

Optimization of groundnut decortivating machine parameters using response surface methodology

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Paper History

Received: 20th July, 2023

Accepted: 12th August, 2023

Published: August, 2023

Abstract:

Performance efficiency is heavily influenced by the decortivating machine's operational settings. This study assessed the impact of feed rate, moisture content, and decortivating speed on the performance indices of groundnut decortication. To analyse the impact of the input factors and improve the processing settings, response surface approach was utilized. The performance responses for decortivating capacity and cleaning efficiency were sufficiently represented by the established second-order polynomial model. Significant influences on performance responses were revealed by the input factors. The ideal performance responses were obtained with a 180-rpm drum speed, an 8% moisture content, and a 300 kg/h feed rate. The optimal results were 49.34% cleaning efficiency and 94.86% decortivating efficiency. These provided standard input parameters capable of yielding high decortivating and cleaning efficiency with minimum seed damage on groundnut seeds. The outcome of the groundnut decorticator's theoretical optimisation suggests that farmers who shell for seeds can now acquire more seeds shelled with little breakage and hence earn more money. These performance responses were empirically verified and matched the outcomes rather well.

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Keywords: Decorticator, Efficiency, Feed rate, Groundnut, Response surface methodology

1. Introduction

The development of indigenous technology at small and medium scale levels to increase agricultural production is a result of population growth. As a result, many technologies, such groundnut shellers, were developed and altered. The leguminous groundnut, also known as the peanut, is farmed for its edible seeds, oil, and kernels, which are packed with protein [1]. Groundnut (*Arachis hypogaea*) is the sixth most significant oil crop in the world. India, China, Nigeria, Senegal, Sudan, Burma, and the United States of America are the largest groundnut-producing nations, with a global yield of 1.4 metric tonnes per hectare (t/ha) [2, 3].

Due to home and industrial use, the demand for groundnuts has increased to 47.1 million tonnes within an area of 2.8 million hectares [4]. However, the groundnut heap is still beaten with sticks on hard ground surfaces or shelled by hand using conventional methods. According to Paulsen, *et al.* [5], these approaches are linked to contamination with dirt and kernel damage up to 22%, low productivity dependent on the worker's motivation and health [6], and inefficiency with high drudgery and time requirements.

By manually beating the pods in sacks, groundnut decortivating is the most used technique in Nigeria. Although there have been numerous attempts to motorize the process, there are still issues with cost, seed damage, and efficient seed cleaning.

Using manually operated groundnut decorticators, which have a high rate of kernel breakage and low efficiency. Gitau, *et al.* [7] conducted an experiment to optimize the performance of the device. Farmers as a result experience low income due to the cheap cost of shattered kernels and lose a lot of time during the laborious shelling process. A decorticator was created as part of efforts to produce an efficient and practical motorized groundnut decortivating machine for Nigerian farmers. This objective of this work is to optimize the groundnut decorticator's performance for simple adaptation and future enhancement.

2. Materials and methods

2.1 Sample Preparation

Local accessible Groundnut pods of several varieties were bought from the Jimeta Yola Temporary Market in Adamawa, Nigeria, and soaked for 24 hours in clean water. Then, using a portable digital grain moisture metre for rice, Paddy, Maize and Wheat to measure the proper moisture levels, the pods were spread out under shed in a thin layer to dry naturally with ambient air. Range for detecting moisture: 2% to 30%. To ensure stable and uniform moisture content, the groundnut pods with the desired moisture contents were divided into groups of 8%, 14%, and 20% and sealed in marked polythene bags. According to

Gitau, et al. [7] and Saleh, et al. [8]. All the sample were weighted at 2 kilogram each.

2.2 Groundnut Decorticator

Figure 1 shows the decorticator unit, cleaning unit, delivery, and discharge chutes made up the Groundnut decorticator. To lessen the severe kernel damages, the

decortication unit used a rasp bar constructed of an iron rod as opposed to the rasp bar. A cylindrical iron rod was also used to create the concave. A centrifugal blower made of metal iron sheet made up the cleaning apparatus. Metal sheets were used in the construction of the delivery chute and discharge chute (outlet). The delivery chute was built to enable a smooth, gravity-driven kernel release.

