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Response surface methodology for optimization of process and machine parameters for sieving of gram flour using a multi-purpose portable sieve shaker

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Abstract

The present study was conducted to optimize process and machine parameters for sieving of gram flour using a multi-purpose portable sieve shaker, with the objective of maximizing flour yield and minimizing flour loss. After preliminary trials, three independent variables, namely feed rate, speed of sieve and mesh size of sieve, were selected at three levels. A three-factor, three-level Box-Behnken Design comprising 17 experimental runs, including five centre points, was employed and the data were analysed using Design-Expert software. Feed rate was varied from 2 to 6 kg/batch, sieve speed from 40 to 50 rpm and sieve mesh size from 200 to 300 μ m. Flour yield and flour loss were considered as the response variables. The experimental flour yield ranged from 95.30 to 97.70%, while flour loss ranged from 2.30 to 4.70%. The fitted flour-yield model was significant with an F-value of 9.49 ($p = 0.0036$), R^2 of 0.9242, adjusted R^2 of 0.8268 and predicted R^2 of 0.8186. The lack of fit was non-significant ($F = 0.0815$, $p = 0.9667$), indicating adequacy of the model. The flour-loss model showed the same response relationship because flour loss was evaluated as the complementary loss response. Numerical multi-response optimization selected feed rate of 2 kg/batch, sieve speed of 50 rpm and sieve mesh size of 250 μ m, with predicted flour yield of 97.419% and flour loss of 2.581%, and desirability of 1.000. Verification experiments gave 97.602% flour yield and 2.398% flour loss, which were close to the predicted values. The developed portable sieve shaker therefore showed satisfactory potential for efficient and consistent sieving of gram flour under small-scale processing conditions.

Keywords: Gram flour, portable sieve shaker, flour yield, flour loss, feed rate, sieve speed, mesh size, response surface methodology

1. Introduction

Gram flour (besan) is an important pulse-based flour widely used in food processing. After grinding, the material contains particles of different sizes, and effective sieving is required to obtain a relatively uniform product and remove coarse particles. Conventional manual sieving is labour-intensive, time-consuming and dependent on operator skill. The development of an affordable and portable mechanized sieve shaker is therefore useful for small-scale food-processing applications.

Sieving is an important post-grinding operation because it contributes to particle-size classification, removal of unwanted coarse material and improvement of product uniformity. The performance of a sieve depends on operating and material-related factors such as feed rate, sieve speed, mesh size, moisture and particle characteristics. Mechanized systems can provide more uniform motion and reproducible operating conditions than manual sieving.

The present research work entitled "Development of Multi-Purpose Portable Sieve Shaker" was carried out at the Department of Agricultural Process Engineering, College of Agricultural Engineering and Technology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The study focused specifically on gram flour data from the thesis and on optimization of feed rate, sieve speed and sieve mesh size using Response Surface Methodology. The main objective was to obtain maximum flour yield with minimum flour loss. The study used the developed multi-purpose portable sieve shaker, which was intended as an economical and portable mechanization option for small-scale processing. The thesis identifies the three main objectives of the overall work as development of the machine, performance evaluation of the machine and cost analysis of the developed machine. The present paper is restricted to the gram-flour RSM component.

2. Materials and Methods

2.1 Experimental location and material

The research work was carried out in the Department of Agricultural Process Engineering, College of Agricultural Engineering and Technology, Dr. Panjabrao Deshmukh

Krishi Vidyapeeth, Akola, Maharashtra. Gram flour used for the experiments was procured from the local market of Akola. The present manuscript uses the gram-flour experimental information reported in the thesis.



Plate 1: Multi-Purpose Portable Sieve Shaker Machine

2.2 Experimental design

Response Surface Methodology (RSM) was applied for optimization of the sieving process. A Box-Behnken Design for three independent variables at three levels was used. The

design consisted of 17 trials, including five centre-point replications. The experimental data were analysed using Design-Expert software. The independent variables were feed rate (A), speed of sieve (B) and mesh size of sieve (C).

Table 1: Levels of independent variables used for optimization of gram-flour sieving.

