Milling Study of Multiple Pulses Using CIAE Dhal Mill for Optimal Responses

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Abstract

Generally many numbers of experimental trials are under taken for milling study of various pulses for getting optimum responses. However, optimization of machine parameters greatly over come the numbers of trials apart from maximizing the out put of the system. The independent milling parameters of CIAE (Central Institute of Agricultural Engineering Bhopal, India) dhal mill were roller speed, emery grit size and feed rates. These parameters were optimized for pigeon pea, chickpea and green gram dehulling using response surface methodology (RSM) and Central Composite Rotatable design (CCRD). The roller peripheral speed of 10 m/s, emery grit size 0.3 mm and feed rate 101.60 kg/h were found optimal. The maximum pulse recovery on the optimized independent parameters was found for pigeon pea (76.36% against 77.04% predicted) followed by chickpea (73.80% against 73.06% predicted) and green gram (71.25% against 69.82% predicted). The maximum milling efficiency on optimal machine parameters was observed in pigeon pea (83.0% against 82.79% predicted) followed by chickpea (74.8% against 75.53% predicted) and green gram (78% against 78.24% predicted).

Keywords: Pigeon pea; Chick pea; Green gram; Milling efficiency; Pulse recovery; Emery grit size; Response surface methodology; Central composite rotatable design

Nomenclature: a1, a2, a3, a4, a5, a6, a7: Regression coefficients; d1: Content of crushed kernels after hulling; d2: Content of crushed kernels before huling; E1: Effectiveness of huling; E2: Effectiveness of wholeness of kernels; k1: Amount of whole kernels before huling; m1: Content of mealy waste in the product before huling; m2: Content of mealy waste in the product after huling; n1: Amount of unhulled grains before huling; n2: Amount of unhulled grains after huling; N: Total number of experiments; r1: Pulse recovery; r2: Pulse recovery of pigeon pea; r3: Pulse recovery of chickpea; r4: Pulse recovery of green gram; x1, x2, x3, x5: Coded values of the independent variables X1, X2, and X3 respectively; Y1: Experimental value of responses; Yp: Predicted value of the responses from the developed models; γ: Milling efficiency; γp: Milling efficiency of pigeon pea; γc: Milling efficiency of chickpea; γg: Milling efficiency of green gram; CIAE: Central Institute of Agricultural Engineering, Bhopal, India

Introduction

India is the largest pulse producer in the world. Pulses along with cereals play a vital role in human nutrition [1]. Grain legumes such as Pigeon pea (Cajanus cajan), Chickpea (Cicer arietinum) and green gram (Phaseolus aureus) are commonly used as pulses in the Indian sub-continent. Pulses are also referred to as a source of “Poor man’s Protein”. It is more popular in vegetarian diet especially for the poor socio-economic group. The Annual production of pulses in the world in 2006-2007 is 54.4 million tonnes and in India is around 13.2 million tonnes from 22.5 x 106 ha area [2]. India ranks first by contributing about 22.52% to the global pulse production and 35.2% area of global production [2]. The per capita availability of pulses was around 35g as against the requirement of 70g per day for an optimal diet [3]. Chickpea and pigeon pea account for about 80% of total production and 7.5% of area under cultivation. Among pulses, chickpea is the most popular principal crop, contributing roughly 40% of production of total pulses in India followed by pigeon pea and green gram [4].

