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Response Surface Methodology for Selection of Machine Parameters for Enhancing Pearling Efficiency of Finger Millet Dehuller-Cum-Pearler

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Abstract: ***Designed experiments using Box Benkhen Design were conducted for optimizing the machine parameters of finger millet dehuller-cum-pearler. Effect of three parameters having three levels of each i.e. dispersed density (0.43 – 0.55 gm/cc), residence time (12-18 min) and roller speed (1200-1600 rpm)was studied on pearling efficiency. A second order model was developed for predicting response and studying the effect of individual parameters on the response. Pearling efficiency was observed to be in the range of 70.02% - 83.68% for given set of experimental conditions. Best performance of the dehuller –cum- pearler was obtained at optimized parameters i.e. 0.51 gm/cc dispersed density, 12 minute residence time and 1200 rpm of the roller speed.***

Keywords: Finger millet Dehuller-cum-Pearler, pearling, machine parameters, optimization

1. Introduction

India is the largest producer country of finger millet. It contributes 55% of total world production **(Ushakumari 2009).** The production of finger millet is 170484 metric tonne in 128070 ha area of Uttarakhand. **(Anonymons, 2011)** Among the minor millets, finger millet stands unique because of its superior nutritional qualities. Finger millet is a good source of dietary carbohydrates**.** It contains about 7.3g protein, 1.3g fat, 19.8g dietary fibre, 72g carbohydrates, 2.7g minerals, 0.344g calcium, 0.283g phosphorus, and 0.039g iron from 100g of finger millet. It provides 1700 kcal of energy from 100 gm of finger millet. **(Melleshi 2007).** The presence of all the required nutrients makes the finger millet suitable for large scale utilization in the Manufacture of different bakery product like noodles, idly, dosa etc. Finger millet is usually eaten as whole-grain flour. Due to the presence of outer layer in finger millet the flour colour is black and taste is also not good due to presence of bitterness. So dehulling / pearling of finger millet is necessary to remove its outer layer to improve its flour quality.

Finger millet grains are smaller in size with 1.2 - 1.7 mm diameter. The colour of seed coat of the millet varies from dark red to purple but brick red is the most common colour. The endosperm and seed coat accounting for about 85% and 13% of seed mass, respectively whereas the embryo forms only 1-2% of it. . Finger millet seed is a challenge to mill because it is very small and because its seed coat is bound tightly to the edible part (endosperm) inside. Moreover, the grain is so soft and friable that conventional milling equipment cannot remove the outside without crushing the inside. So pearling of finger millet is very difficult.

In traditional dehulling, the grain is mixed with water, allowed to stand for 5 minutes and pounded with a wooden pestle for 10-15 minutes. Then grains are subjected to drying and then winnowing remove the bran and other fine material. The pounding and winnowing processes are repeated several times till the good quality millet flour is obtained. This operation is time consuming, laborious and uneconomical to the farmers.

The mechanical dehuller / pearler works on the principle that the hull of the grain is scraped away by the grinding action of whirling stones and the friction of other grains. There are limitations with this dehuller / pearler as the dehulling / pearling efficiency is very low, more losses occur due to breakage of seed and more undehulled / unpearled grains are produced. Keeping all the above limitations of dehuller / pearler and dehulling / pearling practices, a 8 kg capacity finger millet dehuller cum pearler was designed and developed, which can dehull / pearl the finger millet easily without any losses. pearling of grain and removal of hull from seed will greatly improve the appearance of the product and enhances the digestibility and quality.

2. Materials and Methods

2.1 Materials

The experiments were conducted to develop a finger millet dehuller-cum- pearler. Finger millet grains were purchased from Haldwani, Uttarakhand. The initial moisture content of finger millet was found to be 13 ± 0.5% (w.b.). The finger millet was cleaned to remove the foreign material like plant leaves, dust, stones etc. Cleaned samples were stored properly in gunny bags or metallic containers for further experiments.

2.2 Experimental Design

Selection of machine parameters and their ranges were carried out on the basis of review of literature, the variables: dispersed density, residence time and roller speeds were selected as independent parameters to see their effect on dehulling / pearling efficiency of the finger millet. Response surface methodology (RSM) was used for the design and analysis of all experiments for three independent variables at three levels. Box-Behnken Design which is efficient design tool for fitting second order model was selected for the study. The design includes five repeated experiments at the central point of the coded variables. This was necessary for finding out the 'error sum of square' and the 'lack of fit ' of regression equations developed between the dependent and independent variables. The total numbers of experiments designed by software were found to be 17.