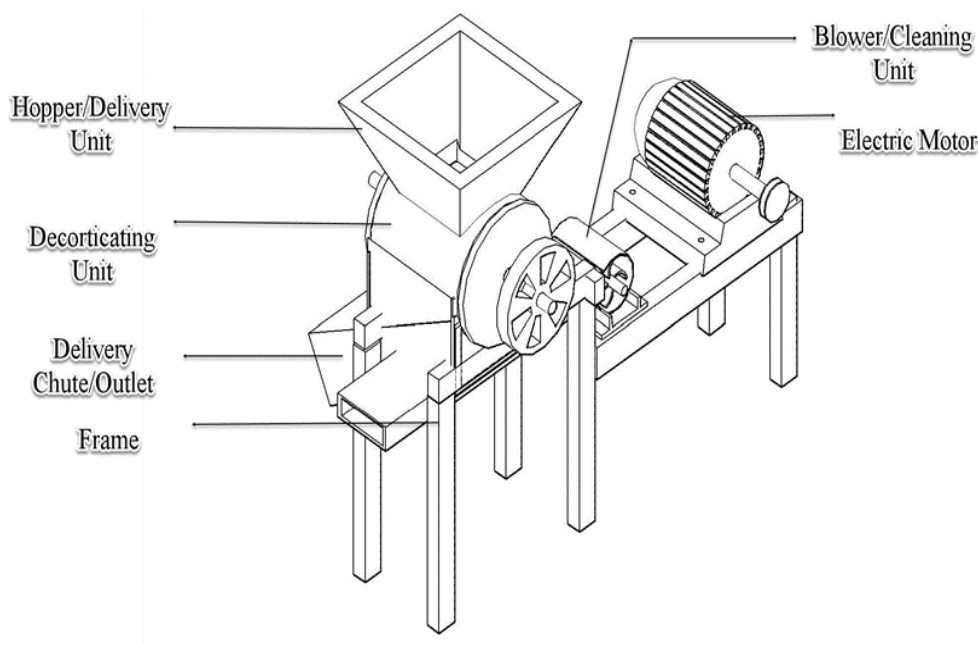


Figure 1: Groundnut decorticator

2.3 Performance Evaluation of Machine

Oluwole, et al. [7] protocol was followed in the tests to assess the efficacy of the groundnut decorticator. The amount of in-shell per decortications trial was set at 2Kg at moisture contents of 8%, 14%, and 20%, respectively, to eliminate bias and enable fairness to all the trials so that findings achieved should not be by chance. This was manually inserted into the hopper. According to Muhammad et al. [10], the decorticator drum speed was varied at 180rpm, 220rpm, and 260rpm rotations per minute (rpm), and the feed rate was 10 kg per hour, 15 kg per hour, and 30 kg per hour, respectively.

After being released into the decorticator, the pods were decorated until the hopper was empty. Initial testing revealed that the 20 mm concave clearance might produce good results. Therefore, throughout the performance tests, this clearance was upheld. The clearance level selected was in accordance with Saleh, et al. [8], Oluwole, et al. [9], and Khan [11], who discovered clearance levels when maximizing the operating conditions for a model machine to crush groundnuts while maintaining the concave clearance between 20 and 30 mm. The diameters of the three screen apertures that were used are 8, 10, and 12. Based on the physical dimensions of the groundnut variety used, these were chosen. Groundnut samples in their shells were decorated.

Machine was evaluated based on, Decorticator efficiency, cleaning efficiency, and mechanical damage

2.3.1 Decorticator efficiency

The machine decorticator efficiency was calculated from the following relation According to Alonge & Kosemani, [12]:

$$\varepsilon_s = 1 - \frac{Q_u}{Q_T} \times 100 \quad (1)$$

Where, ε_s = shelling efficiency (%), Q_u = totalweight of groundnut sample (kg), Q_T = weight of unshelled groundnut (kg).

2.3.2 Cleaning efficiency

The cleaning efficiency was estimated by the ratio of weight of cleaned groundnut by that of chaff plus weight of cleaned groundnut as reported by Mohammed & Hassan, [13]:

$$C_e = \frac{Q_s}{Q_s + Q_c} \times 100 \quad (2)$$

Where, C_e =cleaning efficiency (%), Q_c =weight of chaff collected at the main outlet (kg), Q_s = weight of cleaned groundnut kernels received at the outlet (kg).

