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OPTIMIZATION OF DEHULLING PROCESS PARAMETERS FOR BLACK GRAM USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Milling of pulses without pre-treatment result in low *dal* recovery. It is, therefore, important to look at different aspect of milling so that proper process and machinery are used to obtain maximum recovery of good quality *dal* from grain and take corrective measure to reduce milling losses to minimum. Keeping in view the above; the present study will be undertaken for maximum whole dehulled grain recovery. The performance of the machine was evaluated for dehulling of black gram at three feed rates (70, 140 and 210 kg/h), three clearances (3, 5 and 7 mm), and three roller speed (700, 1000 and 1300 rpm) respectively. Three variables, three level Central Composite Rotatable Design (CCRD) model was followed and analysis was done using response surface methodology by using Design Expert Software to optimize machine parameter for *gota* recovery, *dal* yield and dehulling efficiency. The optimum *gota* recovery 12.53 % and dehulling efficiency 71.53 % was observed at 210 kg/h feed rate, 7mm clearance and 1300 rpm roller speed and *dal* yield of 66.28 % was observed at 210 kg/h feed rate, 3 mm clearance and 1300 rpm roller speed.

***Key words*:** Milling, Clearance, Feed rate, Roller speed, Gota recovery, Dal yield, Dehulling efficiency

Introduction

Black gram (*Vigna mungo* L.) or urad is one of the important pulses containing 24% protein, 59.6% carbohydrate and 1.4% fat (Gopalan *et al*., 1989). India is the largest producer and consumer of black gram which accounts for more than 40 % of total legume seeds traded in the world (CRN India, 2011). It was grown in about 31.92 lakh ha area to produce about 1.83 million tonnes in 2011-2012 (Reddy, 2013). India is its primary origin and is mainly cultivated in Asian countries including Pakistan, Myanmar and parts of South Asia. About 70 per cent of world's black gram production comes from India. Urad is growing primarily for its protein rich seeds. It is as dal and as ingredient in snacks like *idli*, *dosa*, *vada* and *papad*. The per capital availability of pulses is only around 32 g against the recommendation of 65 g per day by Indian Council of Medical Research (Reddy, 2013). This gap could be reduced through post-harvest losses reduction and improving the productivity of pulses milling industries. Moreover, in India, about 80% of the pulses produced are consumed in the form of dehulled splits (*dhal*) or powder which entails the need for pulse milling (Mangaraj and Kapur, 2005). Conversion of pulses into dhal is the third largest food processing industry in the country after rice and wheat milling industries (Kamble, 2021). Removal of seed coat (husk) reduces roughage and anti-nutritional elements presents in seed coat, improve nutritional values and palatability for consumption of pulses in various form. It also improves cooking quality and digestibility. Black gram, if stored without de-hulling, is more liable to be attacked by insects. Moreover, storage longevity of hulled black gram is more than that of dehulled black gram (Joyner and Yadav, 2013). Majority of pulse milling is done at domestic, cottage and small to medium-scale industries. Losses during milling at domestic and cottage levels are high about 10-15% (Lal and Verma, 2007). About 10-25% of pulses are converted into dhal at the domestic level and the rest are sold in the market at low price for conversion into dhal by organized pulse milling industries. The extent of losses that takes place at different stages of post-harvest chain differs from grain to grain (Mohapatra, 2025; Dronachari, 2015). There is no machine available for milling of pulses at home level. There are several research and development institutions, which contributed to develop various machineries for dehulling of pulses. However, these machineries are commercial scale and expensive for small scale processing. Therefore, there was need of small scale and low-cost black gram dehuller, which would be suitable for small level processing of black gram.

Materials and Methods

Raw material

Among the different variety of black gram cultivated in Maharashtra, "TAU-1" of black gram was selected for the present investigation which was procured from the local market of "Akola" in the month of June. The pulse grain was dried for 1 h in tray drier at 75^{0}C to reduce the moisture content up to 10 per cent (w b.).

