

Effect of operational factors on the efficiency and throughput capacity of African locust bean processing machine

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Abstract: De-hulling and cleaning of beans remains a major tedious operation in the processing of locust bean. Using a locust bean de-huller that combine de-hulling and cleaning is one approach to reduce drudgery and improve the quality of the seed. The aim of research is to optimise the operating conditions of a locust bean processing machine for de-hulling and cleaning. To measure de-hulling and cleaning efficiency, dried locust beans were boiled at 2, 4 and 6 hr boiling time, loaded onto the machine at various feeding rates (15, 20, and 25 kg hr⁻¹) and shaft speed (7, 8, 9). The response surface methodology (RSM) was utilised to optimize the operating parameter used in de-hulling process. Quadratic models were developed to establish the interaction between the operational parameters and the response factors. The effect of the investigated operational parameters on the de-hulling and cleaning efficiency was significant ($p \leq 0.01$). The optimal condition of the process for shaft speed, boiling time and feeding rate were 7 m s⁻¹, 6 hr and 25 kg hr⁻¹, respectively, resulting in quantitative de-hulling efficiency, qualitative de-hulling efficiency, throughput capacity and cleaning efficiency of 98.67%, 25.85%, 21.66 kg hr⁻¹ and 84.62%, respectively. This indicate that the locust bean processing machine performed efficiently at optimal conditions thus valid the models developed.

Keywords: Models; De-hulling; Optimization; Locust bean; Parameters; Processing; response factors

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1 Introduction

African locust bean (*Parkia biglobosa*) is legume commonly found in African environment because of its high commercial values as food condiment and a

medicinal agent. It is rich in numerous nutrients including protein, carbohydrate, fat, sugar and ascorbic acid (Omodara and Olowomofe, 2015; Ojukwu et al., 2019; Afolabi et al., 2025). Whenever the bean is fermented, it contains 5% of the total daily protein intake and 1.4% of calorie intake (Odunfa, 1985; Akinyele et al., 2023). African locust bean has been consumed as an alternative source of protein for most people because it is very cheaper than the animal protein (Ajayi, 2014; Omodara and Omojokun,

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2024; Masters and Kelly, 2024). African locust bean seeds are processed into some essential food products like condiments and flavouring agents used in preparing soups, stews and porridges (Adeoye et al., 2018; Afolabi et al., 2025; Ogunlade et al., 2023). When fermented, it gives a pleasant aroma needed as a flavouring agent and food condiments like *iru*, *dawadawa* and *okpeye* which are majorly used in food preparation (Odunfa, 1985; Sanya et al., 2013, Ifesan et al., 2019; Masters and Kelly, 2024).

Locust bean processing typically involves pod shelling, bean sorting, cleaning, steaming or boiling, de-hulling washing, and fermentation (Das et al., 2022). Despite research efforts of previous researcher including Olaoye (2010), Adeokun (2016), and Akinyele et al. (2023), locust bean processing is still done majorly using traditional method. This is because few processors adopt the use of existing locust bean processing machines due to factors including primitive belief, low bean quality and low output. Although the existing locust bean processing machine has solved the problem of unhygienic condition, time consuming, excessive labour and low quality of bean associated with traditional method of processing locust bean (Olabiwonnu et al., 2017; Das et al., 2022; Akinyele et al., 2023). Traditional method of processing locust is characterised with drudgery, consume time and give low quality yield (Raheem et al., 2017; Ajewole et al., 2018; Masters and Kelly, 2024). Production and consumption of locust bean is becoming unpopular most especially in the urban centers due to increase in the importation of foreign condiments and flavour. Consequently, it is imperative to mechanized locust bean production techniques and optimise processing conditions in order to increase the production substantially and sustainable (Audu et al., 2004; Okunola et al., 2019). Dehulling operation in locust bean processing is an important operation which determines the bean yield and acceptability (Kabanda et al., 2017; Afolabi et al., 2025). The primary goal of this research was to determine the optimal operating conditions for a locust bean processing machine in order to improve

the de-hulling and cleaning efficiency.

2 Materials and methods

2.1 Sample preparation

Locust bean seed used for the experiments was purchased in a farmer's market in Ibadan, Oyo State Nigeria. 500kg of the locust bean seed was used to conduct the experiment in Department of Agricultural Engineering workshop, Federal College of Agriculture, Ibadan Oyo State, Nigeria at latitude 7.3792° N, and longitude 3.8444° E. The weight of the bean was measured using a digital weighing scale. The average moisture content of the locust bean, after purchase, was 13% (w.b) measured with a digital moisture analyser. Impurities such as stones, straw, immature and unfilled bean were removed through hand picking methods to reduce breakage during de-hulling. The cleaned bean seed was divided into three portion and then boiled using a Nigerian developed boiler for 4, 5 and 6 hours, respectively.

2.2 Description and operation of the locust beans processing machine

The locust bean processing machine operates on the principle of abrasion. It combines both de-hulling and cleaning operations. Figure 1 depicts the 3-Dimensional drawing of the locust bean processing machine components majorly consist of the de-hulling chamber and cleaning section. The de-hulling chamber consist of the hopper, de-hulling shaft, a fixed non-perforated concentric cylinder. The concentric cylinder housed the de-hulling shaft made from 30 mm stainless rod materials. The cleaning section consist of a perforated cylinder, seed outlet, water inlet, an outlet (waste water and seed coat outlet). All made from a stainless-steel material. Other components include structural frame and engine seat both made from 50 × 50 × 4 mm mild steel angle iron. The hopper which is trapezoidal in shape was placed directly on concentric cylinder at the de-hulling section of the machine at one end of the machine. It was constructed using 3 mm stainless steel sheet of length of 700 mm and radius of 75 mm. The de-hulling shaft was made from a 600 mm long,

30 mm diameter shaft wound with a 10mm rod to the length of 200 mm and 4 straight square rods of length 400 mm arranged equally on the circumference of the rod. The de-hulled seed is collected from the seed outlet tangentially. The seed outlet is 100 × 100 mm square shaped components made from 3 mm stainless sheet as show in Figure 1. The frame

supported all other components and was constructed with 50 x 50x 3 mm angle iron bars. The prime mover which transmitted rotatory power through belt-pulley arrangement to the pulley mounted on the de-hulling shaft rating was 3.76 kW single phase electric motor. The locust bean processing machine is depicted in Plate 1.