Independent variable	Symbol	Coded levels	Un-coded levels
Feed rate (kg/batch)	A	-1, 0, + 1	2, 4, 6
Speed of sieve (rpm)	B	-1, 0, + 1	40, 45, 50
Mesh size of sieve (μm)	C	-1, 0, + 1	200, 250, 300

2.3 Response parameters

Flour yield was calculated as

$$\text{Flour Yield (\%)} = \frac{\text{Gram flour at outlet (kg)}}{\text{Gram flour (kg)}} \times 100$$

Flour loss was calculated as

$$\text{Flour Loss (\%)} = \frac{\text{Gram flour loss (kg)}}{\text{Gram flour (kg)}} \times 100$$

3. Results and Discussion

3.1 Experimental results for flour yield and flour loss

Table 2: Box-Behnken experimental layout and observed responses for gram flour.

Run	Feed rate (kg/batch)	Speed (rpm)	Mesh size (μm)	Flour yield (%)	Flour loss (%)
1	2	40	250	97.2	2.8
2	6	40	250	95.8	4.2
3	2	50	250	97.7	2.3
4	6	50	250	96.2	3.8
5	2	45	200	97.4	2.6
6	6	45	200	95.6	4.4
7	2	45	300	96.8	3.2
8	6	45	300	95.3	4.7
9	4	40	200	96.5	3.5
10	4	50	200	97.1	2.9
11	4	40	300	96.3	3.7
12	4	50	300	96.7	3.3
13	4	45	250	96.6	3.4
14	4	45	250	96.8	3.2
15	4	45	250	97.0	3.0
16	4	45	250	97.3	2.7
17	4	45	250	97.5	2.5

The observed flour yield ranged from 95.30 to 97.70%. The highest observed yield was 97.70% at a feed rate of 2 kg/batch, sieve speed of 50 rpm and mesh size of 250 μm . Flour loss ranged from 2.30 to 4.70%, with the lowest

observed loss of 2.30% at the same experimental combination. These observations indicate that the operating variables influenced the separation performance of the developed sieve shaker.

3.2 Effect of process and machine parameters on flour yield

The flour-yield response was fitted using a second-order polynomial model. The model F-value of 9.49 was significant ($p = 0.0036$), indicating that the fitted model explained a substantial part of the observed variation. Feed rate was the most influential linear term in the ANOVA,

followed by sieve speed, while mesh size also contributed to the response. The quadratic terms A^2 and C^2 were significant, whereas the interaction terms were not significant at the 5% level. The non-significant lack of fit ($F = 0.0815$; $p = 0.9667$) indicated that the lack of fit was not significant relative to pure error.

Table 3: Analysis of Variance (ANOVA) showing the effect of process and machine parameters on flour yield.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.88	9	0.7650	9.49	0.0036	significant
A-Feed Rate	4.80	1	4.80	59.58	0.0001	
B-Speed of Sieve	0.4513	1	0.4513	5.60	0.0039	
C-Mesh Size of Sieve	0.2813	1	0.2813	3.49	0.0041	
AB	0.0025	1	0.0025	0.0310	0.0752	
AC	0.0225	1	0.0225	0.2790	0.0437	
BC	0.0100	1	0.0100	0.1240	0.0551	
A^2	0.5012	1	0.5012	6.21	0.0414	
B^2	0.0038	1	0.0038	0.0470	0.0246	
C^2	0.7427	1	0.7427	9.21	0.0190	
Residual	0.5645	7	0.0806			
Lack of Fit	0.0325	3	0.0108	0.0815	0.9667	not significant
Pure Error	0.5320	4	0.1330			
Cor Total	7.45	16				
Std. Dev.	0.2840		R^2	0.9242		
Mean	96.69		Adjusted R^2	0.8268		
C.V.%	0.2937		Predicted R^2	0.8186		
			Adeq Precision	10.9045		

Regression equation in coded factors:

$$\text{Flour Yield} = 97.04 - 0.7750A + 0.2375B - 0.1875C - 0.0250AB + 0.0750AC - 0.0500BC - 0.3450A^2 + 0.0300B^2 - 0.4200C^2$$

Where,

A = Feed rate (kg/batch)

B = Speed of sieve (rpm)

C = Mesh size of sieve (μm)

The thesis reports show that mesh size had a greater impact on recovery of flour as compared with feed rate and sieve speed.