Preparation of sample for dehulling

After tempering by dehuller black gram was treated with oil and heaped over night for conducting various trials on dehulling. Pre-milling treatment was performed to loosen the husk from cotyledons, which is attached through a gum layer. In black gram the husk adheres the endosperm tightly making dehulling a difficult operation (Kurien *et al.*, 1968). In oil pre-treatment sunflower oil was used and oil treated sample was heaped for overnight, dried in a tray dryer at 70ºC for 30 min.

Plate 1: Dehuller use for black gram dehulling

Table 1: Independent variables for dehulling of black gram.

Independent variables	Levels	Dependent variable
Feed rate (kg/h)	70, 140 and 210	*Gota* Recovery (%)
Clearance between roller and sieve (mm)	3, 5 and 7	*Dal* Yield (%)
Roller speed (rpm)	700, 1000 and 1300	Dehulling Efficiency (%)

Working principle of dehuller

The small capacity dehulling machine was taken for the study and it was working on the principle of impact and shear force. The emery roller was part of de-hulling machine, which was fitted inside the dehulling chamber, in which the dehulling process takes place. Dehulling chamber having sieve inside, it is placed around the emery roller at some clearance. Feed was provided from the hopper to dehulling chamber having sieve inside, which allows repetitive impact and shear force exert to detach the husk from the grain. Detaching the husk from the grain requires friction force between emery roller and pulse grain, which was generated by the circular motion of the roller.

Table 2: Experimental layout for three variables and three level response surface analysis.

Tr. No.	Feed Rate, kg/h	Clearance, mm	Roller speed, rpm	Feed Rate, kg/h	Clearance, mm	Roller speed, rpm
	Coded independent variables			Decoded independent variables		
	x_1	x_2	x_3	X_1	X_2	X_3
1	-1	-1	-1	70	3	700
2	+1	-1	-1	210	3	700
3	-1	+1	-1	70	7	700
4	+1	+1	-1	210	7	700
5	-1	-1	+1	70	3	1300
6	+1	-1	+1	210	3	1300
7	-1	+1	+1	70	7	1300
8	+1	+1	+1	210	7	1300
9	-1.682	0	0	22	5	1000
10	+1.682	0	0	258	5	1000
11	0	-1.682	0	140	2	1000
12	0	+1.682	0	140	8	1000
13	0	0	-1.682	140	5	495
14	0	0	+1.682	140	5	1505
15	0	0	0	140	5	1000
16	0	0	0	140	5	1000
17	0	0	0	140	5	1000
18	0	0	0	140	5	1000
19	0	0	0	140	5	1000

Table 3: Effect of various levels of operational parameters on *Gota* recovery (%).

Sr. No.	Feed rate, kg/h	Clearance, mm	Roller speed, rpm	*Gota* Recovery, %
1	70	3	700	4.91
2	210	3	700	7.81
3	70	7	700	1.91
4	210	7	700	4.20
5	70	3	1300	4.57
6	210	3	1300	6.21
7	70	7	1300	8.93
8	210	7	1300	12.53
9	22	5	1000	4.46
10	258	5	1000	8.52
11	140	2	1000	5.50
12	140	8	1000	8.22
13	140	5	495	3.22
14	140	5	1505	11.00
15	140	5	1000	10.58
16	140	5	1000	11.32
17	140	5	1000	12.13
18	140	5	1000	12.26
19	140	5	1000	11.44

Table 3.1: ANOVA for effect of operational parameters on *Gota* recovery (%).