In India, about 80% of the pulse production is consumed in the form of dal or powder, and remaining 20% as the whole seed and other forms [5]. Whole pulses are milled into split dalh by various method/Process. The recovery of dhal varies from 60 to 75%, depending upon the type of pulses and techniques adopted by the millers such as methods of pretreatment and milling machinery used [3,5]. Generally, the husk is tightly attached to the cotyledons in pulses [7]. In most pulses husk are attached with cotyledons through a layer of gums [8]. Hence, a pre-treatment for loosening of the husk prior to milling is desirable as it increases the recovery of dal [9-11]. Erskine [12] studied effect of seed size and different pre-treatments on splitting and dehulling of lentil (Lens culinaris) and reported that dehulling efficiency was highest with low seed moisture content. Kurien [13] reported that dehulling of pigeon pea can be rendered easier by prolonged soaking in water for 12h or more, but the dal so obtained remains uncooked and tough even with prolonged boiling. The maximum dehulling efficiency for pigeon pea was obtained at 10.1% moisture content (db), dehulling time 12.3s and mustered oil treatment 0.3% [Goyal et al. 2008]. Tiwari [1] studied application of oil and subsequent heating of black gram as a premilling treatment on the removal of husk and observed that 85% of dehusking was obtained at 0.8% oil and at drying temperature of 90°C.

Dehulling is the most important operation of post harvest handling of pulses. The removal of seed coat is very important because it is indigestible and bitter. At present, loss of about 10-12%, edible portion takes place during milling operation due to improper milling practices, uncontrolled operational parameters and lack of knowledge about the appropriate emery/carborundum grit size for different pulses and operations [5,10,11]. Ehiwe [14] studied the dehulling quality of cowpea, pigeon pea, and green gram cultivars with the tangential abrasive dehulling device and reported that seed size was the most important factor affecting the dehulling process. Seed size affected both

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efficiency of dehulling and splitting of cotyledons. Dehulling efficiency was negatively and significantly correlated with seed size in green gram and cowpea. Some work has been done in identification of emery/carborundum grade and few tried for milling studies [6,10,11]. Other researchers have worked on the optimization of process parameter for milling of various pulses [1,15]. Response surface methodology has been employed for the optimization of pulse milling operation [16-18]. The present study was there fore under taken to optimize machine parameter for the CIAE dal mill for dehulling of different pulses namely pigeon pea, chickpea and green gram.

Materials and Methods

Raw material

Three pulses namely pigeon pea variety - ICPL-87 (Cajanus cajan), chickpea, JG-351 (Cicer arietinum) and green gram, K-851 (Phaseolus aureus) were obtained from CIAE farm/commercial sources.

Machine

The CIAE dal mill with over all dimensions of 770mm x 630mm x 1020mm, total weight 90kg (without motor). capacity 100kg/h, power unit 2hp electric motor, labour requirement two (one to operate and other to load/unload grains) was used for all the milling studies. It consists of a feed hopper, feed screw, shaft, pulley, frame and abrasive roller cylinder. The abrasive roller rotated inside the perforated screen cage. Dehulling took place due to friction between grain and abrasive surface. Scratching of raw grain and milling of pre-treated grains was also done in the same mill [6,10,11].

Fabrication of carborundum roller

The roller was a main component in CIAE dal mill and basically consisted of a cylinder of 2mm thick mild steel, 250mm diameter with 10 mm mild steel end plates. It was coated first with emery of grade No: 30 by mixing of two parts (by volume) of emery and one part of special cement (Magnesium oxide, MgO) with hot salted water prepared into a paste of desired consistency and then pasted in the roller. Finally, it was coated with a working outer layer of desired carborundum grits, which were thoroughly mixed with white cement and magnesium chloride salt in a proportion of 6:1. Separate roller was made for each grit size.

Pre-treatments methods

The CIAE pre milling treatment methods was used for the milling study [10,11] and the details is given in Figure 1. The experiments were conducted at different moisture content of 9-10% (db) (Sahay et al., 1985; 6,10,11, Goyal et al, 2008).

Drying

The pre-treated pulses was dried in open sunlight to a desired moisture content of 9-10% (db) (Sahay et al., 1985; 6,10,11, Goyal et al, 2008).