2.3 Optimization procedure

Data analysis and optimization were carried out by using Design-Expert 8.0.6 software. Effect of independent variables on the responses was interpreted using the models. ANOVA was applied for testing the significance of parameters. Multiple linear regression analysis was used and the data was fitted in a second order equation. The equation is as follows,

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} X_i X_j + \sum_{i=1}^{n} \beta_{ii} X_i^2 \quad ....(1)$$

Where,

$\beta_0, \beta_i, \beta_{ii}, \beta_{ij}$ are constants

X_i, X_j are variables (coded)

The experimental data were analyzed employing multiple regression techniques to develop response functions and variable parameters optimized for best outputs.

2.4 Response measurement technique

The following pearling parameters were calculated as dependent variable of the experiment and for optimization of machine parameters **(Sahay and Singh, 2001)**

Pearling efficiency: The pearling efficiency was calculated by the following formula **(Ushakumari 2009)**

$$\eta\,(\%) = \frac{W_p}{W_p + W_{br} + W_{po}} \times 100 \quad 2$$

where, η = pearling efficiency, %; W_{br} = weight of brokens,g; W_p = weight of pearled finger millet, g; W_{po} = weight of powder, g

Table 1: Coded values and corresponding real values used in experiment

Independent variables Coded Levels			
Name	-1	0	1
	Actual Levels		
Dispersed density X_1 (gm/cc)	0.43	0.49	0.55
Residence time X_2 (minute)	12	15	18
Roller speed X_3 (rpm)	1200	1400	1600

Figure 1: Raw finger millet

Figure 2: Fully dehulled / pearled finger millet

Table 2: Experimental design matrix

	Coded value		
Exp. No.	*Dispersed density*	*Residence time*	*Roller speed*
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0

Figure 3: Dehuller-cum-pearler used in pearling of finger millet

Table 3: Regression analysis for dependent parameters of finger millet pearler

Source	Pearling efficiency	
	Coeff.	P (%)
Cons	71.15	0.01***
X_1	-2.66	0.01***
X_2	-1.52	0.07***
X_3	-2.28	0.01***
$X_1 X_2$	1.50	0.52***
$X_1 X_3$	1.79	0.20***
$X_2 X_3$	-0.16	69.11
X_1^2	3.31	0.01***
X_2^2	0.38	33.48
X_3^2	1.62	0.30***
R^2%	98.07	
F value	39.73	
LOF	NS	

Table 4: ANOVA for Pearling efficiency

Source	*DF*	*SS*	*MSS*	*F- Value*
Model	9	200.25	22.25	39.73***
Linear	3	116.83	38.94	69.54***
Interactive	3	21.81	7.27	12.98***
Quadratic	3	57.86	19.29	34.45***
Residual error	7	3.92	0.56	
Total	16	204.17		

Note: ***, Significant at 1% level of significance

Table 5: Overall effects of individual parameters for Pearling efficiency

Source	DF	SS	MSS	F- Value
Model	9	200.25	22.25	39.73***
Dispersed density (X_1)	4	124.68	31.17	55.66***
Residence time (X_2)	4	28.06	7.02	12.54***
Roller speed (X_3)	4	65.57	16.39	29.27***
Residual error	7	3.92	0.56	
Total	16	204.17		

Note: ***, Significant at 1% level of significance

2.5 Numerical Analysis of Pearling Efficiency

Full second order model, Eq. 1 was fitted to the responses observed for levels of pearling efficiency at various experimental conditions using multiple regression analysis. As shown in Table 3, the coefficient of determination (R^2) for the regression model for pearling efficiency was 0.9807. This implies that the model could account for 98.07% data. Model was highly significant at 1% level of significance ($p<0.01$) as lack of fit was non-significant. Therefore, second order model was found to be adequate in describing change in pearling efficiency. Second order regression equation 4.2 is given below:

$$Y_1 = 71.15 - 2.66X_1 - 1.52 X_2 - 2.28 X_3 + 1.50 X_1 X_2 + 1.79 X_1 X_3 - 0.16 X_2 X_3 + 3.31 X_1^2 + 0.38 X_2^2 + 1.62 X_3^2 \quad \ldots 3$$

Table 3 reveals that all the three independent parameters i.e. dispersed density, residence time and roller speed had highly significant negative effect on pearling efficiency showing p values < 0.01, 0.07, 0.01 respectively.

Interaction effect of dispersed density and residence time had highly significant (P< 0.52) positive effect on pearling efficiency whereas interaction effect of dispersed density and roller speed had highly significant (P< 0.20) positive effect on pearling efficiency. The interaction effect of residence time and roller speed on pearling efficiency was insignificant and therefore was not considered for further graphical analysis.