Source	Sum of Square	df	Mean sum of square	F Value	p-value Prob>F
Model	207.86	9	23.1	46.85	< 0.0001**
A-Feed rate	21.7	1	21.7	44.02	< 0.0001**
B-Clearance	5.43	1	5.43	11.02	0.0089*
C-Roller Speed	51.34	1	51.34	104.13	< 0.0001**
AB	0.2138	1	0.2138	0.4337	0.5267*
BC	0	1	0	0.0001	0.9931*
AC	37.16	1	37.16	75.37	< 0.0001**
A^2	45.12	1	45.12	91.51	< 0.0001**
B^2	38.88	1	38.88	78.86	< 0.0001**
C^2	34.87	1	34.87	70.73	< 0.0001**
Residual	4.44	9	0.493		
Lack of Fit	2.57	5	0.5138	1.1	0.4764^{NS}
Pure Error	1.87	4	0.467		
Cor Total	212.3	18			
R^2	0.9791				
Adj R^2	0.9582				
Pred R^2	0.8884				
C.V. %	8.91				

** Significant at 1 % level, *Significant at 5 % level, NS-Non significant

Operation of black gram dehuller

For dehulling operation, a known quantity of black gram grains was fed to the feed hopper and the inlet feed regulator was opened to allow the grain to enter the dehulling chamber. The initially charged material is retained until the appropriate dehulling was initiated. Continuous-flow dehulling was then achieved by matching the settings of the inlet and outlet gates to ensure that the dehulling unit is always adequately full.

Performance evaluation of dehuller

The operational process parameters of black gram milling unit were optimized using Response Surface Methodology (RSM) technique, since this is useful statistical techniques for investigation of complex processes. The response surface analysis involves fitting the experimental value of *gota* recovery, dal yield, and dehulling efficiency to reduce suitable polynomial equation and subsequently optimizing the values with suitable optimization software or mathematical solutions. The machine parameters for dal milling were clearance between roller and sieve (mm), feed rate (kg/h), and roller speed (rpm) were optimized for *gota* recovery, dal yield, and dehulling efficiency.

Gota Recovery (%)

Gota recovery was defined as the quantity of tempered black gram that is being dehulled by the machine and it is expressed in percentage (Singh, 1995).

$$Gota\ Recovery(\%) = \frac{W_d}{W_1} \times 100$$

Dal Yield (%)

Dal yield was defined as the yield of dehulled splits as a percentage of original seed weight (Singh, 1995).

$$Dal\ Yield\ (\%) = \frac{W_s}{W_1} \times 100$$

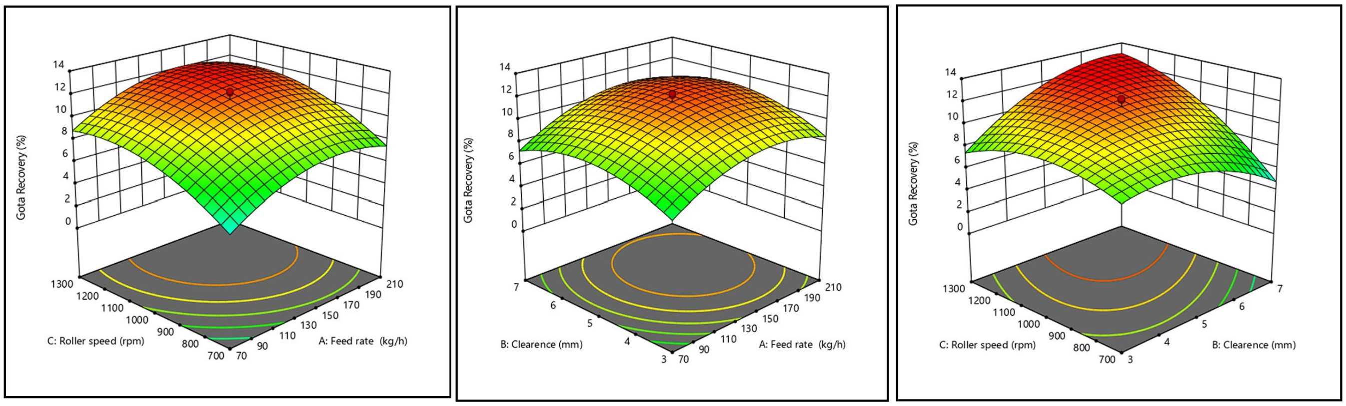

Fig. 1: Effect of Feed rate, clearance and roller speed on *Gota* recovery (%).