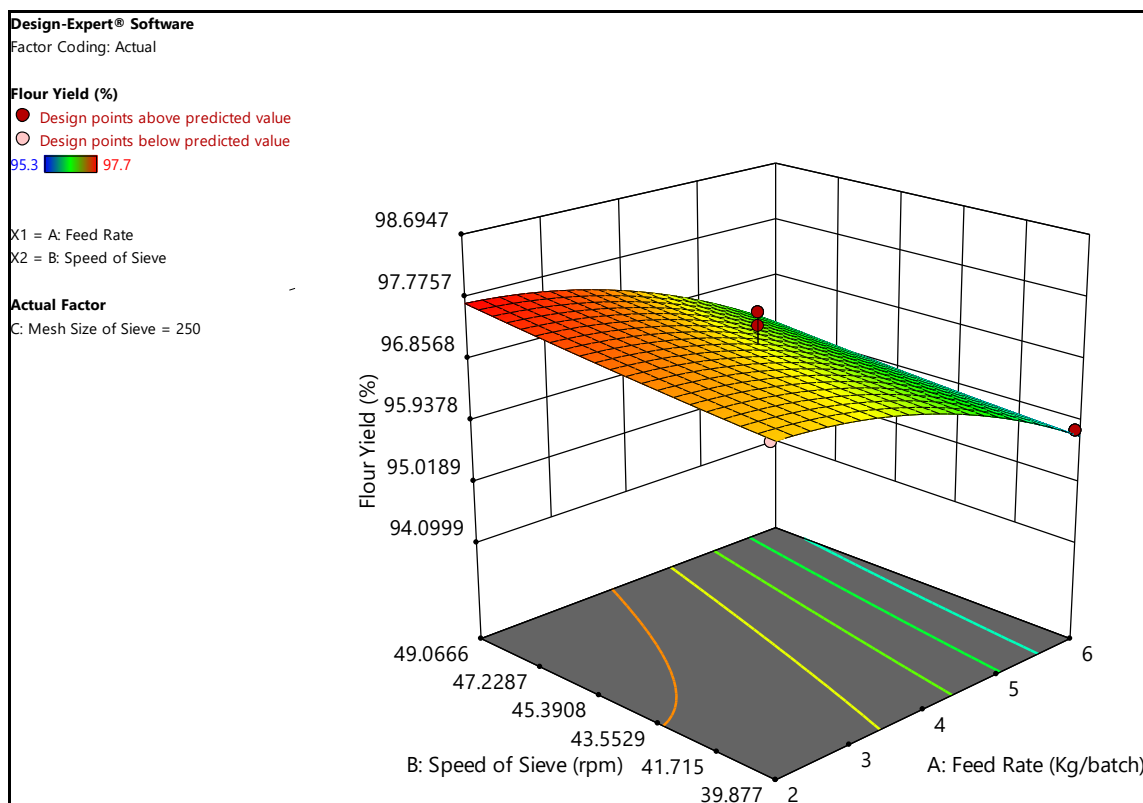


Fig 1: Effect of Feed Rate (kg/batch) and Speed of Sieve (rpm) on Flour Yield.

