inlet air velocity and feed rate were maintained at 72.2 m/s and 1.5 kg/min respectively. Abrasion under moderate pressure results in effective polishing of grains under low mechanical and thermal stress. Absence of moving part might be beneficial also to reduce breakage percentage of kernels. The present study is aimed to optimize the moisture content of brown rice and type of abrasive surface for maximizing the degree of polishing with minimum broken content.

## Materials and Methods

### Pneumatic rice polishing system

The improved pneumatic rice polishing system consisted of no moving part. Basically, it comprised of two parts - an upper cylindrical part and a conical bottom part; similar to that of a cyclone separator as shown in Figure 1. In the present study, a system having diameter of

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**Figure 1:** Laboratory pneumatic rice polishing systems.



**Figure 2:** Picture showing (a) Paddy (b) brown rice (c) polished rice.

the cylinder and height of the polisher as 0.2 m and 1.06 m respectively was selected. The cylindrical part consisted of an inlet port (feed inlet) provided with 180° scroll. This facilitated two-phase tangential flow of air and brown rice at the entry. The inside surface of the polisher was layered with three grades of hard abrasive particles (Concord, India). These were categorized as fine (FN), medium (MD) and coarse (CR) depending upon their grit sizes as commonly expressed in industry; like 100, 60 and 36, respectively. Corresponding average particle dimension were 122, 254 and 483  $\mu\text{m}$ . Air velocity of  $30 \text{ m s}^{-1}$  was used. This flow rate was adequate for generating high centrifugal force on the rice grains (terminal velocity of rice is around  $6.0 \text{ ms}^{-1}$ ) for its movement along the abrasive surface. The final stream of bran and polished rice mixture at the outlet passes through the bran separator where bran particles escape through the perforations and deposited in the outer chamber of the cylinder. Partially polished rice is collected at the bottom of the system. Due to less residence time of rice inside the polisher, required degree of polishing cannot be achieved in a single pass. The collected rice was recycled for 60 times and the broken content and degree of polishing was measured after every 10 passes. The air escaped at the top and carried very fine bran particles with it. Experiments were conducted with brown rice of 10, 11, 12, and 13% (wb) moisture content.

## Raw materials

To ascertain uniformity in polishing of grains, visual examination was the first choice. For this study, "Annapurna" a pigmented variety of paddy, was procured from Hatigeria village (Kharagpur, West Bengal). These variety exhibit a whitish endosperm covered with 10.5% purple color bran (Figure 2 shows the picture of paddy, kernel, and polished kernel). So, the changes of color (purple to white) due to removal of bran can be easily ascertained qualitatively by visual inspection. The paddy was procured with initial moisture content around 11.62% (wb) and dried with conventional sun drying method up to moisture content of 10.35% (wb) before de-husking it (Figure 1).

For de-husking the paddy, a laboratory rubber roll sheller (Satake

Corporation, Model THU35A, Japan) was used. For using the whole kernels for polishing with the developed polisher, broken kernels were separated from brown rice by using laboratory grader (Burrows equipment Company, Illinois, USA) (Figure 2).

## Preparation of pre-conditioned rice (Hydration or dehydration)

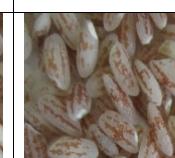
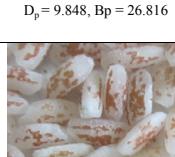
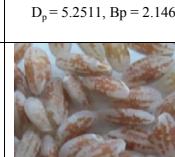
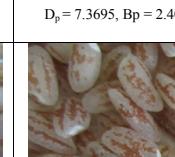
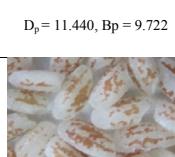
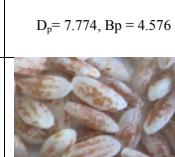
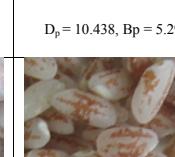
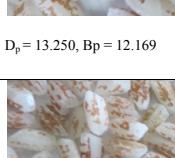
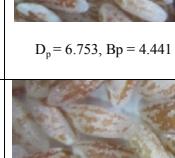
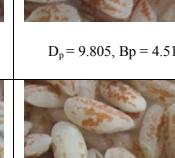
The polishing operations were designed to perform at different wet basis moisture levels (10, 11, 12 and 13). The initial moisture content of the sample was determined by using air oven method [2]. About 5 g brown rice were taken and kept in a hot air oven maintained at  $105 \pm 10^\circ\text{C}$  for 24 h, the moisture content,  $11.82 \pm 0.09\%$  (wb) was determined gravimetrically by mean of four replications. Brown rice with desired moisture levels was obtained by the following procedure.