2.4 Experimental design and statistical analysis

It used a four-factor, three-level design. Table 1 lists the variables as decorticator drum speed shown by (A), moisture content indicated by (B), feed rate indicated by (C), and screen aperture indicated by (D). Based on the early

trial results, the experimental ranges for each factor were chosen. Using response surface methodology (RSM) of Stat-Ease Design Expert software version 13. These variables were used to develop and optimize the performance parameters of the groundnut sheller.

The RSM's benefit is that it minimizes the quantity of experimental runs required to assess numerous parameters and their interactions. In order to generate a higher-order response with a minimal number of runs necessary to sustain the higher order surface response, a Box-Behnken design was used. In total, five replicates at centre points were used in a total of 17 experimental runs. Table 2, and Table 1. Equation 4 illustrates how these responses were optimised using a second-order polynomial model [10, 14, 15].

$$y = \beta_0 \sum_{i=1}^n \beta_i x_i + \sum_{i=1}^n \beta_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n \beta_{ij} x_i x_j \quad (3)$$

Where: y = predicted response, β_0 = Constant, $\beta_i \beta_{ii} \beta_{ij}$ = linear, quadratic and interaction coefficients, respectively, $x_i x_j$ = levels of the independent variables

The generated non-linear models' goodness of fit was evaluated using the analysis of variance (ANOVA) by looking at fit, R-squared values (R^2 , adjusted R^2 , and predicted R^2), sufficient precision, and coefficient of variation (CV).

Table 1: Parameters used for Response surface methodology (Box-Behnken design)

SN	Parameters	Unit	low	Medium	High
1	Moisture Contents	%	8	14	20
2	Drum Speeds	Rpm	140	180	220
3	Feed Rate	Kg/h	150	225	300

Table 2: Box-Behnken design showing the experimental results responses and Parameters

Std	Run	Factor 1 A: speed (rpm)	Factor 2 B: Moisture Content (%)	Factor 3 C: Feed Rate (Kg/h)	Response 1 Decorticating Efficiency (%)	Response 2 Cleaning Efficiency (%)
4	3	220	20	225	88.5	41.8
8	8	220	14	300	93.2	47
2	16	220	8	225	95.9	53.1
6	17	220	14	150	95.7	47.2
11	2	180	8	300	96.2	52.6
10	4	180	20	150	88.5	39.4
15	6	180	14	225	95.6	49.3
14	7	180	14	225	96	48.4
9	9	180	8	150	95.1	50.1
16	11	180	14	225	96.1	48.2
13	12	180	14	225	95.9	48.6
12	13	180	20	300	83.4	36.2
17	15	180	14	225	94.7	48.3
3	1	140	20	225	82	29.3
1	5	140	8	225	94	46.9
7	10	140	14	300	89.7	36.1
5	14	140	14	150	93.4	37.3

3 Results and discussion

Groundnut decorticator was evaluated by studying the effect of the operating speed and moisture content and feed rate on the decorticating efficiency, and cleaning efficiency.

3.1 Effects of Input Variables on machine Efficiency

The ANOVA results in Table 3 show the response surface of a quadratic model (Sequential sum of squares for the quadratic (A-squared, B-squared, etc.) terms machine efficiency. The F-value test the significance of adding quadratic terms to the 2FI model. Terms for all responses are shown in Table 3. The Model F-value of 92.77 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, BC, A², B², C² are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many

insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The Lack of Fit F-value of 1.50 implies the Lack of Fit is not significant relative to the pure error. There is a 34.37% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Table 4 shows that the Predicted R² of 0.9235 is in reasonable agreement with the adjusted R² of 0.9810; i.e., the difference is less than 0.2. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 28.332 indicates an adequate signal. This model can be used to navigate the design space.

A Quadratic equation in terms of coded factors was generated to fit the experimental data using response surface methodology as shown in equation 5. Actual factors equation was not used to determine the relative impact of each factor.