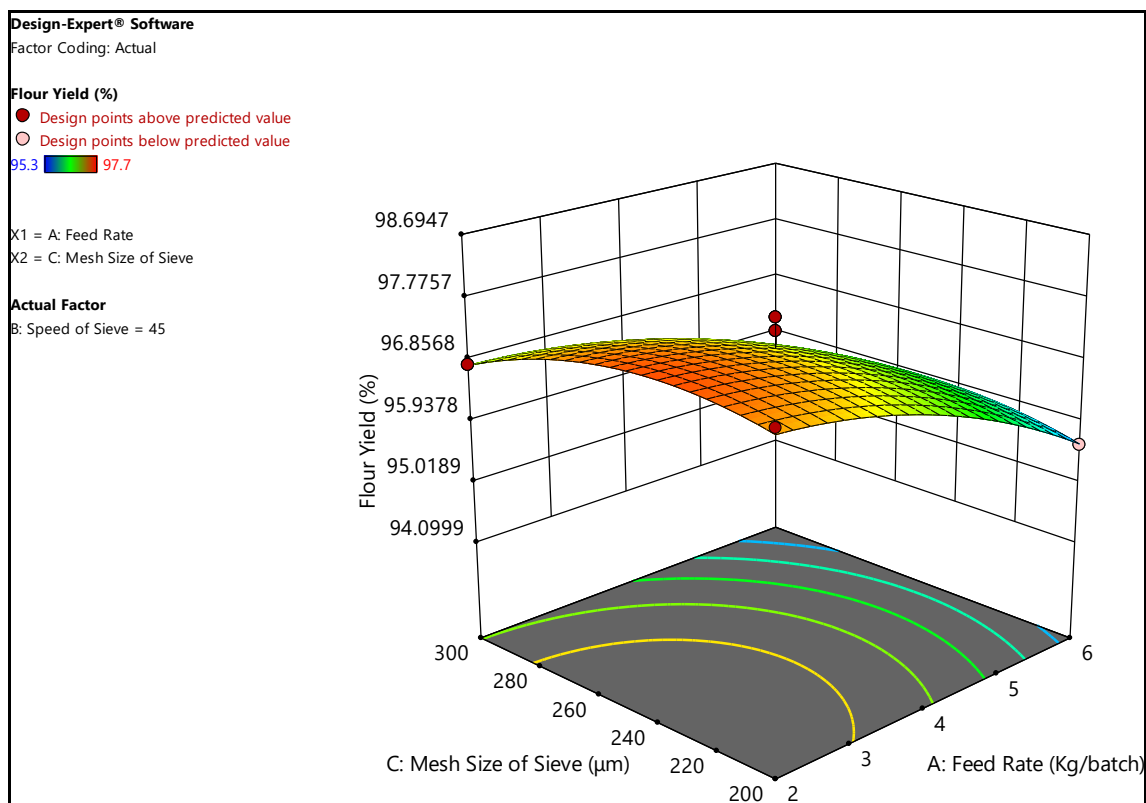


Fig 2: Effect of Feed Rate (kg/batch) and Mesh Size of Sieve (μm) on Flour Yield.

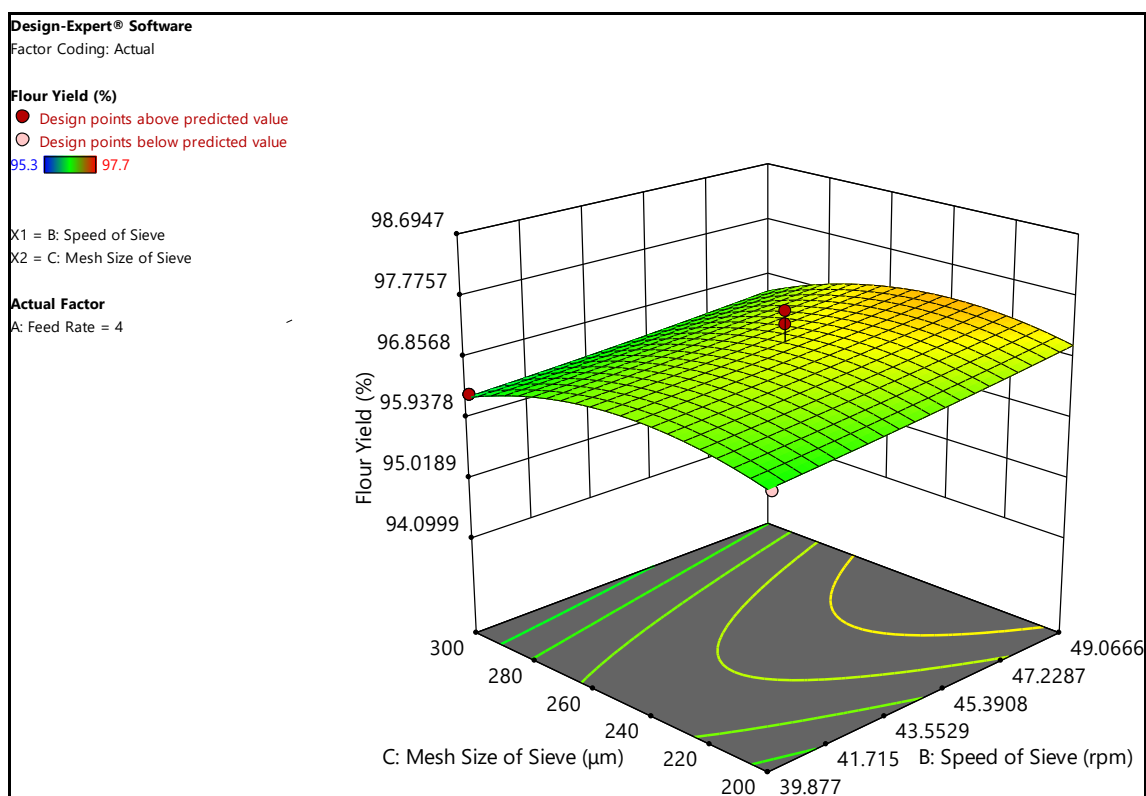


Fig 3: Effect of Speed of Sieve (rpm) and Mesh Size of Sieve (μm) on Flour Yield.