**Decreasing moisture content (Dehydration):** A lump of silica gel was placed inside a hot air oven maintained at  $90^\circ\text{C}$  up to an extent until the color become dark blue. The completely moisture free silica gel was filled up to the screen glass desiccator. A known quantity of brown rice was then kept inside the desiccator. The sample was then weighed periodically until the silica gel absorbed the excess moisture.

**Increasing of moisture content (Hydration):** A bottom of the desiccator was filled with water up to 2-3 cm below the screen. A known quantity of brown rice was then spread uniformly over the screen fitted at the middle of the desiccator. Weight of the grain was then taken periodically until the grain absorbed the desired moisture.

## Polishing of rice with the pneumatic polishing system

Each experiment was carried out with 180 g brown rice at 10%, 11%, 12% and 13% moisture content. Only whole kernels were taken for polishing as stated above. The grains were fed into the system from the hopper. The grains, collected carefully were recycled 60 times. After 60 recycling of grains (pass), the degree of polishing was evaluated gravimetrically. To study the effect of abrasive material of abrasive cyclone on degree of polishing and yield of broken, experiment was

M, % wb	Coarse Emery	Medium Emery	Fine Emery
10 ± 0.15			
11 ± 0.15			
12 ± 0.15			
13 ± 0.15			

**Figure 3:** Surface view of rice after polishing (60 passes) at different moisture content using different emery grit size.

carried out with 3 different abrasive material (36E (Coarse Emery), 60E (Medium Emery) and 100E (Fine Emery)), degree of polishing was determined for samples after 60 passes as stated above. After 60 passes, broken rice was separated from the sample using laboratory grader, and total breakage of kernels was estimated gravimetrically.

#### Estimation of degree of polishing

Gravimetric method Juliano and Bechtel [6] was adopted for measuring the degree of polishing. An accurately weighed amount of the sample was subjected to polishing operation. After each experiment the milled rice samples were aspirated by using a laboratory aspirator (Bates Aspirator, USA) out to remove any adhering bran sticking to sample surface followed by weighting it using electronic balance (Sartorius, Model BT 323 S, accuracy 0.001 g) and change of weight was recorded to calculate the degree of polishing,  $D_p$  using Eq. (1).

$$D.O.M. (\%) = \left( \frac{w}{W_i} \right) \times 100 \quad (1)$$

Where,  $w$  and  $W_i$  are weight of removed bran after 60 passes and initial weight of brown rice respectively.

#### Estimation of broken content (%)

In each set of experiment with varying moisture content and grit size of abrasive material, broken content was determined after 60 passes. After 60 passes, the polished rice put on the laboratory grader to separate broken kernels. Both these streams were collected, weighted and  $B_p$  was estimated from Eq. (2).

$$\text{Broken Content: } B_p = \left( \frac{w_{blk}}{W_i} \right) \times 100 \quad (2)$$

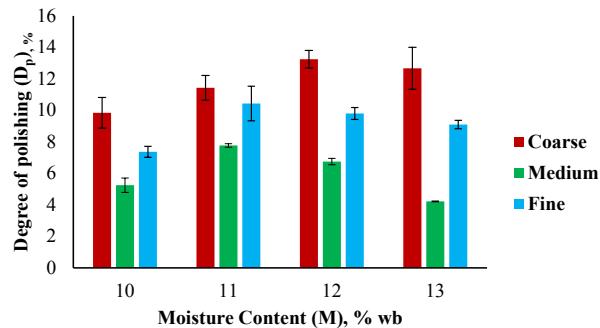
A designated program (Design Expert 7.0) was used to obtain regression equation correlating independent and dependent parameters. The significant terms in the model were determined by analysis of variance (ANOVA) for each of the response parameters. The goodness of fit was evaluated with several statistical parameters like probability of failure ( $P$ ), adjusted  $R^2$ , predicted  $R^2$ , predicted error sum of squares (PRESS) and adequate precision. A good model should have large predicted  $R^2$  and a low PRESS.