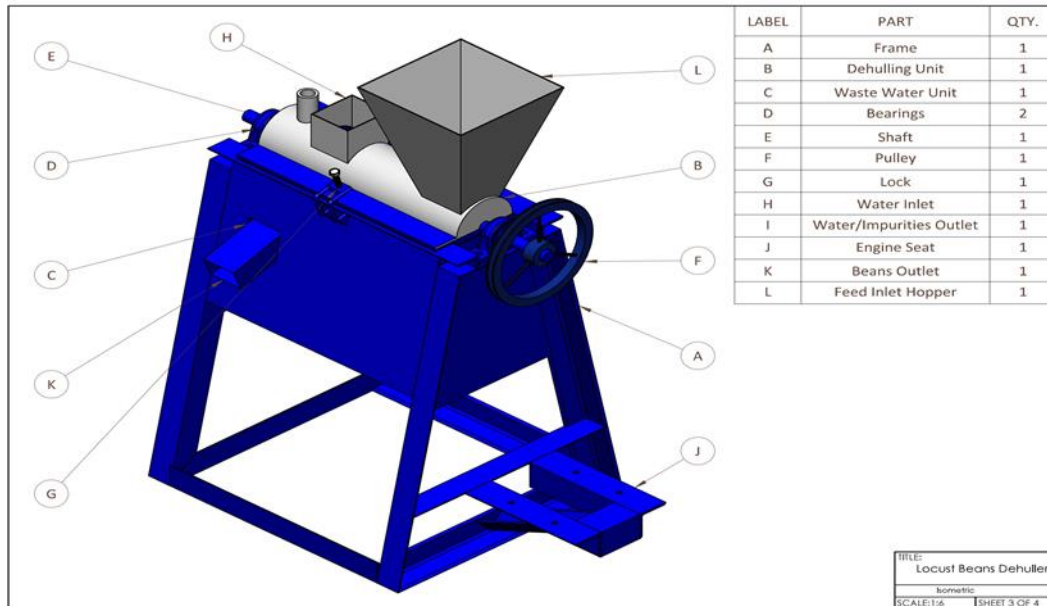


Figure 1 3- Dimensional drawing of the locust bean processing machine



Plate 1 Locust bean processing machine

2.3 Experimental procedure

For each experiment, 20 kg samples of boiled locust bean seed were processed using shaft speed (7, 8, and 9 m s⁻¹) and feeding rate (15, 20 and 25 g hr⁻¹) for bean seed already boiled at (4.5, 6 hr), respectively. The shaft speed was determined using a sensitive tachometer. While the boiling time was

measure using a stopwatch. After de-hulling, the locust bean seeds were labelled for its combination of de-hulling variables (shaft speed, feeding rate, and boiling time).

The indices used to evaluate the performance of the locust bean processing machine were de-hulling throughput capacity (%), quantitative de-hulling

efficiency (%), qualitative de-hulling efficiency (%) and cleaning efficiency (%). These indices were determined following standard procedure and using expression obtain from literatures as shown in Equations 1-4 (Okonkwo et al., 2019; Owolarafe et al., 2013; Okunola et al., 2019).

$$T_c = \frac{m_t}{t_d} \quad (1)$$

$$E_{qt} = 100 \times \frac{m_u}{m_t} \quad (2)$$

$$E_{qt} = 100 \times E_{qt} \times C_w \quad (3)$$

$$E_{cl} = 100 \times \frac{w_c}{w_o + w_s} \quad (4)$$

Where,

T_c — throughput capacity (kg hr⁻¹),

m_t — weight of sample before de-hulling (kg),

t_d — de-hulling times (hr),

E_{qt} — qualitative de-hulling efficiency (%) ,

m_u — dehulled bean mass in the final product,

E_{qt} — quantitative de-hulling efficiency (%),

C_w — wholeness coefficient defining the quality of locust beans de-hulled,

E_{cl} — cleaning efficiency (%),

w_c — weight of clean beans (kg),

W_o — weight of coat (kg), and

W_s — weight of un- dehulled bean (kg).

2.4 Experimental design and statistical analysis

Response surface methodology (RSM) was used to evaluate the effect of three levels of shaft speed (7, 8, and 9 m s⁻¹), boiling time (4, 5, and 6 hr), and feeding rate (15, 20, and 25 kg hr⁻¹) on the performance of the locust bean processing machine. RSM was selected to determine the optimal condition for de-hulling and cleaning locust bean seed after boiling operation due to its ability to determine the effect of operating factors on the de-hulling and cleaning conditions and establish the optimum conditions of the process. The actual levels and coded factor levels of three independent variables, as indicated in Table 1, were utilised to develop 20 experimental runs with 8 centre points for evaluating the performance of the locust bean processing machinery, as shown in Table 2.

The data of the responses collected during performance evaluation was statistically analysed using Design Expert 13.0.1. Contour and 3D model graphs were generated using the software to analyse the interaction between the independent variables and the dependent variables and also to optimize the de-hulling and cleaning process.

Table 1 Actual and coded factor levels of independent variables used

Symbol	Independent variable	Actual levels at coded factor levels		
		-1	0	1
X1	Shaft speed (m s ⁻¹)	7	8	9
X2	Boiling time (hr)	4	5	6
X3	Feeding rate (kg hr ⁻¹)	15	20	25

3 Results and discussion

3.1 Effects of the input variables on the performance of the locust bean processing machine.

Table 2 presents the experimental findings of the effect of shaft speed, boiling time, and feeding rate on performance evaluation of the locust bean processing machine using box-behnken design (BBD) of RSM.