Table 4: Effect of various levels of operational parameters on *Dal* yield (%).

Sr. No.	Run	Feed rate, kg/h	Clearance, mm	Roller speed, rpm	*Dal* Yield, %
1	4	70	3	700	50.29
2	8	210	3	700	54.75
3	5	70	7	700	6.85
4	18	210	7	700	7.00
5	17	70	3	1300	51.40
6	15	210	3	1300	66.28
7	1	70	7	1300	57.56
8	13	210	7	1300	59.37
9	10	22	5	1000	45.91
10	12	258	5	1000	47.94
11	9	140	2	1000	53.29
12	2	140	8	1000	17.89
13	11	140	5	495	23.88
14	6	140	5	1505	64.30
15	14	140	5	1000	40.70
16	19	140	5	1000	43.25
17	16	140	5	1000	40.94
18	7	140	5	1000	43.45
19	3	140	5	1000	43.31

Dehulling Efficiency (%)

Dehulling yield was defined as the quantity of whole dehulled kernels and splits that are produce in the dehulling process (Joyner and Yadav, 2013).

$$Dehulling\ Efficiency\ (\%) = \left(1 - \frac{W_u}{W_1}\right) \times \frac{W_2}{(W_h + W_2 + Wb)} \times 100$$

Results and Discussion

Optimization of dehulling Process parameters

Optimization of dehulling process parameters such as feed rate, clearance between roller sieve and roller speed was necessary to obtain maximum *gota* recovery, *dal* yield and de-hulling efficiency. During the preliminary experiments, it was found that *gota* recovery, *dal* yield and dehulling efficiency depends on feed rate, clearance between roller and sieve and roller speed. Therefore, keeping these factors in mind de-hulling process was optimized. As per 3 numeric variables with 3 levels, 19 trials were performed as per Central Composite Design enumerated in Table 2 for obtaining maximum *gota* recovery, *dal* yield and dehulling efficiency for each treatment. To avoid bias, the 19 trials were performed in random order. The decision for range and central point of the variables was taken through preliminary trials.

Table 4.1: ANOVA for effect of operational parameters on *Dal* yield (%).

Source	Sum of Square	df	Mean sum of square	F Value	p-value Prob>F
Model	5418.11	9	602.01	80.88	< 0.0001**
A-Feed rate	44.67	1	44.67	6.00	0.0368*
B-Clearance	1680.41	1	1680.41	225.76	< 0.0001**
C-Roller Speed	2470.92	1	2470.92	331.96	< 0.0001**
AB	37.78	1	37.78	5.08	0.0508*
BC	18.25	1	18.25	2.45	0.1519*
AC	1022.43	1	1022.43	137.36	< 0.0001**
A^2	57.36	1	57.36	7.71	0.0215*
B^2	52.26	1	52.26	7.02	0.0265*
C^2	14.95	1	14.95	2.01	0.1900*
Residual	66.99	9	7.44		
Lack of Fit	59.33	5	11.87	6.20	0.0508^{NS}
Pure Error	7.66	4	1.91		
Cor Total	5485.10	18			
R^2	0.9878				
Adj R^2	0.9756				
Pred R^2	0.9130				
C.V. %	6.33				

** Significant at 1 % level, *significant at 5 % level, NS-Non significant

Gota recovery (%)

The *gota* recovery was observed to be ranging between to 1.91 to 12.53 %. The maximum *gota* recovery of 12.53 % was observed at 210 kg/h feed rate, 7 mm clearance and 1300 rpm roller speed. Table 3 and Table 3.1 shows effect of various levels of operational parameters on *gota* recovery and ANOVA for effect of operational parameters on *gota* recovery (%). The minimum *gota* recovery of 1.91 % was observed at 70