Table 3: ANOVA (partial sum of squares) for the quadratic model of Decortating Efficiency (%)

Model	327.06	9	36.34	92.77	< 0.0001	significant
A-decortating Speed	25.20	1	25.20	64.35	< 0.0001	
B-Moisture Content	188.18	1	188.18	480.40	< 0.0001	
C-Feed Rate	13.00	1	13.00	33.20	0.0007	
AB	5.29	1	5.29	13.50	0.0079	
AC	0.3600	1	0.3600	0.9190	0.8697	
BC	9.61	1	9.61	24.53	0.0017	
A ²	11.88	1	11.88	30.34	0.0009	
B ²	63.39	1	63.39	161.82	< 0.0001	
C ²	4.04	1	4.04	10.32	0.0148	
Residual	2.74	7	0.3917			
Lack of Fit	1.45	3	0.4833	1.50	0.3437	not significant
Pure Error	1.29	4	0.3230			
Cor Total	329.80	16				

Table 4: Predicted and adjusted R-squared for Decortating Efficiency

Std. Dev.	0.6259	R ²	0.9917
Mean	92.58	Adjusted R ²	0.9810
C.V. %	0.6760	Predicted R ²	0.9235
		Adequate Precision	28.3321

Because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the centre of the design space.

$$\text{Decortating Efficiency} = 95.66 + 1.775A - 4.85B - 1.275C + 1.15AB + 0.3AC - 1.55BC - 1.68A^2 - 3.88B^2 - 0.98C^2 \quad (5)$$

To confirm the model validity, the model prediction was compared with experimental data as shown in Figure 2. It was found that the model was successful in capturing the correlation between the process parameters to the response with a correlation coefficient. The high value of adjusted determination coefficient (Adj.R² = 0.9810) further confirms the significance of the model, and a relatively low value of

variation coefficient (CV = 0.6760%) indicates a high precision and reliability of our experimental data. The adequate precision higher than 4 confirms the adequacy of model by measuring the signal to noise ratio.

Figure 3 displays the 3D graphs created for the fitted model to highlight how input factors affect efficiency. Efficiency levels varied between 82.0 and 96.2%. As shown in Figure 2, the lowest speed of 140 rpm, highest moisture content of 20%, and feed rate of 225 kg/h resulted in the lowest shelling efficiency, while the highest speed of 220 rpm, lowest moisture content of 8%, and feed rate of 300 kg/h resulted in the highest shelling efficiency. Increased drum speed and a drop in groundnut pod moisture content both boost decortating efficiency. Because groundnut pods are fragile at low moisture levels, decorating them is simpler. It was noted that the efficiency was 98% [16]. According to other studies' findings, factors affecting the machine efficiency of groundnut shellers include concave size, shelling drum clearance, cylinder speed, feed gate width, and moisture level of the nuts [1, 10, 17].

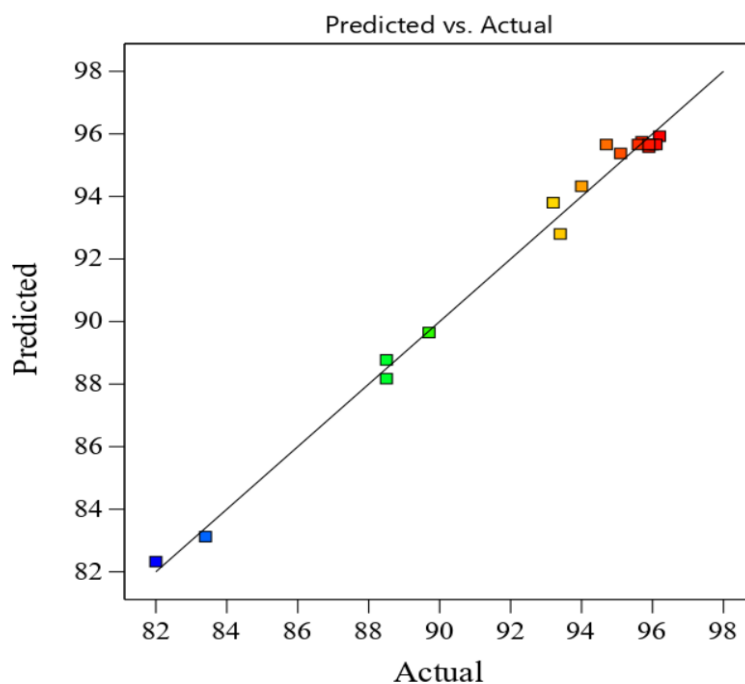


Figure 2: Plot of predicted Decortating Efficiency (%) against experimental Decortating Efficiency (%)