3.2 Quantitative and qualitative de-hulling efficiency

The quantitative and qualitative de-hulling efficiency of the machine ranged from 75.66% to

98.35% and 14.52% and 63.37% as shown in Table 2. A Three-dimensional (3D) surface plot of the effect of the three independent variables and their interaction on the quantitative and qualitative efficiency of the machine were as plotted on Figure 2 and 3. The plots showed that the shaft speed has a negative influence on the quantitative and qualitative de-hulling efficiency of the machine while the boiling time of the locust bean positively influences the quantitative efficiency of the machine. Therefore, increasing the shaft speed (from 7 to 9 m s⁻¹) and decreasing the boiling times (from 6 to 4 hr) during the de-hulling process at a constant feeding rate

decreased the quantitative and qualitative de-hulling efficiency of the machine as shown in Figures 2 and 3. This could be as a result of the testa of the seed which becomes softer and thicker at high boiling time and make de-hulling slower at increased shaft speed. This finding is in agreement with the Owolarafe et al. (2013) and Okonkwo et al. (2019).

3.3 Throughput capacity

The throughput capacity of the machine ranged from 13.08 to 21.30 kg hr⁻¹ at different shaft speeds, feeding rate and boiling times are as shown in Table 2. A plot of the effect of the shaft speed feeding rate and boiling time and their interaction on the throughput capacity of the machine were as plotted on Figure 4. The plots showed that the shaft speed has a positive influence on the throughput capacity of the machine while the boiling time of the locust bean also positively influences the throughput capacity. Therefore, increasing the shaft speed (from 7 to 9 m s⁻¹) and increasing the boiling times (from 4 to 6 hr) during the de-hulling process at a constant feeding rate increased the throughput capacity of the machine. This could be as a result of retention period of the locust bean in the de-hulling unit which reduces as the shaft speed increases and testa of the seed which

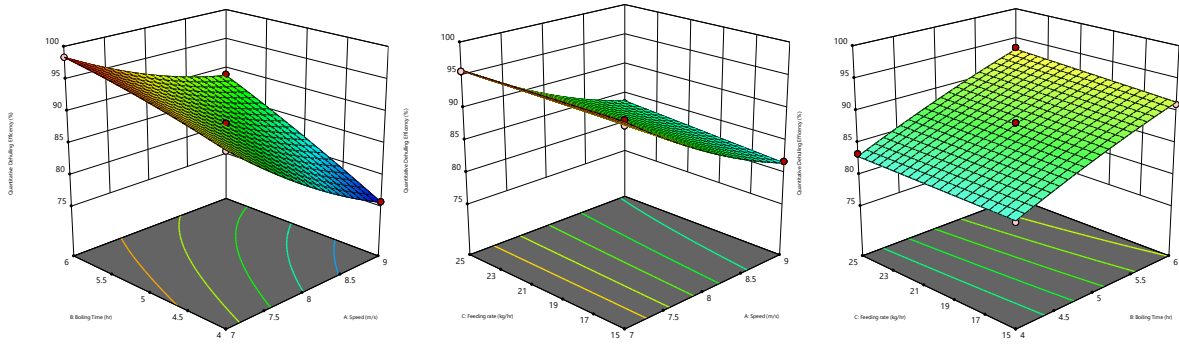
become softer as the boiling time increases and become easily conveyed the shaft. These findings are similar to that of Okonkwo et al. (2019).

3.4 Cleaning efficiency

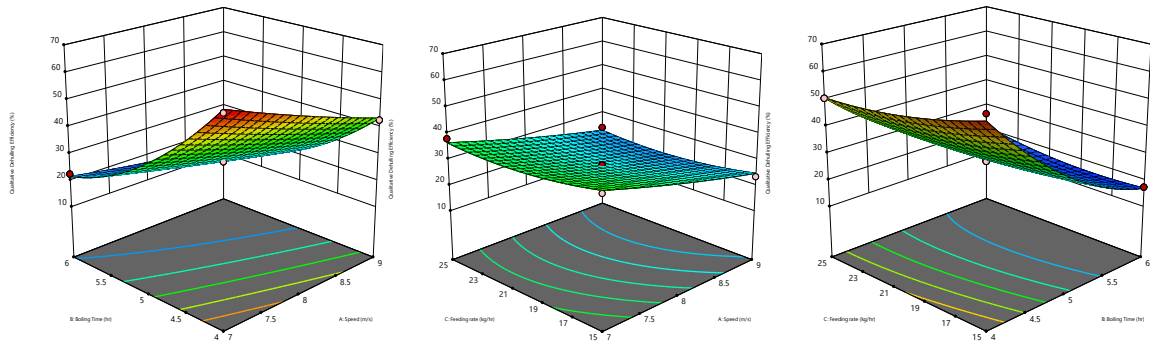
The cleaning efficiency of the machine ranged from 65.86% to 85.00% at different shaft speeds, feeding rate and boiling times are as shown in Table 2. A plot of the effect of the shaft speed feeding rate and boiling time and their interaction on the cleaning efficiency of the machine were as plotted on Figure 5. The plots showed that the shaft speed has a negative influence on the cleaning efficiency of the machine while the boiling time of the locust bean also positively influences the cleaning efficiency. Therefore, decreasing the shaft speed (from 9 to 7 m s⁻¹) and increasing the boiling times (from 4 to 6 hr) during the de-hulling process at a constant feeding rate increased cleaning efficiency capacity of the machine. This due retention period of the locust bean in the de-hulling unit which increases as the shaft speed decreases and testa of the seed which become softer as the boiling time increases and become easily crushed and conveyed the shaft at the cleaning unit of the machine. These findings are similar to that of Okonkwo et al. (2019).