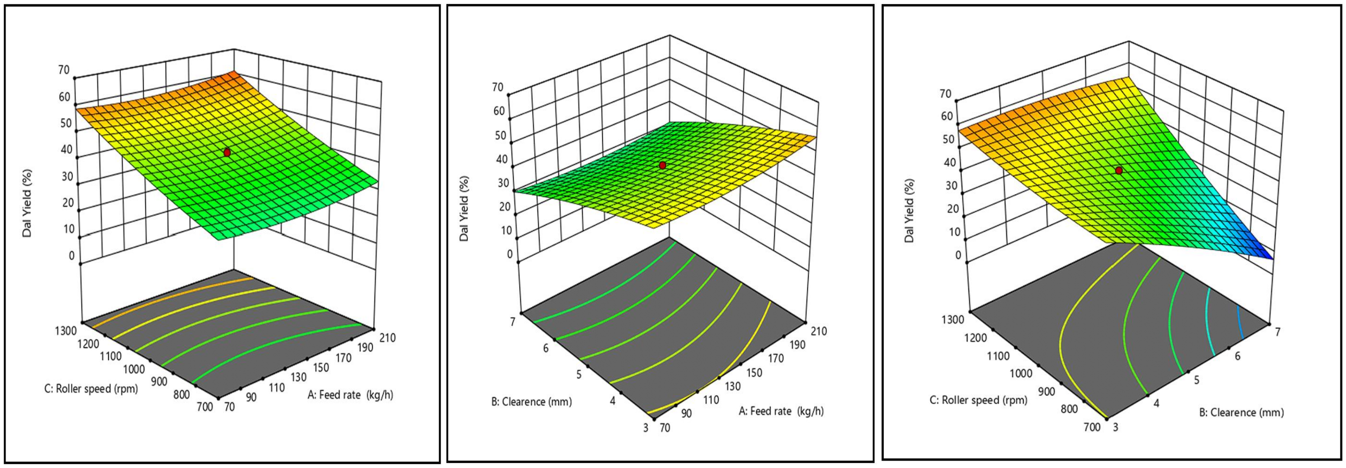

Fig. 2: Effect of Feed rate, clearance and roller speed on *Dal* yield (%).

Table 5: Effect of various levels of operational parameters on Dehulling Efficiency (%).

Sr. No.	Run	Feed rate, kg/h	Clearance, mm	Roller speed, rpm	Dehulling Efficiency, %
1	4	70	3	700	48.64
2	8	210	3	700	47.47
3	5	70	7	700	5.95
4	18	210	7	700	8.73
5	17	70	3	1300	50.97
6	15	210	3	1300	66.15
7	1	70	7	1300	55.14
8	13	210	7	1300	71.53
9	10	22	5	1000	40.24
10	12	258	5	1000	58.18
11	9	140	2	1000	51.91
12	2	140	8	1000	24.93
13	11	140	5	495	18.14
14	6	140	5	1505	70.48
15	14	140	5	1000	50.37
16	19	140	5	1000	51.00
17	16	140	5	1000	50.15
18	7	140	5	1000	51.66
19	3	140	5	1000	51.58

kg/h. feed rate, 7 mm clearance and 700 rpm roller speed. Three dimensional responses for *gota* recovery of samples were generated. From these surfaces, it could be evident that the *gota* recovery was found to be increased with increase in clearance between roller and sieve up to its maxima and when the clearance is increased further then *gota* recovery decreased. Also, *gota* recovery was found to be increased with increase in roller speed up to some extent. This *gota* recovery was low at less roller speed and increased initially with increased in roller speed up to its maxima and when the roller speed is increased further then *gota* recovery decreased as shown in Fig 1. Similar result was found in experiment conducted on PKV mini dal mill for dehulling for black gram and green gram (Rokade *et al.*, 2019) and Optimization of machine parameters for hulling efficiency of black gram (Jayas, 2005).