3.3 Effect of process and machine parameters on flour loss

Flour loss ranged from 2.30 to 4.70% within the experimental combinations. The minimum observed flour loss was 2.30%. The fitted second-order response model

showed the influence of feed rate, sieve speed and mesh size on flour loss. The thesis reports that mesh size had greater impact on flour loss compared with feed rate and sieve speed.

Table 4: Analysis of Variance (ANOVA) showing the effect of process and machine parameters on flour loss.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.88	9	0.7650	9.49	0.0036	significant
A-Feed Rate	4.81	1	4.81	59.58	0.0001	
B-Speed of Sieve	0.4512	1	0.4512	5.60	0.0099	
C-Mesh Size of Sieve	0.2813	1	0.2813	3.49	0.0041	
AB	0.0025	1	0.0025	0.0310	0.0552	
AC	0.0225	1	0.0225	0.2790	0.0637	
BC	0.0100	1	0.0100	0.1240	0.0351	
A ²	0.5012	1	0.5012	6.21	0.0414	
B ²	0.0038	1	0.0038	0.0470	0.0546	
C ²	0.7427	1	0.7427	9.21	0.0190	
Residual	0.5645	7	0.0806			
Lack of Fit	0.0325	3	0.0108	0.0815	0.9667	not significant
Pure Error	0.5320	4	0.1330			
Cor Total	7.45	16	R ²	0.9242		
Std. Dev.	0.2840		Adjusted R ²	0.8268		
Mean	3.31		Predicted R ²	0.8186		
C.V.%	8.59		Adeq Precision	10.9045		

Regression equation in coded factors:

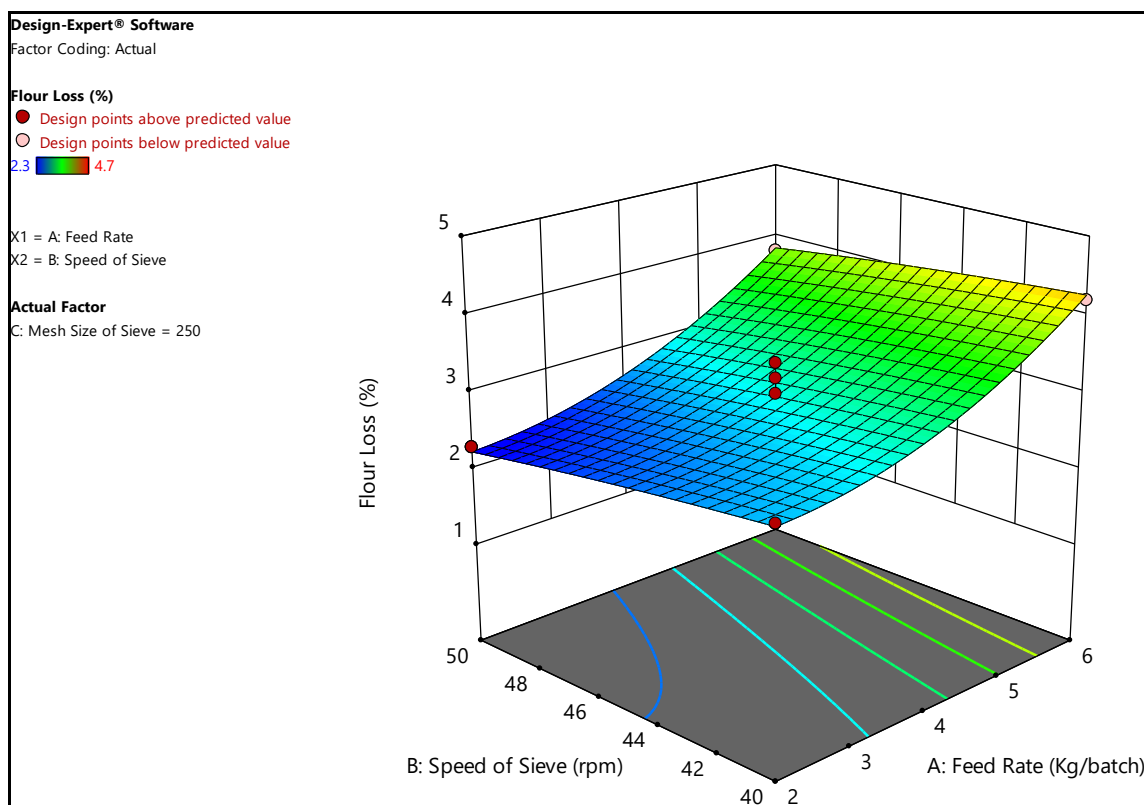
$$\text{Flour Loss} = 2.96 + 0.7750A - 0.2375B + 0.1875C + 0.0250AB - 0.0750AC + 0.0500BC + 0.3450A^2 - 0.0300B^2 + 0.4200C^2$$