#### Optimization of the process parameters

For optimization of process parameters, experiments were conducted using three levels of emery paper, four level of moisture content at fixed number of passes (60). The general factorial option for experiment design was applied for optimizing the process in Design Expert 7 software (Design expert version 7.0.0, Stat {Ease INC., 2009, USA}). The number of distinct combinations of the experiments was worked out to be 12 (with replication it was 36). Twelve combinations came for each level of emery paper combination with moisture content. To find out the effect of independent variable (X) on dependent variable (response, Y), the following quadratic regression equation (model) was fitted.

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_{12} X_1 X_2 + b_{11} X_1^2 + b_{22} X_2^2 \quad (3)$$

Optimization of independent parameters, moisture level (M), and emery paper (coarse, medium, and fine) was carried out for maximization of degree of polishing and minimizing of percentage of broken. Optimum conditions were finally selected considering the feasibility of moisture content and grade of emery paper following the desirability function approach which is one of the most widely used



**Figure 4:** Degree of polishing at different moisture content using different emery grit size.

For each response,  $Y_i(x)$  a desirability function  $d_i(Y_i)$  assigns numbers between 0 (completely undesirable) and 1 (completely desirable or ideal response value). Based on desirability function of each of the parameters involved [ $d_i(Y_i)$ ], the overall desirability ( $D$ ) was obtained from geometric mean of the individual desirability as:

$$D = [d_1(Y_1) \times d_2(Y_2) \dots \times d_k(Y_k)]^{1/k} \quad (4)$$

Where,  $k$  denotes the number of responses. The designated software (Design Expert 7) was employed for optimization of parameters.

## Results and Discussion

Figure 3 shows the image of polished rice at different moisture content after 60 passes in a pneumatic polisher with different abrasive surfaces. Visual assessment with all these samples reveals that the rice kernels were polished uniformly with all the moisture content and emery papers. Figures 4 and 5 shows the variation of  $D_p$  after 60 passes for different moisture content and grit size of emery. Changes of  $D_p$  were found to vary with moisture content and grit size of emery paper.  $D_p$  was found to vary from  $4.224 \pm 0.02\%$  (13% M and Medium emery) to  $13.250 \pm 0.56\%$  (12% M and Coarse emery). Figures 6 and 7 show the variation of  $B_p$  after 60 passes for different moisture content and grit size of emery. Changes of  $B_p$  were found to vary with moisture content and grit size of emery paper.  $D_p$  was found to vary from  $2.146 \pm 0.14\%$  (10% M and Medium emery) to  $49.717 \pm 2.64\%$  (13% M and Coarse emery).

## Analysis of quality parameters of polished rice

From the foregoing discussion, it is apparent that both degree of polishing and broken percentage are affected by the combined effects of moisture content brown rice and grit size of abrasive materials. This will lead to obtaining an optimum condition for maximizing the effects. The correlation between moisture content (M) and polishing characteristics are shown in Table 1.

**Degree of polishing:** Analysis of variance for this regression equation showed close agreement between adjusted  $R^2$  and predicted  $R^2$  (0.8628 and 0.8124) with the estimated values of coefficient of  $R^2$  and the coefficient of variance (C.V.) are 0.8794 and 11.81% respectively. This indicates that the regression equation fits best with the experimental results. Further all the linear terms, M and E significant at  $p < 0.05$  and  $M^2$  and  $E^2$  significant at  $p < 0.01$  on degree of polishing. A generalized regression equation for  $D_p$  (Eq. (5)) has been obtained using specific software (Design Expert 7.0) (Figures 6 and 7).