In quadratic terms dispersed density and roller speed had highly significant (P< 0.01 & 0.30) positive effect on pearling efficiency whereas residence time had insignificant positively effect.

2.6 Graphical Analysis of Pearling Efficiency at Optimum Point

The dispersed density, residence time and roller speed had significant effect on pearling efficiency. The behaviour of pearling efficiency with dispersed density, residence time and roller speed keeping other at optimum point is shown in Fig 4, 5 and 6. From Fig 4 it was observed that pearling efficiency had a decreasing trend with increase in dispersed density ranging from -1 to 0.50 (0.43 to 0.52gm/cc) then become constant with increase in dispersed density ranging from 0.50 to 1(0.52 to 0.55gm/cc). The minimum pearling efficiency at 0.50 (0.52gm/cc) was 76%. Fig. 5 shows the effect of residence time on pearling efficiency at linear level that pearling efficiency had decreasing trend with increase in residence time ranging from -1 to 1 (12 to 18 minute). The minimum pearling efficiency at 1 (18 minute) was 76%. Fig 6 shows that pearling efficiency had decreasing trend with increase in roller speed ranging from -1 to 0.50 (1200 to 1500 rpm) then got constant with further increase in roller speed ranging from 0.50 to 1 (1500 to 1600 rpm). The minimum pearling efficiency at 0.50 (1500 rpm) was 74%.

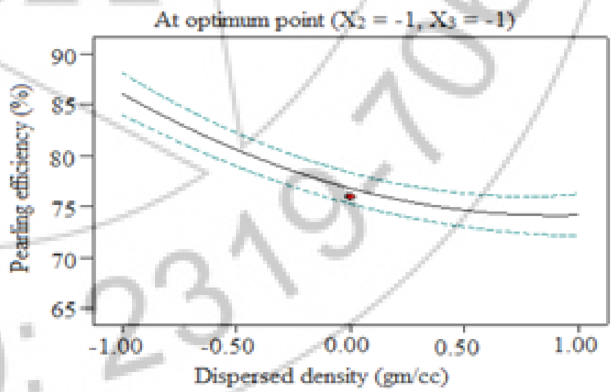

Figure 4: Pearling efficiency vs. dispersed density

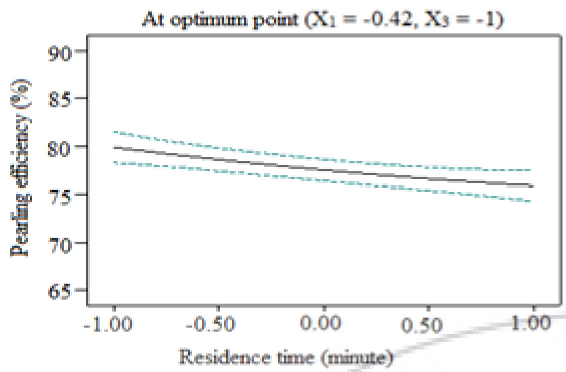

Figure 5: Pearling efficiency vs. residence time

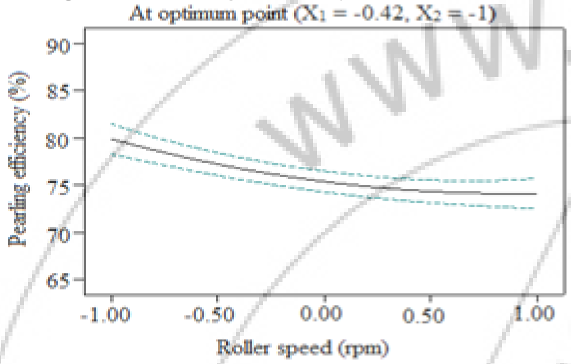

Figure 6: Pearling efficiency vs. roller speed

To see the effect of residence time and dispersed density on pearling efficiency, contour was plotted between residence time, dispersed density and pearling efficiency. Fig 7 expresses that pearling efficiency was decreasing with increase in dispersed density, whereas there was not much effect of residence time on pearling efficiency. From Fig 8 it is clear that pearling efficiency was decreasing with increase in dispersed density, whereas there was not much effect of roller speed on pearling efficiency.

3. Conclusion

Performance testing of dehuller-cum- pearler gave 70.02 to 83.68 % pearling efficiency. Maximum pearling efficiency 83.68% was found for given set of experimental conditions. Best performance of the dehuller – cum- pearler was obtained at optimized parameters i.e. 0.51 gm/cc dispersed density, 12 minute residence time and 1200 rpm of the roller speed. Pearling efficiency was highly affected by dispersed density followed by roller speed and residence time.

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