Where,

A = Feed rate (kg/batch)

B = Speed of sieve (rpm)

C = Mesh size of sieve (μm)

**Fig 4:** Effect of Feed Rate (kg/batch) and Speed of Sieve (rpm) on Flour Loss.

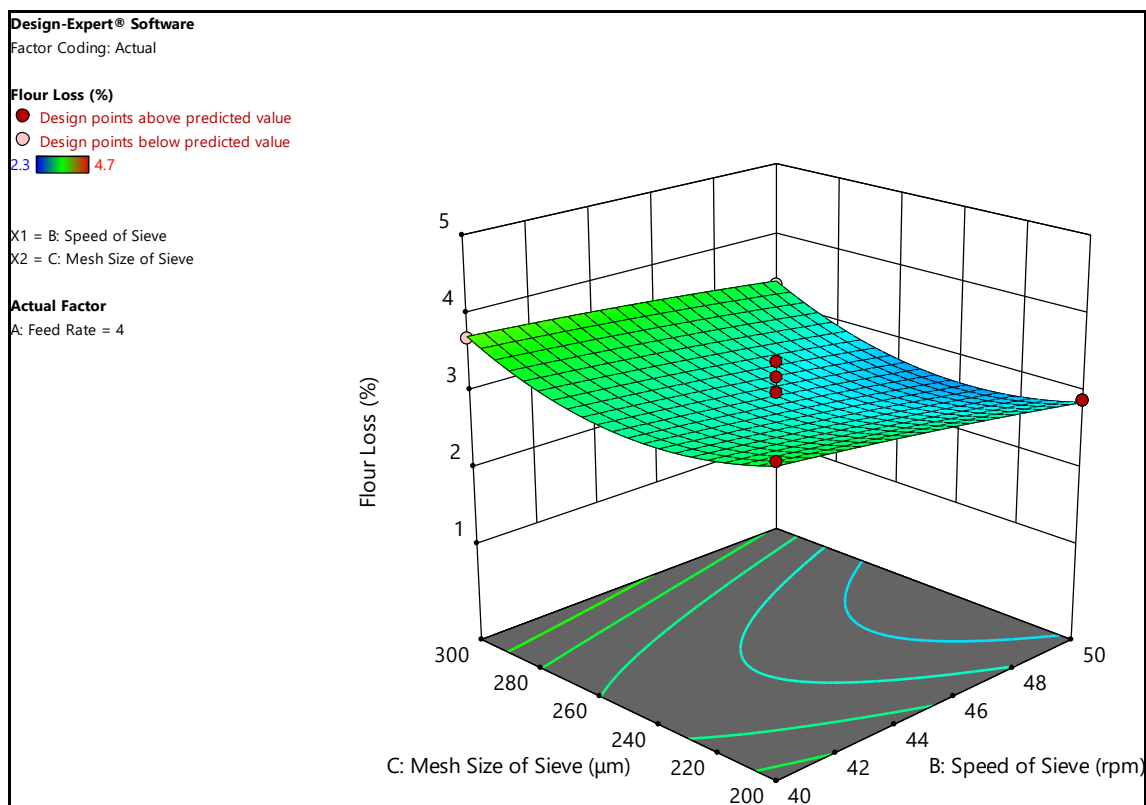


Fig 5: Effect of Feed Rate (kg/batch) and Mesh Size of Sieve (μm) on Flour Loss.