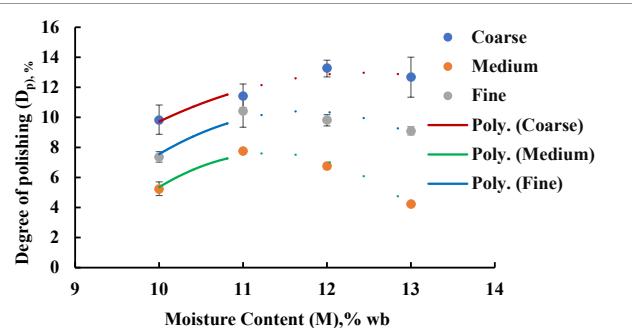
$$D_p = -92.73317 - 0.72355 \times E + 21.41956 \times M + 5.01878 \times 10^{-3} E^2 - 0.91569 \times M^2 \quad (5)$$

Figure 8 shows the response surface plot for degree of polishing as a function of moisture content and emery grit size. Degree of polishing changed with both moisture content and emery grit size where it increased from 10 to 12% moisture content and then decreased at 13% moisture content (Table 2).

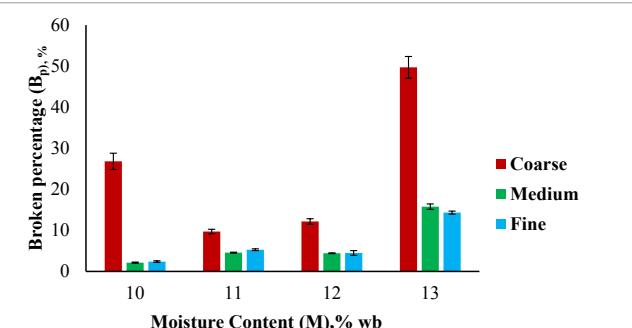
Emery	Degree of Polishing ( $D_p$ )	Broken Content ( $B_p$ )
Coarse	$D_p = 0.541M^2 + 13.489M - 71.001$ $R^2 = 0.9502$	$B_p = 8.0025M^2 - 183.73M + 1063.5$ $R^2 = 0.9904$
Medium	$D_p = 1.2629M^2 + 28.637M - 154.73$ $R^2 = 0.972$	$B_p = 2.2294M^2 - 47.198M + 251.88$ $R^2 = 0.9126$
Fine	$D_p = 0.9425M^2 + 22.134M - 119.54$ $R^2 = 0.8745$	$B_p = 1.7335M^2 - 36.368M + 193.45$ $R^2 = 0.8776$

$R^2$  = Coefficient of determination

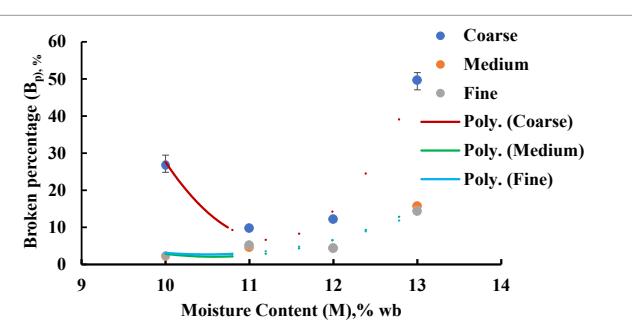
**Table 1:** Relationship between moisture content (M) and polishing characteristics.