Design of experiment

Central composite rotatable design: (CCRD) Fractional factorial experiment design with three independent machine parameters viz., $X_1$ (peripheral speed of the roller), $X_2$ (emery grit size) and $X_3$ (feed rate) were finally considered from a total number of 20 experiments [22]. The independe parameters were developed and machine parameters were optimized for maximizing the $r_{cp}$, $γ_{cp}$, $γ_{gg}$ and $γ_{mg}$ using design expert 7.0.0

$$Y_p = a_0 + a_1 \times X_1 + a_2 \times X_2 + a_3 \times X_3 + a_11 \times X_1^2 + a_{22} \times X_2^2 + a_{33} \times X_3^2 + a_{12} \times X_1 \times X_2 + a_{23} \times X_2 \times X_3 + a_{13} \times X_1 \times X_3$$

(1)

The independent variables were fixed at five levels as per CCRD type experimental design and a total number of 20 experiments were carried out as evident from the Table 1. The experiments were conducted in random order. Five repeated experiments were conducted at the central points of the coded variables to calculate the error sum of squares and the lack of fit of the developed regression equation between the responses and independent variables [22].

Milling operation: The experiments were conducted at different roller speed, feed rates and were repeated for all the three pulses and with different grade of carborundum rollers and the samples of milled product were taken for determination of pulse recovery and dehulling.
efficiency. The milling efficiency was calculated as per the following formula given by Kuprits [23].

\[ \gamma = \frac{E_{a} \times E_{w}}{n} \times 100 \]  

(2)

\[ E_{h} = 1 - \frac{n}{n_{1}} \]  

(3)

\[ E_{wk} = \frac{\left(k_{2} - k_{1}\right)}{\left(k_{2} - k_{1}\right) + \left(d_{2} - d_{1}\right) + \left(m_{2} - m_{1}\right)} \]  

(4)

Results and Discussion

Response surface analysis was applied to the experimental data (Table 1) and the second order polynomial response surface model (Equations 5-10) was fitted to each of the response variable \( r_{pp}, \gamma_{cp}, \gamma_{gg}, \gamma_{pp}, r_{pp}, r_{pp}, r_{pp} \), and \( \gamma_{pp} \). Regression analysis and ANOVA were conducted for fitting the model and to examine the statistical significance of the model terms. The estimated regression coefficients of the quadratic polynomial models for the response variables, along with the corresponding R² and coefficient of variation (CV) values are given in Table 2. Analysis of variance showed that all the models were significant (p<0.05) for all the responses (Table 2). The lack of fit (Table 2), which measures the fitness of the model, did not result in a significant F-value in case of pigeon pea, chickpea and green gram pulse recovery and efficiencies, indicating that these models are sufficiently accurate for predicting those responses. The coefficient of determination (R²) values

* The value shown in the brackets are coded values of respective independent variables. The method of conversion from coded to actual value can be seen from Singh et al., 2008

Table 1: Treatment combinations for pulse milling with three variable second order RSM design.

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<th>Exp. No.</th>
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<th>( e_{pp} ) (mm)</th>
<th>( f_{r} ) (kg/h)</th>
<th>( r_{pp} ) (%)</th>
<th>( \gamma_{cp} ) (%)</th>
<th>( \gamma_{gg} ) (%)</th>
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* Significant at p < 0.05; ** Significant at p < 0.01; ***Significant at p < 0.001

Table 2: Analysis of Variance (ANOVA) and regression coefficients of the second-order polynomial model for the response variables (in coded units).
of all responses are sufficiently (>0.60) explained by the data and the RSM models were adequate (Table 2). As a general rule, the coefficient of variation (CV) should not be greater than 10%. In this study, the coefficients of variation were less than 10% for all the responses (Table 2), a relatively lower value of the coefficient of variation indicates better precision and reliability of the experiments carried out.