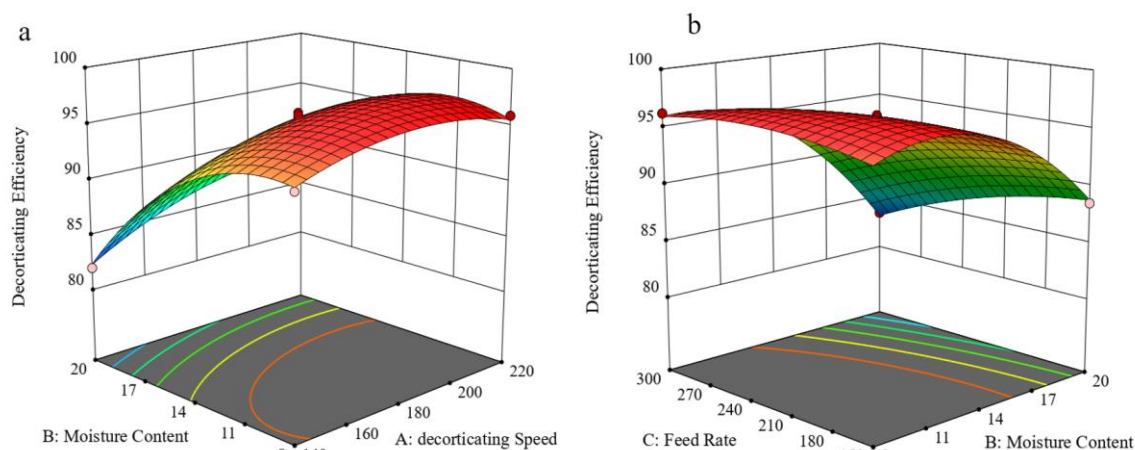


Figure 3: 3D response surface plot Decortating Efficiency interaction between (a) Moisture Content versus speed, (b) Feed Rate versus Moisture Content

3.2 Effects of Input Variables on cleaning Efficiency

Terms for all responses is shown in Table 5. The responses are shown in ANOVA result for the response surface of a quadratic model (Sequential sum of squares for the quadratic (A-squared, B-squared, etc.) terms for Cleaning Efficiency. The F-value tests shows the significance of adding quadratic terms to the 2FI model while the Model F-value of 315.81 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case A, B, AB, BC, A², B², C² are significant model terms. Values greater than 0.1000 indicate

the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The Lack of Fit F-value of 1.76 implies the Lack of Fit is not significant relative to the pure error. There is a 29.38% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Table 6 shows that the Predicted R² of 0.9760 is in reasonable agreement with the Adjusted R² of 0.9944; i.e., the difference is less than 0.2. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 61.5674 indicates an adequate signal. This model can be used to navigate the design space.

Table 5: ANOVA table (partial sum of squares) for the quadratic model of Cleaning Efficiency (%)

Model	726.62	9	80.74	315.81	< 0.0001	significant
A-decortating Speed	195.03	1	195.03	762.91	< 0.0001	
B-Moisture Content	392.00	1	392.00	1533.39	< 0.0001	
C-Feed Rate	0.5513	1	0.5513	2.16	0.1854	
AB	9.92	1	9.92	38.81	0.0004	
AC	0.2500	1	0.2500	0.9779	0.3557	
BC	8.12	1	8.12	31.77	0.0008	
A ²	75.34	1	75.34	294.70	< 0.0001	
B ²	10.18	1	10.18	39.83	0.0004	
C ²	24.86	1	24.86	97.26	< 0.0001	
Residual	1.79	7	0.2556			
Lack of Fit	1.02	3	0.3392	1.76	0.2938	not significant
Pure Error	0.7720	4	0.1930			
Cor Total	728.41	16				

Table 6: Predicted and adjusted R-squared for Cleaning Efficiency

Std. Dev.	0.5056	R ²	0.9975
Mean	44.69	Adjusted R ²	0.9944
C.V. %	1.13	Predicted R ²	0.9760
		Adequate Precision	61.5674

A Quadratic equation in terms of coded factors was generated to fit the experimental data using response surface methodology as shown in equation 6 below. Actual factors equation was not used to determine the relative impact of each factor because the coefficients are scaled to

accommodate the units of each factor and the intercept is not at the center of the design space

$$\text{Cleaning Efficiency} = 48.56 + 4.9375A - 7 - 0.2625C + 1.575AB + 0.25AC - 1.425BC - 4.23A^2 - 1.555B^2 - 2.43C^2 \quad (6)$$

To confirm the model validity, the model prediction was compared with experimental data as shown in Figure 3. To confirm the model validity, the model prediction was compared with experimental data as shown in Figure 4. It was found that the model was successful in capturing the

correlation between the process parameters to the response with a correlation coefficient.