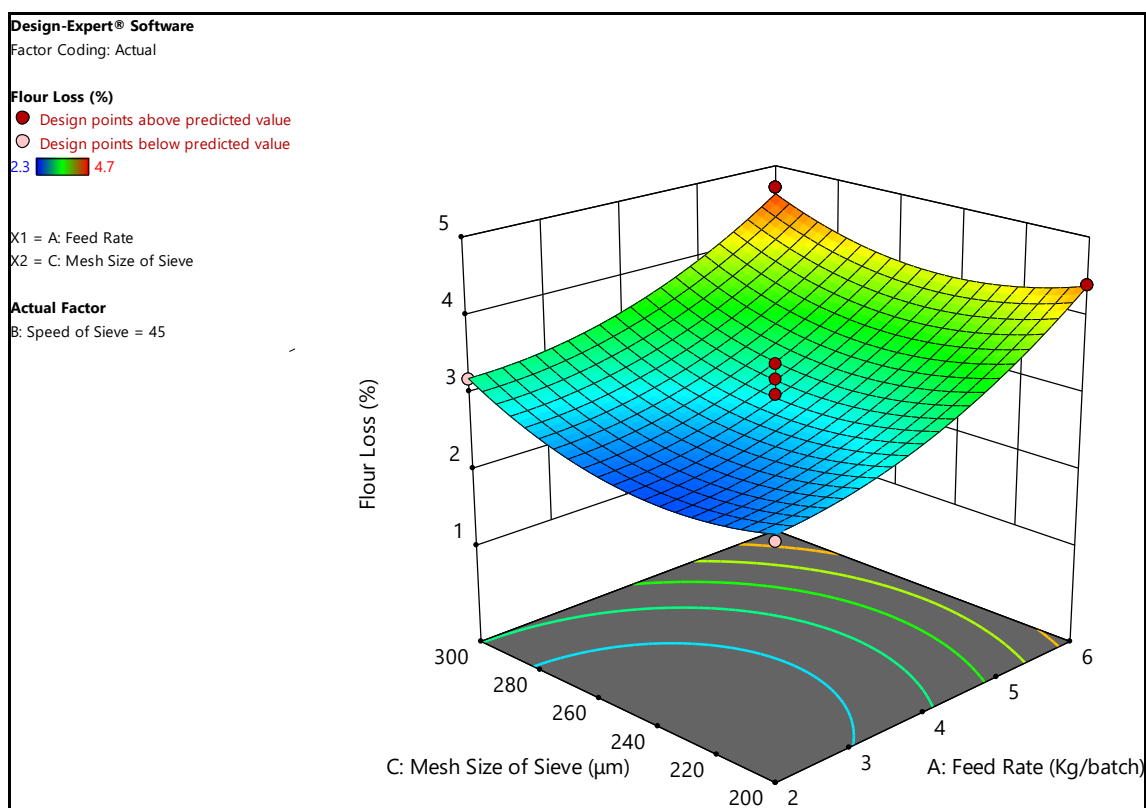


Fig 6: Effect of Speed of Sieve (rpm) and Mesh Size of Sieve (μm) on Flour Loss.

3.4 Numerical multi-response optimization

Numerical multi-response optimization was performed using Design-Expert software. The independent variables were kept within their experimental ranges, while flour yield was maximized and flour loss was minimized. The

optimization criteria were feed rate 2-6 kg/batch, sieve speed 40-50 rpm, mesh size 200-300 μm , flour yield 95.3-97.7% and flour loss 2.3-4.7%. Each factor and response was assigned a desirability importance of 3 in the thesis.