Table 2 Experimental runs

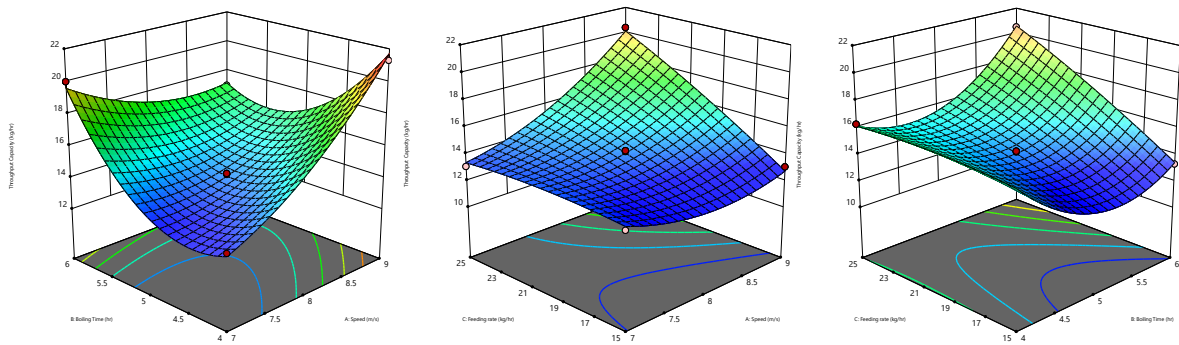
Run	Shaft speed (m s ⁻¹)	Boiling time (hr)	Feeding rate (kg hr ⁻¹)	Quantitative de-hulling efficiency (%)	Qualitative de-hulling efficiency (%)	Throughput capacity (kg hr ⁻¹)	Cleaning efficiency (%)
1	8	5	20	88.23	28.00	14.27	70.23
2	8	5	20	88.23	27.11	14.20	71.00
3	8	4	15	82.36	63.37	16.02	66.43
4	8	5	20	87.35	28.01	14.28	71.42
5	9	5	25	83.32	23.61	20.39	67.39
6	7	6	20	98.35	22.44	20.01	85.00
7	9	5	15	81.78	23.36	13.05	65.85
8	8	5	20	87.34	28.01	14.27	71.41
9	8	6	15	91.08	17.29	13.30	75.15
10	8	4	25	83.34	50.54	16.29	67.41
11	8	6	25	93.43	19.02	20.50	77.5
12	8	5	20	88.23	28.01	14.25	72.3
13	7	5	15	96.34	39.22	13.08	80.41
14	8	5	20	88.23	28.03	14.27	72.3
15	8	5	20	88.25	28.01	14.01	71.34
16	9	4	20	75.66	42.71	21.3	59.73
17	7	5	25	95.62	38.13	13.08	79.69
18	7	4	20	92.36	63.78	13.32	76.43
19	9	6	20	88.95	14.52	19.13	73.02
20	8	5	20	88.2	28.01	14.27	72.27



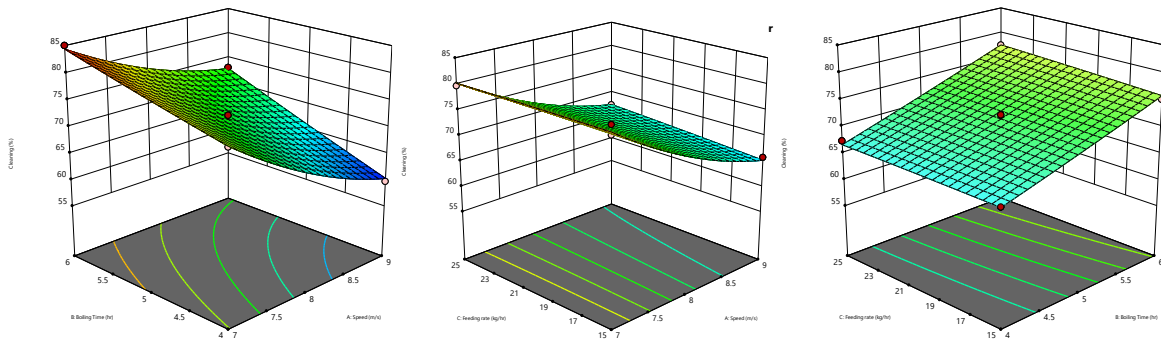
(a) Effects of boiling time and speed on the QDE (b) Effects of feeding rate and speed on the QDE (c) Effects of feeding rate and boiling time on the QDE
 Figure 2 Response surface charts displaying the interaction effects of shaft speed, boiling time and feeding rate on the quantitative de-hulling efficiency (QUDE)



(a) Effects of boiling time and speed on the QDE (b) Effects of feeding rate and speed on the QDE (c) Effects of feeding rate and boiling time on the QDE
 Figure 3 Response surface charts displaying the interaction effects of shaft speed, boiling time and feeding rate on the qualitative de-hulling efficiency



(a) Effects of boiling time and speed on the QTE (b) Effects of feeding rate and speed on the QTE (c) Effects of feeding rate and boiling time on the QTE
 Figure 4 Response surface charts displaying the interaction effects of shaft speed, boiling time and feeding rate on the qualitative throughput capacity (QTE)



(a) Effects of boiling time and speed on the CE (b) Effects of feeding rate and speed on the CE (c) Effects of feeding rate and boiling time on the CE
 Figure 5 Response surface charts displaying the interaction effects of shaft speed, boiling time and feeding rate on the cleaning efficiency (CE)

3.5 Effect of process factors on the evaluation indices of the machine

To forecast the effect of operating conditions on response variables across a large range, independent

and dependent variables were fitted to a second-order polynomial equation to develop regression models, as shown in Equations 5-8.

Table 3 displays the regression coefficients, their p - values and the coefficients of determination (R^2) of second order polynomials developed. The result of the statistical analysis showed that the developed models for all the responses were good, with acceptable values of R^2 and are non-significant lack of fit as shown in Table 4.