**Figure 5:** Effect of moisture content and emery grit size on degree of polishing.

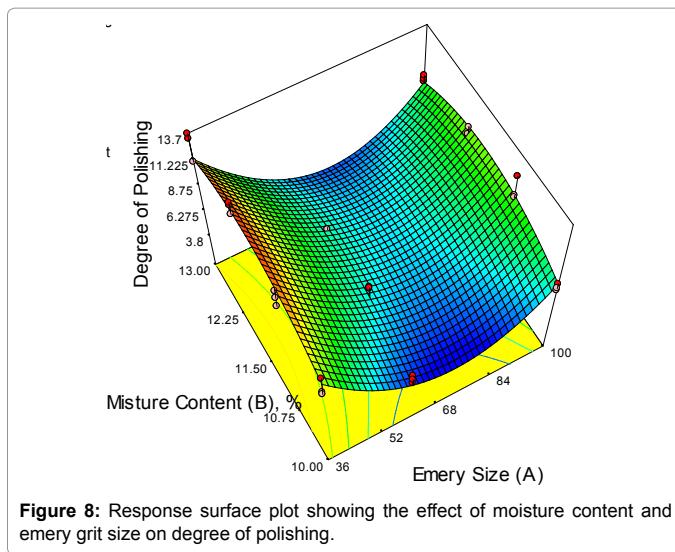


**Figure 6:** Broken percentage at different moisture content using different emery grit size.

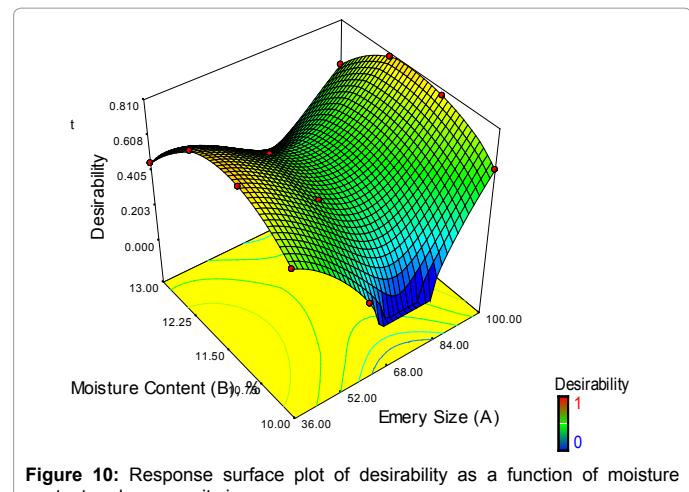


**Figure 7:** Effect of moisture content and emery grit size on broken content of brown rice.

industry methods for the optimization of multiple response processes. The method finds operating conditions (x) that provide the "most desirable" response



**Figure 8:** Response surface plot showing the effect of moisture content and emery grit size on degree of polishing.

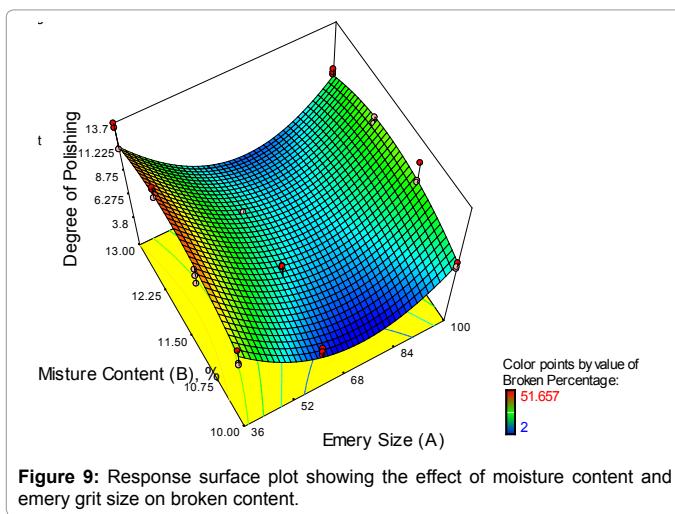


**Figure 10:** Response surface plot of desirability as a function of moisture content and emery grit size.

Source	Sum of Squares	D <sub>f</sub>	Mean Square	F-value	p-value
Model	238.7	5	59.64	52.87	0.0001
E*	41.31	1	41.31	36.62	0.0001
M**	5.76	1	5.79	5.13	0.0312
E2*	181.92	1	181.92	161.25	0.0001
M2*	30.19	1	30.19	26.76	0.0001

R<sup>2</sup> = 0.8794, R<sup>2</sup>(adjusted) = 0.8628 and R<sup>2</sup>(predicted) = 0.8124 \*Significant at p<0.01%, \*\*significant at p<0.05