Table 5.1: ANOVA for effect of operational parameters on Dehulling Efficiency (%).

Source	Sum of Square	df	Mean sum of square	F Value	p-value Prob>F
Model	6312.06	9	701.34	389.16	< 0.0001**
A-Feed rate	293.92	1	293.92	163.09	< 0.0001**
B-Clearance	1006.65	1	1006.65	558.58	< 0.0001**
C-Roller Speed	3577.10	1	3577.10	1984.88	< 0.0001**
AB	3.33	1	3.33	1.85	0.2071*
BC	112.16	1	112.16	62.24	< 0.0001**
AC	1034.47	1	1034.47	574.01	< 0.0001**
A^2	2.80	1	2.80	1.55	0.2441*
B^2	248.56	1	248.56	137.92	< 0.0001**
C^2	65.18	1	65.18	36.17	0.0002**
Residual	16.22	9	1.80		
Lack of Fit	14.34	5	2.87	6.10	0.0521^{NS}
Pure Error	1.88	4	0.4699		
Cor Total	6328.27	18			
R^2	0.9974				
Adj R^2	0.9949				
Pred R^2	0.9821				
C.V. %	2.92				
** Significant at 1 % level, *significant at 5 % level, NS-Non significant					

Dal yield (%)

The *dal* yield was observed to be ranging between to 6.85 to 66.28 %.Table 4 and Table 4.1 shows effect of various levels of operational parameters on *dal* yield (%) and ANOVA for effect of operational parameters on *dal* yield (%). The maximum *dal* yield of 66.28 % was observed at 210 kg/h. feed rate, 3 mm clearance and 1300 rpm roller speed. The minimum *dal* yield of 6.85 % was observed at 70 kg/h. feed rate, 7 mm clearance and 700 rpm roller speed. From three dimensional responses generated for *dal* yield it was observed that *dal* yield was high at low clearance and when clearance between roller and sieve increase further then *dal* yield was less. On the other hand dal yield was gradually increased with increase in feed rate. The *dal* yield was found to be increased with increase in roller speed whereas there was no effect of feed rate on *dal* yield as shown in Fig.

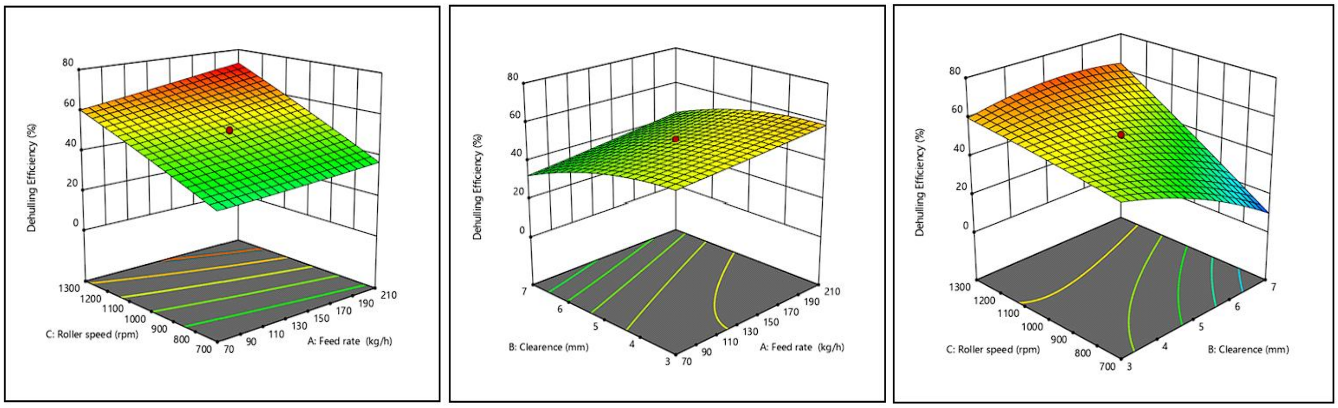

Fig. 3: Effect of Feed rate, clearance and roller speed on Dehulling Efficiency (%).