As shown in Tables 3 and 4, the values of adequate precision of the quantitative efficiency, qualitative efficiency, throughput capacity and

cleaning efficiency were 70.94, 48.94, 31.47 and 43.44, respectively. These values greater than 4 implies that the regression models adequately describe the experimental process (Islam-Shishir et al., 2016). Therefore, all the developed quadratic models consistently describe the experimental data.

$$E_{qt} = 88.0075 - 6.62A + 4.7615B + 0.51875C + 1.825AB + 0.565AC + 0.3425BC + 1.2675A^2 + 0.445B^2 - 0.01C^2 \quad (5)$$

$$E_{qt} = 27.8987 - 7.4213A - 18.391B - 1.4925C + 3.2875AB + 0.335AC + 0.3640BC + 0.7443A^2 + 7.2193B^2 + 2.43688C^2 \quad (6)$$

$$T_c = 14.1025 + 1.53125A + 0.485B + 1.85125C - 2.7475AB + 1.835AC + 1.7325BC + 1.08875A^2 + 2.71625B^2 - 0.2913C^2 \quad (7)$$

$$E_{cl} = 71.5337 - 6.9425A + 5.08375B + 0.51875C + 1.180AB + 0.5650AC + 0.3425BC + 1.86188A^2 + 0.149385B^2 - 0.0606C^2 \quad (8)$$

Table 3 Regression coefficients of second order polynomials

Model	Quantitative de-hulling efficiency (%)		Qualitative de-hulling efficiency (%)		Throughput capacity (kg hr ⁻¹)		Cleaning efficiency (%)	
Intercept	88.0075		27.8987		14.1025		71.5337	
A- Shaft speed	-6.62	< 0.0001	-7.4213	< 0.0001	1.53125	< 0.0001	-6.9425	< 0.0001
B –Boiling time	4.76125	< 0.0001	-18.391	< 0.0001	0.485	0.0067	5.08375	< 0.0001
C- Feeding rate	0.51875	0.009	-1.4925	0.0179	1.85125	< 0.0001	0.51875	0.0904
AB	1.825	< 0.0001	3.2875	0.0013	-2.7475	< 0.0001	1.18	0.013
AC	0.565	0.032	0.335	0.6629	1.835	< 0.0001	0.565	0.1796
BC	0.3425	0.1621	3.64	0.0006	1.7325	< 0.0001	0.3425	0.4022
A ²	1.2675	0.0001	0.74438	0.3111	1.08875	0.0002	1.86188	0.0005
B ²	-0.445	0.0624	7.21937	< 0.0001	2.71625	< 0.0001	0.14938	0.692
C ²	-0.01	0.9633	2.43688	0.0058	-0.2913	0.1527	-0.0606	0.8718
R ²	0.09963		0.9938		0.9892		0.9902	
Adjusted R ²	0.9930		0.9883		0.9795		0.9814	
Predicted R ²	0.9719		0.9041		0.9103		0.9316	
Adeq. Precision	70.9413		48.9429		31.4795		43.4414	

The ANOVA result for the performance evaluation of the locust bean processing machine are presented in Table 4. The ANOVA result for quantitative and qualitative de-hulling efficiency showed that effect of shaft speed, boiling time and feeding rate were significant at 1% level. This means that de-hulling efficiency depends on speed at which the machine is operated, the locust bean boiling time and the rate at which the bean is feed into the machine. This finding was in agreement with Egbe and Roland (2016) and Okonkwo et al. (2019). The interaction of the three factors considered showed a significant effect for AB, AC, A² in quantitative de-hulling efficiency while it showed a significant effect for AB, AC, B² and C². For throughput capacity, three factors considered were significant at 1% level. This implies that the shaft speed of the machine, the

boiling time of the locust bean and the feeding rate affect the throughput capacity of the machine. The interaction of the factors considered showed a significant effect for AB, AC, A² and B². For cleaning efficiency, one out of three factors considered was not significant at 1% level as shown in Table 4. Speed of the shaft and boiling time of the locust bean significantly affect cleaning efficiency. This implies that the cleanability of the locus bean seed is determine by the speed of shaft of the machine and boiling time of the locust bean. AB and A² were the only interactions of the factors that were significant.

The coefficient of determination (R^2) values of the responses (quantitative de-hulling efficiency, 0.9963; qualitative de-hulling efficiency, 0.9938; throughput capacity, 0.9892; cleaning efficiency, 0.9902) were above 0.8, indicating that the developed quadratic

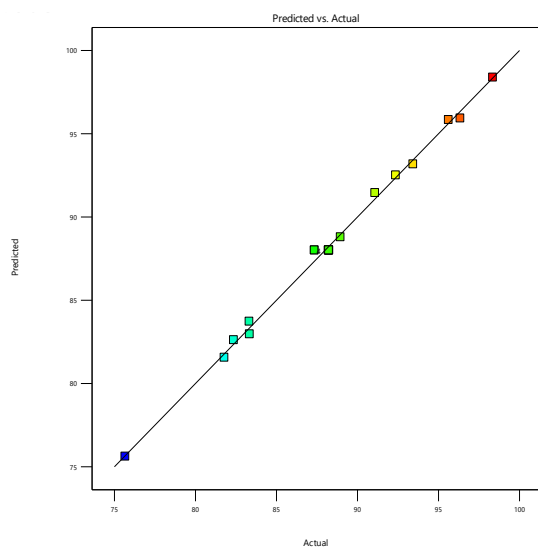
models appropriately predict the response variables. Zaibunnisa et al. (2009) stated that R^2 value greater 0.80 shows a good fit of a regression model.

Figure 2 showed correlation plots of the expected and actual values of the response variables. The plots show that the points are closely distributed near the straight line. This means that the generated quadratic models best represent the de-hulling and cleaning processes and are adequate predictors of the response variables.