Pigeon pea pulse recovery

It was observed from ANOVA (Table 2) that roller peripheral speed, emery grit size and feed rate are not significantly affecting the pulse recovery of pigeon pea at linear level (p ≥ 0.05) while, quadratic term of roller peripheral speed is more significant (p ≤ .01) parameter affecting the pulse recovery of pigeon pea. Figure 2 shows that at fixed value of emery grit size (2.21mm), the pulse recovery of pigeon pea \((r_{pp})\) gradually increased with roller speed upto 10.47m/s and reduced thereafter. Similarly with increase of feed rate it is decreased gradually. At fixed value of roller speed (10.60m/s) the pulse recovery decreased with feed rate upto 105.95kg/h and increased there after upto 111.89

![Figure 2: Response surface and contours plots for pulse recovery of pigeon pea as a function of roller speed, emery grit size and federate. For each plots, the third machine parameter is fixed at ‘0’ level.](image)

![Figure 3: Response surface and contours plots for milling efficiency of pigeon pea as a function of roller speed, emery grit size and federate. For each plots, the third machine parameter is fixed at ‘0’ level.](image)
kg/h. Similarly the maximum pulse recovery was observed at 1 mm grit size and decreased thereafter. At fixed feed rate (102.25kg/h), the pulse recovery increased with roller speed up to 10.47 m/s and decreased thereafter up to 12.03 m/s at all emery grit size. The pigeon pea pulse recovery was found to be maximum at roller speed 10.6 m/s, emery grit size 2.21 mm and feed rate 102.25kg/h. The second order polynomial equation for pigeon pea pulse recovery is shown in equation 5 as follows.

\[ p_{pp} = 73.94 - 0.52x_1 - 0.96x_2 - 0.86x_3 - 2.12x_1^2 + 0.53x_2^2 + 0.23x_3^2 + 1.09x_1x_2 + 0.16x_1x_3 + 0.36x_2x_3 \]  

(5)

Figure 4: Response surface and contours plots for milling efficiency of pigeon pea as a function of roller speed, emery grit size and federate. For each plots, the third machine parameter is fixed at ‘0’ level.

**Pigeon pea milling efficiency**

The quadratic term of roller peripheral speed and interaction term of roller speed and emery grit size are more significant (p ≤ .01) parameter affecting the milling efficiency of pigeon pea (γ\(_{pp}\)) (Table 2). Figure 3 a shows that at fixed value of emery grit size (2.21 mm), the milling efficiency of pigeon pea (γ\(_{pp}\)) gradually increased with roller speed up to 11.25 m/s and reduced thereafter up to 12.03 m/s. Similarly with increase of feed rate it is increased up to 105.95 kg/h and reduced...
thereafter. At fixed value of roller speed (10.47 m/s) milling efficiency gradually decreased with feed rate up to 105.95 kg/h and increased thereafter up to 111.89 kg/h (Figure 3b). Similarly the maximum milling efficiency was observed at 1 mm grit size and decreased there after. At fixed feed rate (100.64 kg/h), the milling efficiency was maximum at roller speed of 8.91 m/s and decreased thereafter up to 12.03 m/s at grit size 1 mm (Figure 3c). However the reverse effect was observed at emery grit size of 3.42. The pigeon pea milling efficiency was found to be maximum at roller speed 10.47 m/s, emery grit size 2.21 mm and feed rate 100.64 kg/h. The second order polynomial equation for milling efficiency of pigeon pea is shown in equation 6.

$$\eta_{pp} = 79.24 - 0.08x_1 - 0.95x_2 - 0.59x_3 - 1.57x_1^2 + 0.62x_2^2 + 0.51x_3^2 + 2.34x_1x_2 + 1.29x_1x_3 - 0.54x_2x_3$$

(6)

Chick pea pulse recovery

From ANOVA (Table 2) it was revealed that the quadratic term of roller peripheral speed is highly significant (p ≤ .001) parameter affecting the pulse recovery of chickpea. Figure 4 shows that at fixed value of emery grit size (2.21 mm), the pulse recovery of chickpea (r_p) gradually increased with roller speed up to 10.47 m/s and reduced thereafter up to 12.03 m/s (Figure 4a). Similarly with increase of feed rate pulse recovery decreased slightly and increases gradually thereafter (Figure 4b). At fixed value of roller speed (10.60) the pulse recovery

Figure 6: Response surface and contours plots for pulse recovery of green gram as a function of roller speed, emery grit size and feed rate. For each plots, the third machine parameter is fixed at ‘0’ level.