**Table 2:** Analysis of variance (ANOVA) for degree of polishing.



**Figure 9:** Response surface plot showing the effect of moisture content and emery grit size on broken content.

Source	Sum of Squares	d <sub>f</sub>	Mean Square	F Value	p-value
Model	4891	4	1222.75	26.75	0.0001
E*	1937.74	1	1937.74	42.38	0.0001
M*	1097.77	1	1079.77	23.62	0.0001
E2*	971.13	1	971.13	21.24	0.0001
M2*	1241.86	1	1241.86	27.16	0.0001

R<sup>2</sup> = 0.7867, R<sup>2</sup>(adjusted) = 0.7573 and R<sup>2</sup>(predicted) = 0.6701 \*Significant at p<0.01%,

**Table 3:** Analysis of variance (ANOVA) for broken content.

Number	E, grit	M, % wb	B <sub>P</sub> , %	D <sub>P</sub> , %	Desirability
1	100	11.70	0.476	10.359	0.806
2	100	11.68	0.343	10.359	0.806
3	36	11.32	16.578	12.854	0.803
4	36	11.39	16.785	12.895	0.803

**Table 4:** Optimization value of moisture content and emery grit size.

**Broken content:** Analysis of variance for this regression equation showed close agreement between adjusted R<sup>2</sup> and predicted R<sup>2</sup> (0.7573 and 0.6701) with the estimated values of coefficient of R<sup>2</sup> and the coefficient of variance (C.V.) are 0.7876 and 53.40% respectively. This indicates that the regression equation fits best with the experimental results. Further all the linear terms, M and E and M<sup>2</sup> and E<sup>2</sup> significant at p < 0.01 on broken content. A generalized regression equation for B<sub>P</sub> (Eq. (6)) has been obtained using specific software (Design Expert 7.0)

$$B_P = 789.53708 - 1.85782 \times E - 130.18820 \times M + 0.011596 \times E + 5.87333 \times M^2 \quad (6)$$

Figure 9 shows the response surface plot for broken content as a function of moisture content and emery grit size. Broken content changed with the increase of moisture content and decrease of emery grit size. Brocen content changed rapidly from 12% to 13% moisture content (Table 3).

### Optimization of pneumatic polishing of rice

Neumatical optimization of the above Eqs. (3) and (4) were carried out using a designated software programme (Design Expert 7) as stated in the previous section. The response criteria for optimization were chosen for maximization of degree of polishing and minimization broken content. On the basis of highest desirability value of 0.806, the optimized values of independent parameters A and B were 100 and 11.70. Which gave broken content 0.4755% while degree of polishing 10.3588% (Figure 10) (Table 4).

### Conclusion

The developed pneumatic rice polishing system was found to give uniform polishing and yielded less breakage compared to abrasive polishers (D<sub>P</sub> ≈ 10% causes around 20% B<sub>P</sub>; Model TM 05, Japan) currently used. Linear increasing trend of degree of polish with moisture content reveals possibility of this system with higher grit size. However, energy consumption needs to be evaluated with further study

## References

1. FAO (2014) Food and Agriculture Organization: Statistical Data base. Rome.
2. AOAC (2005) Official methods of analysis. (18th edn), Association of Official Analytical Chemists Inc, Washington DC.
3. Mohapatra D, Bal S (2010) Optimization of polishing conditions for long grain basmati rice in a laboratory abrasive mill. *Food Bioprocess Technol* 3: 466-472.
4. Satake RS (1994) New methods and equipment for processing rice. Rice Science and Technology, New York, USA.
5. Prakas KS, Someswararao CH, Das SK (2014) Pneumatic polishing of rice in a horizontal abrasive pipe: A new approach in rice polishing. *Innovative Food Sci Emerg Technol* 22: 175-179.
6. Juliano BO, Bechtel DB (1985) The rice grain and its gross composition. Rice: Chemistry and technology, American Association of Cereal Chemists, St. Paul Minnesota, USA pp: 17-50.