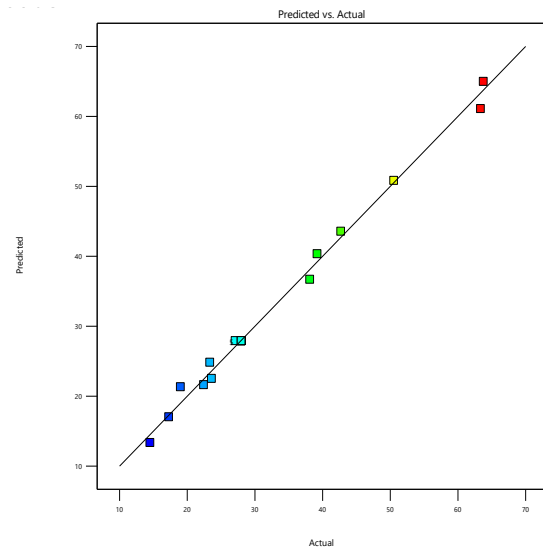
Figure 3 shows a plot of studentized residuals against expected values for the response variables. The points on the plots for all of the response variables are randomly distributed around 0.00, implying that the assumption of random errors having a mean of zero has not been violated, and the points are spread randomly from left to right, indicating that the developed quadratic models best fit the experiment.

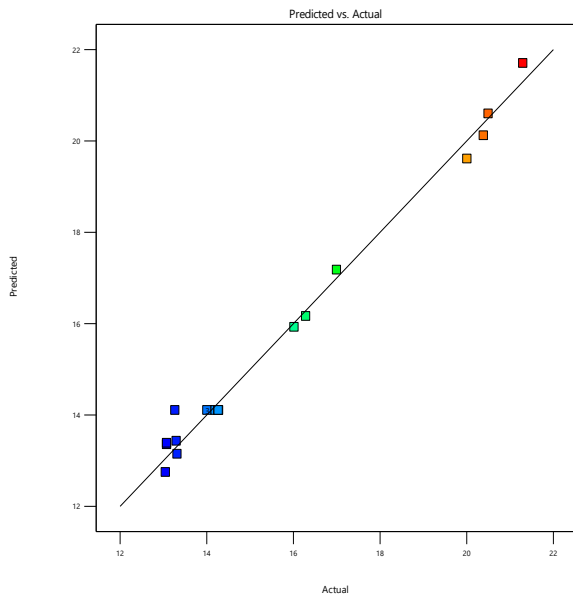
Table 4 ANOVA for the performance evaluation of the locust bean processing machine

Source	df	Quantitative de-hulling efficiency (%)		Qualitative de-hulling efficiency (%)		Throughput capacity (kg hr ⁻¹)		Cleaning efficiency (%)	
		Sum of squares	<i>p</i> -value	Sum of squares	<i>p</i> -value	Sum of squares	<i>p</i> -value	Sum of squares	<i>p</i> -value
Model	9	556.92	< 0.0001	3581.99	< 0.0001	148.20	< 0.0001	618.83	< 0.0001
A- Shaft Speed	1	350.60	< 0.0001	440.60	< 0.0001	18.76	< 0.0001	385.59	< 0.0001
B –Boiling Time	1	181.36	< 0.0001	2705.90	< 0.0001	1.88	0.0067	206.76	< 0.0001
C- Feeding Rate	1	2.15	0.0090	17.82	0.0179	27.42	< 0.0001	2.15	0.0904
AB	1	13.32	< 0.0001	43.23	0.0013	30.20	< 0.0001	5.57	0.0130
AC	1	1.28	0.0320	0.4489	0.6629	13.47	< 0.0001	1.28	0.1796
BC	1	0.4692	0.1621	53.00	0.0006	12.01	< 0.0001	0.4692	0.4022
A ²	1	7.34	0.0001	2.53	0.3111	5.42	0.0002	15.85	0.0005
B ²	1	0.9053	0.0624	238.26	< 0.0001	33.73	< 0.0001	0.1020	0.6920
C ²	1	0.0005	0.9633	27.15	0.0058	0.3878	0.1527	0.0168	0.8718
Residual	10	2.06		22.25		1.62		6.13	
Lack of Fit	3	0.8873	0.2407	21.54	< 0.0001	0.7704	0.1863	2.36	0.3042
Pure Error	7	1.17		0.7115		0.8485		3.77	
Cor Total	19	558.98		3604.24		149.82		624.96	
R ²		0.9963		0.9938		0.9892		0.9902	
Adjusted R ²		0.9930		0.9883		0.9795		0.9814	
Predicted R ²		0.9719		0.9041		0.9103		0.9316	
Adeq. Precision		70.9413		48.9429		31.4795		43.4414	