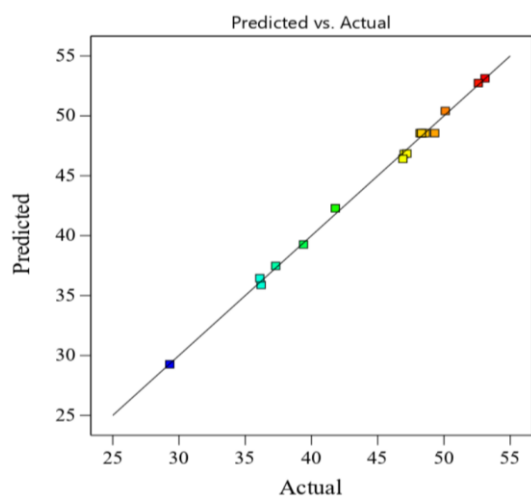


Figure 4: Plot of predicted Cleaning Efficiency (%) against experimental Cleaning Efficiency (%)

The high value of adjusted determination coefficient ($\text{Adj. } R^2 = 0.9944$) further confirms the significance of the

model, and a relatively low value of variation coefficient ($\text{CV} = 1.13\%$) indicates a high precision and reliability of our experimental data. The adequate precision higher than 4 confirms the adequacy of model by measuring the signal to noise ratio.

Figure 5 shows that cleaning efficiency varied from 29.3 to 53.1%. The lowest moisture level of 8% and drum speed of 220 rpm resulted in a cleaning effectiveness of 53.1%, as indicated in the 3D interaction plots (Figure. 5a and 5b). The groundnut pods' moisture content decreased, and the drum speed increased, improving cleaning effectiveness. Groundnut chaffs lose weight when their moisture content drops, making them easier for the blower's air stream to blow out of the exit. An earlier study by Oluwale, *et al.* [18], found that the greatest cleaning effectiveness was 87.3% at a moisture content of 5.3%, Muhammad, *et al.* [10] also found that a cleaning efficiency of 56.1 at moisture content of 8%. According to Atiku, *et al.* [19], the Bambara groundnut's winnowing efficiency declines as moisture content rises. It's possible that the buildup of moisture in the groundnut pods increased the bulk density of the shell, which would have made the pods more resistant to pneumatic separation.

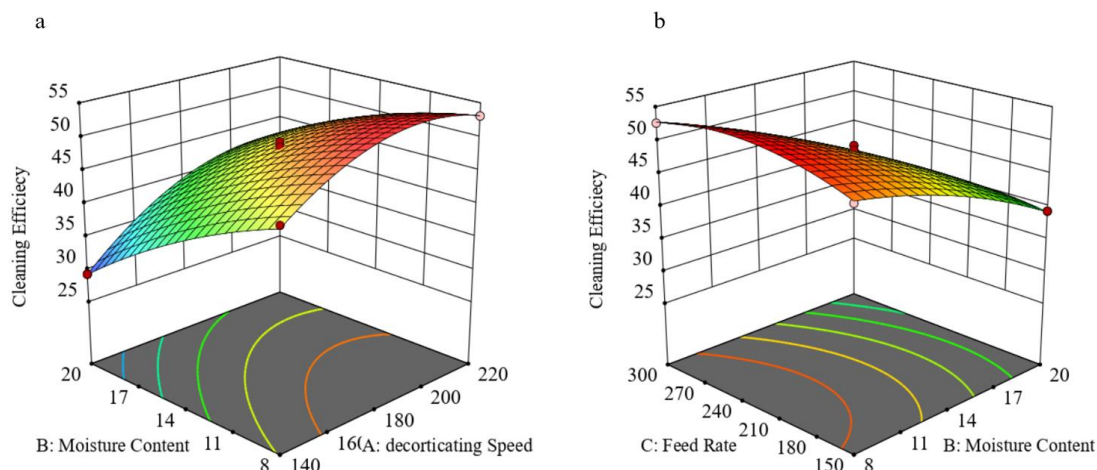


Figure 5: 3D response surface plot Cleaning Efficiency interaction between (a) Moisture Content versus speed, (b) Feed Rate versus Moisture Content