Figure 7: Response surface and contours plots for milling efficiency of green gram as a function of roller speed, emery grit size and feed rate. For each plots, the third machine parameter is fixed at ‘0’ level.
Green gram pulse recovery

It was observed from Table 2 that roller peripheral speed, emery grit size and feed rate are not significantly affecting the pulse recovery of pigeon pea at linear level (p ≥ 0.05) while, quadratic term of roller peripheral speed is significant (p ≤ 0.01) parameter affecting the pulse recovery of green gram. At fixed value of emery grit size (2.21 mm), the pulse recovery of green gram (r_{pg}) gradually increased with roller speed upto 12.03 m/s and decreased thereafter at all feed rate (Figure 6a). Similarly, at fixed value of roller speed (10.47 m/s) the pulse recovery gradually decreased with feed rate from 88.11 to 111.89 kg/h and increased thereafter upto all grit size (Figure 6b). At fixed feed rate (100 kg/h), the pulse recovery increased with roller speed upto 10.47 m/s and reduced thereafter at all emery grit size. The green gram pulse recovery was found to be maximum at roller speed 10.47 m/s, emery grit size 2.21 mm and federate 100 kg/h. The second order polynomial regression equation for green gram pulse recovery is given in equation 9.

\[ r_{pg} = 70.75 - 0.93x_1 - 0.70x_2 - 2.50x_1^2 + 0.19x_2^2 + 1.17x_1x_2 + 0.38x_1x_3 + 0.12x_2x_3 \]

(9)

Roller speed, m/s

Feed rate, kg/h

Emery grid size, mm

Overlay Plot

Figure 6: Optimization of independent parameters of CIAE pulse mill.
Table 3: Solutions for optimum conditions.

<table>
<thead>
<tr>
<th>Number</th>
<th>(d_p) (m/s)</th>
<th>(d_m) (mm)</th>
<th>(f) (kg/h)</th>
<th>(\gamma_p) (%)</th>
<th>(r_p) (%)</th>
<th>(\gamma_{pp}) (%)</th>
<th>(r_{pp}) (%)</th>
<th>(\gamma_{gg}) (%)</th>
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Optimization of machine parameters for development of appropriate milling machine

The pulse recovery (\(r\), kg/h) and milling efficiency (\(\gamma\),%) for pigeon pea, chickpea and green gram were taken as response in order to optimize the machine parameters. The optimization was carried out using response surface methodology (Design Expert 7.0). The optimize value of roller peripheral speed, emery grit size and feed rate were taken in CIAE pulse mill for further study. Numerical (Table 1) and graphical optimization (Figure 8) was carried out for obtaining the appropriate design parameter of the machine for obtaining optimum pulse recovery and efficiency of pigeon pea, chickpea and green gram. Design expert program of the STAT-EASE software was utilized (Design Expert 7.0.0) for simultaneous optimization of the multiple regressions and responses were chosen and different weights assigned to each goal to adjust the shape of its particular desirability function. Table 3 shows the software generated optimum conditions of independent variables with the predicted value of responses. Solution No. 1 was selected as the optimum condition of CIAE pulse mill.

Conclusions

The roller peripheral speed of 10m/s, emery grit size 0.3mm and feed rate 101.60kg/h were found optimal for CIAE pulse mill for higher pulse recovery and milling efficiency of pulses. The maximum pulse recovery on the optimized independent parameters was found with pigeon pea (76.36% against 77.04% predicted) followed by chickpea (73.80% against 73.06% predicted) and green gram (68.25% against 69.82% predicted). The maximum milling efficiency was observed in pigeon pea (83.0% against 82.79% predicted) followed by chickpea (74.8% against 75.53% predicted) and green gram (78% against 78.24% predicted). The calculated F-value for lack of fit, for pulse recovery and milling efficiency of three pulses, were found to be less than tabular values which indicate that the regression equation obtained through RSM are in close agreement with the experimental values.

References