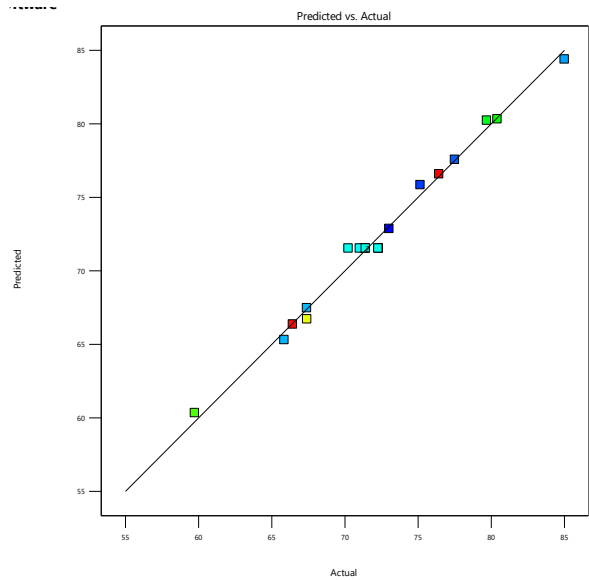


(a) quantitative de-hulling efficiency (b) qualitative de-hulling efficiency



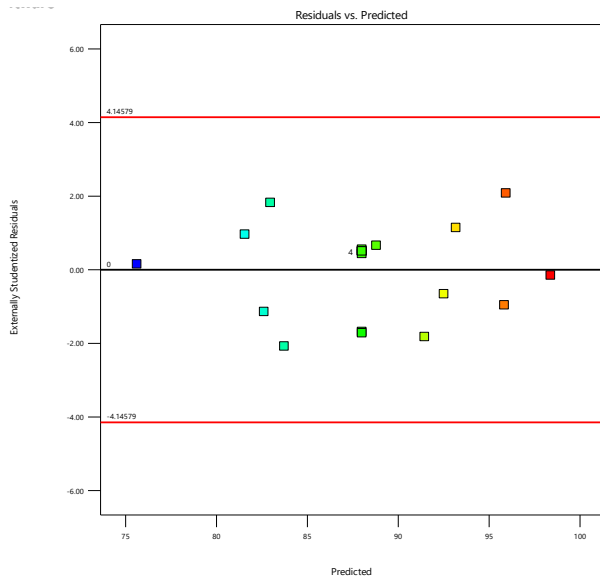


(c) throughput capacity

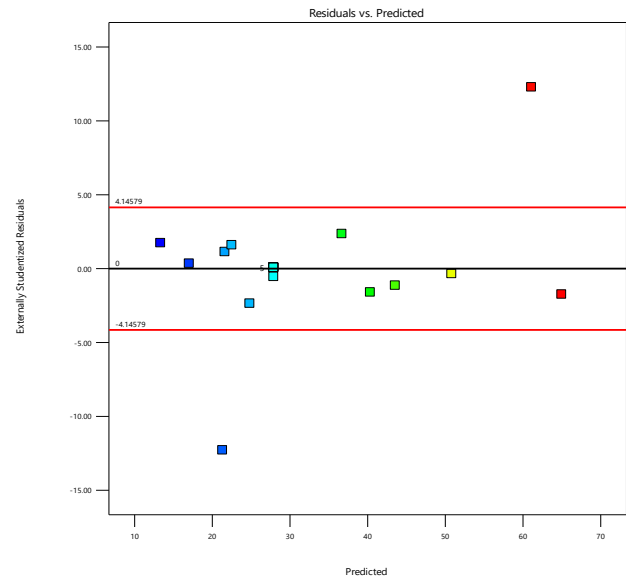


(d) cleaning efficiency

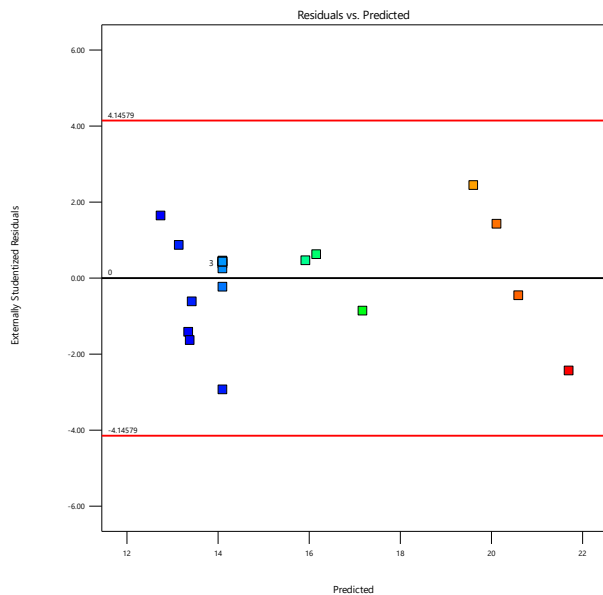
Figure 6 Plot of correlation showing the pattern of predicted against experimental values



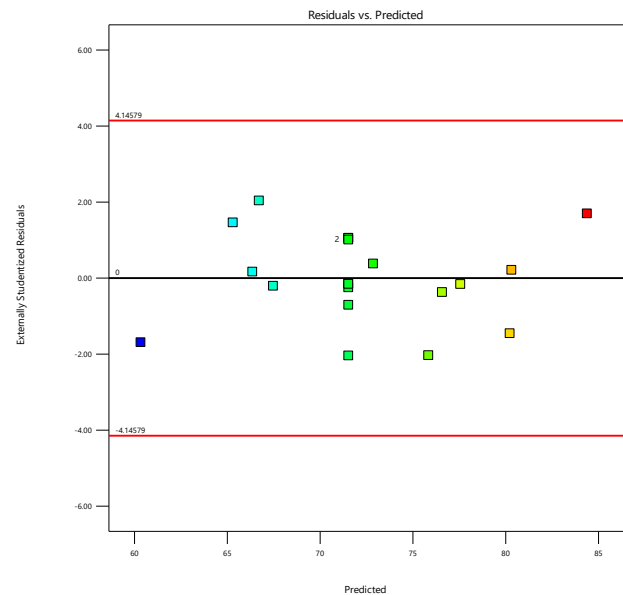
(a) qualitative de-hulling efficiency



(b) quantitative de-hulling efficiency



(c) Throughput capacity



(d) cleaning efficiency

Figure 7 Plot of studentized residual against predicted values

3.2 Numerical optimization of de-hulling and cleaning process conditions

Responses including quantitative de-hulling efficiency, quantitative de-hulling efficiency, throughput capacity and cleaning efficiency were set at maximum and the details of the set targets as presented in Table 5.

Figure 7 shows the desirability values of input variables (shaft speed, boiling time and feeding rate), responses quantitative de-hulling efficiency, qualitative de-hulling efficiency, throughput capacity and cleaning efficiency), and combined optimization. The desirable values of the input variables equal to 1. This is because their target was set to be within the range during optimization process. The desirable values of quantitative de-hulling efficiency, qualitative de-hulling efficiency, throughput capacity and cleaning efficiency while optimizing at a maximum level within the desired range were 1, 0.23, 0.97 and 0.98, respectively while the desirable value for the combined was 0.68. These values ranged from 0 to 1. The optimum values of shaft speed, boiling time and feeding rate were 7 m s^{-1} , 6 hr and 25 kg hr^{-1} , respectively. The predicted optimum response values obtained for quantitative de-hulling efficiency,

qualitative de-hulling efficiency, throughput capacity and cleaning efficiency at this condition were: 98.67%, 25.85%, 21.66 kg hr^{-1} and 84.62%, respectively.