3.3 Optimization of Machine Decortating and Cleaning Efficiency

The performance assessment of the groundnut decorticator was optimised using the quadratic models obtained in this work. One of the primary objectives of the machine performance optimization process is to maximize the efficiency of machine decortating and cleaning. Table 7 displays 10 different optimization solutions. As already indicated, the decortating and cleaning efficiency of the machine are directly impacted by the speed, moisture content, and feed rate. In this instance, maximum decortating and cleaning efficiencies were attained at 94.864% and 49.339%, respectively, by reducing the speed of the decortating process and the moisture content to

157.40 rpm and 8%, and increasing the feed rate to 300 kg/h.

The numerical optimization predicts that the maximum decortating and cleaning efficiencies could be achieved at the speed of 157.37rpm, moisture content of 8.0%, and feed rate of 299.99Kg/h. Further experimental examinations at the suggested optimum conditions were carried out and obtained the decortating efficiency and cleaning efficiency of 94.8638% and 49.3392% respectively, shown in Table 8, which was in a good agreement with the predicted value of 95.113% and 50.901% based on response surface methodology. The relative error between the predicted and actual efficiencies of 0.5919 and 0.478168 for both Decortating Efficiency Cleaning Efficiency.

Table 7: Solutions optimization for Decortiating and Cleaning Efficiency

Number	decortiating Speed	Moisture Content	Feed Rate	Decortiating Efficiency	Cleaning Efficiency	Desirability	
1	157.367	8.000	299.999	94.864	49.339	0.902	Selected
2	157.664	8.000	299.999	94.885	49.401	0.902	
3	157.019	8.000	299.999	94.839	49.266	0.902	
4	158.189	8.000	299.999	94.921	49.510	0.902	
5	156.164	8.000	300.000	94.777	49.083	0.902	
6	155.801	8.000	299.999	94.751	49.004	0.902	
7	156.413	8.000	299.614	94.805	49.156	0.902	
8	157.444	8.000	299.454	94.883	49.383	0.902	
9	158.608	8.000	299.566	94.960	49.618	0.902	
10	159.369	8.000	299.999	95.001	49.749	0.902	

Table 8: Performance of the groundnut decorticator under ideal conditions, as predicted and measured

Response	Predicted Mean	Predicted Median	Std Dev	SE Mean
Decortiating Efficiency	94.8638	95.113	0.625871	0.5919
Cleaning Efficiency	49.3392	50.901	0.505611	0.478168

The numerical optimization predicts that the maximum decortiating and cleaning efficiencies could be achieved at the speed of 157.367rpm, moisture content of 8.000%, and Feed rate of 299.999Kg/h. Further experimental examinations at the suggested optimum conditions were carried out and obtained the Decortiating Efficiency and cleaning efficiency of 94.8638% and 49.3392% respectively, shown in Table 8, which was in a good agreement with the predicted value of 95.113% and 50.901% based on response surface methodology. The relative error between the predicted and actual efficiencies of 0.5919 and 0.478168 for both decortiating and cleaning efficiency.

3.4 Models Validation

For model validation, three separate performance tests were carried out. For the simplicity of taking the measurement, the indicated ideal input variables for the drum speed, moisture content, and feed rate were changed to approximately values of 180 rpm, 8%, and 300 kg/h, respectively. As shown in Table 8, the performance test findings were consistent with the projected optimum responses. Following the performance assessment of a dehulling machine, Goyal, *et al.* [19] showed similar agreement between predicted and experimental values. According to our analysis, the best performance indices were 49.34% for cleaning efficiency and 94.87% for decoratating efficiency. The appropriateness of the constructed models was shown by how closely these values matched the projected values.

4 Conclusion

For the best performance of a groundnut decortiating machine in terms of decortiating efficiency and cleaning efficiency, the input parameters (speed, moisture content, and feed rate) were optimised using response surface approach (Box Behnken Design). The drum speed was 180 rpm, the moisture content was 8%, and the feed rate was 30 kg/h. These values were close to those predicted by the Response surface approach numerical optimization. This showed that, within the permitted range of performance responses, the RSM adequately described the created models. Additionally, increasing the clearance between the

drum and the concave will help to improve low cleaning efficiency.

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