Table 6: Optimization criteria for different input parameters and responses for black gram dehulling.

Sr.	Name	Goal	Lower Limit	Upper Limit
1	A: Feed rate (kg/h)	is in range	100	210
2	B: Clearence (mm)	is in range	5	7
3	C: Roller speed (rpm)	is in range	900	1300
4	*Gota* Recovery (%)	Maximize	11	12.53
5	*Dal* Yield (%)	Minimize	65	66.28
6	Dehulling Efficiency (%)	Maximize	70	71.53

2, similar result was observed by (Mandhyan and Jain, 1993).

Dehulling Efficiency (%)

The dehulling efficiency was observed to be ranging between to 5.95 to 71.53 %. Table 5 and Table 5.1 shows effect of various levels of operational parameters on dehulling efficiency (%) and ANOVA for effect of operational parameters on dehulling Efficiency (%). The maximum dehulling efficiency of 71.53 % was observed at 210 kg/h. feed rate, 7 mm clearance and 1300 rpm roller speed. The minimum dehulling efficiency of 5.95 % was observed at 70 kg/h. feed rate, 7 mm clearance and 700 rpm roller speed. From three dimensional responses generated for Dehulling efficiency, it could be evident that dehulling efficiency was high at less clearance between roller and sieve where as it was gradually decreased with increase in clearance. On the other hand the dehulling efficiency was increase with increasing feed rate. It was found low at less roller speed and increased initially with increased in roller speed as shown in Fig. 3, similar result was observed by (Mandhyan and Jain, 1993).

Numerical Optimization

In order to optimize the input parameters for black gram by numerical optimization which finds a point that maximizes the desirability function equal importance of 3 was given to all the 3 input parameters and 3 responses.

Table 6.1: Solution generated by the software for dehulling, *gota* recovery, *dal* yield and dehulling efficiency of black gram.

Variable	Optimized values	Responses	Predicted values
Feed rate, kg/h	200	*Gota* recovery, %	12.79
Clearance, mm	6	*Dal* yield, %	59.09
Roller speed, rpm	1250	Dehulling efficiency, %	71.90
The optimum values of variables for dehulling were found within the range considered in the study.			

Table 6.2: Predicted and experimental values of response at optimum operational parameters for dehulling of black gram.

Sr. No.	Responses	Predicted values	*Experimental values (±SD)
1	*Gota* Recovery (%)	12.79	12.01 (±0.5)
2	*Dal* Yield (%)	59.09	58.96 (±1.78)
3	Dehulling Efficiency (%)	71.90	70.87 (±1.32)

* Average of three replications

The main criteria for optimization were maximum possible *gota* recovery and dehulling efficiency and *dal* yield was minimum. The optimization criteria for input parameters and responses constraints are as shown in Table 6.

Verification of the model

The three experiments were conducted at the optimum level of independent variables and the responses were determined. The observed experimental values (mean of three experiments) and values predicted by the equation of the model are presented in Table 6.2. The experimental values found to be close to the predicted values for *gota* recovery, *dal* yield and dehulling efficiency. Thus, the closeness between the experimental and predicted values of responses indicated the suitability of corresponding models.

Conclusion

The optimal operational parameters for the small-scale black gram dehulling machine, determined through response surface methodology or similar optimization, were a feed rate of 200 kg/h, roller clearance of 6 mm, and roller speed of 1250 rpm. These conditions maximized *gota* recovery and dehulling efficiency while minimizing *dal* yield. The model-predicted values were 12.79% for *gota* recovery, 59.09% for *dal* yield, and 71.90% for dehulling efficiency, closely aligning with experimentally validated values of 12.09%, 58.96%, and 70.87%, respectively.

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