3.3 Validation of the optimal conditions

The validation of the predicted responses under optimal condition for processing the locust bean is as presented in Table 5. The validation was done using the optimal condition suggested by the RSM. The values of the responses at the optimized processing conditions after testing the locust bean processing machine for quantitative de-hulling efficiency, qualitative de-hulling efficiency, throughput capacity and cleaning efficiency were 98.07%, 25.50%, 20.89 kg hr^{-1} and 84.15%, respectively. As shown in Figure 8, the values of the responses obtained from the test were close to the predicted values. This validates the optimise results and prove the goodness of the developed regression models. The percentage error obtained for all the responses as shown in Table 6 were lesser than 10%. This confirm that the variation between the test during validation and the predicted were with acceptable range, thus approving the suitability of the optimal conditions.

Table 5 Constraints used for the optimization of the de-hulling and cleaning condition

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A:Speed	is in range	7	9	1	1	3
B:Boiling time	is in range	4	6	1	1	3
C:Feeding rate	is in range	15	25	1	1	3
Quantitative de-hulling efficiency	maximize	75.66	98.35	1	1	3
Qualitative de-hulling efficiency	maximize	14.52	63.78	1	1	3
Throughput capacity	maximize	13.05	21.3	1	1	3
Cleaning	maximize	59.73	85	1	1	3

Table 6 Predicted and optimise values of responses

Optimised processing condition			Responses	Test value	Predicted value	Percentage error
Shaft speed (m s^{-1})	Boiling time (hr)	Feeding rate (kg hr^{-1})				
7	6	25	Quantitative de-hulling efficiency (%)	98.07	98.67	0.60
			Qualitative de-hulling efficiency (%)	25.50	25.85	1.35
			Throughput capacity (kg hr^{-1})	20.89	21.06	0.8
			Cleaning efficiency (%)	84.15	84.62	0.5

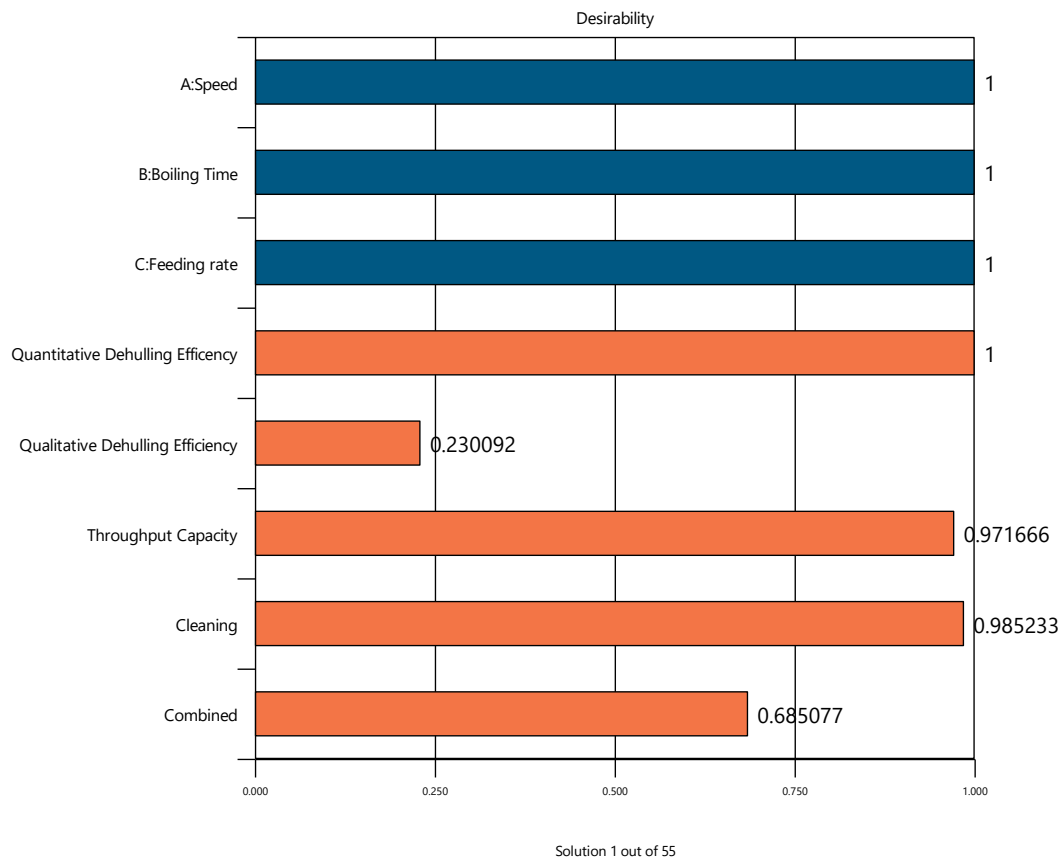


Figure 8 Individual desirability values of input variables, responses, and combined optimization

4 Conclusions

De-hulling operation of a locust bean processing machine was optimised using RSM. The operating parameters used in the experiment were shaft speed, boiling time and feeding rate. While the response parameters used were for quantitative de-hulling efficiency, qualitative de-hulling efficiency, throughput capacity and cleaning efficiency. The operating factors and the response parameter of the machine were seen to interact. The optimum values of shaft speed, boiling time and feeding rate were 7 m s^{-1} , 6 hr and 25 kg hr^{-1} , respectively. The optimum values of responsiveness obtained at optimum de-hulling conditions for quantitative de-hulling efficiency, qualitative de-hulling efficiency, throughput capacity and cleaning efficiency were 98.67%, 25.85%, 21.66 kg hr^{-1} and 84.62%, respectively. The response values obtained during validation of the model were 98.07%, 25.50%, 20.89 kg hr^{-1} and 84.15%, respectively, this implies that the model adequately describes the de-hulling and cleaning process of locust bean.

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