Table 5: Optimization criteria for process variables and responses

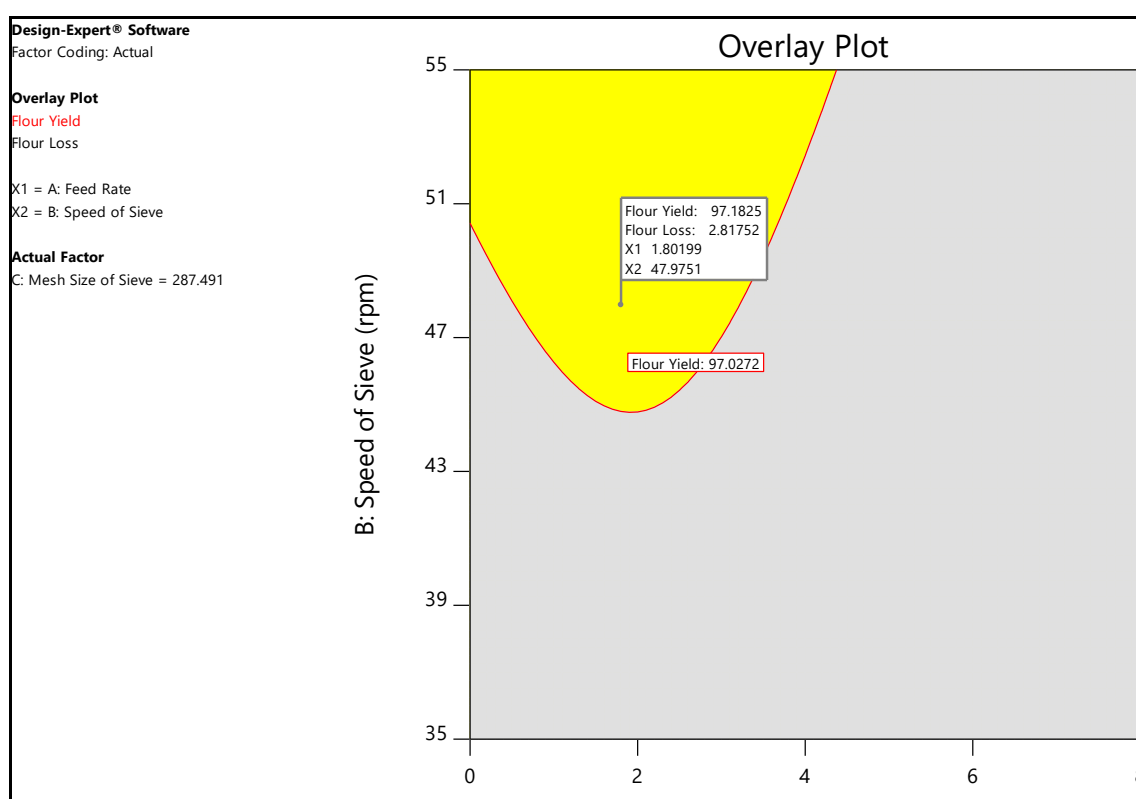
Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A: Feed Rate (kg/batch)	In range	2	6	1	1	3
B: Speed of Sieve (rpm)	In range	40	50	1	1	3
C: Mesh Size (μm)	In range	200	300	1	1	3
Flour Yield	Maximize	95.3	97.7	1	1	3
Flour Loss	Minimize	2.3	4.7	1	1	3

Table 6: Optimized solutions generated by the software

No.	Feed Rate (kg/batch)	Speed (rpm)	Mesh Size (μm)	Flour Yield (%)	Flour Loss (%)	Desirability
1	2.000	50.000	250.000	97.419	2.581	1.000 (Selected)
2	4.240	40.244	242.376	96.756	3.244	1.000
3	4.000	50.000	200.000	97.125	2.875	1.000
4	4.000	45.000	250.000	97.040	2.960	1.000
5	6.000	45.000	300.000	95.388	4.612	1.000

The selected numerical optimum reported in the thesis was feed rate = 2.000 kg/batch, sieve speed = 50.000 rpm and mesh size = 250 μm , with predicted flour yield = 97.419%,

predicted flour loss = 2.581% and desirability = 1.000. This selected solution is retained here because it is the selected solution explicitly reported in the thesis.

**Fig 7:** Effect of superimposed contours for flour recovery and flour loss.

3.5 Verification of optimum responses

Verification experiments were conducted at the optimum operational parameters to test the adequacy of the model equations. The thesis reports predicted and experimentally verified values based on repeated experiments. The experimental values were close to the predicted values, indicating satisfactory adequacy of the models for the gram-flour sieving response.

Table 7: Predicted and experimentally verified values of responses at optimum process parameters

Sr. No.	Response	Predicted value	Experimentally verified value (mean)
1	Flour yield (%)	97.419	97.602
2	Flour loss (%)	2.581	2.398

4. Conclusion

The multi-purpose portable sieve shaker was evaluated for sieving of gram flour using Response Surface Methodology. Three process and machine variables—feed rate, sieve speed and mesh size—were optimized using a 17-run Box-Behnken Design. The observed flour yield ranged from 95.30 to 97.70%, while flour loss ranged from 2.30 to 4.70%. The flour-yield model was significant with $R^2 = 0.9242$ and adequate precision of 10.9045, and the lack of fit was non-significant. Numerical multi-response optimization selected a feed rate of 2.000 kg/batch, sieve speed of 50.000 rpm and mesh size of 250 μm . At these conditions, the predicted flour yield was 97.419% and predicted flour loss was 2.581%, with desirability of 1.000. Verification gave 97.602% flour yield and 2.398% flour loss. The close agreement between predicted and experimental values

indicates that the developed response models were adequate for describing the gram-flour sieving process within the investigated design space.

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