Journal of Engineering Research and Technological Innovations.
[JERTI] Vol. 1, No 1, 1 - 9 (2026)
https://journals.kwasu.edu.ng/index.php/jerti ISSN: 3093-0863

Performance Optimization of an Improved Cassava Mash Sifting Machine

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ABSTRACT

Mechanized cassava processing is important in improving food quality and reducing manual labour in rural and semi-industrial applications. The optimization of an improved cassava mash sifting machine using a general full factorial design (GFFD) to enhance its operational efficiency was investigated. In this research, the response variable (viz. sifting efficiency) was analyzed with respect to two critical operational factors: cassava mash mass and operational time. A 3^2 factorial experimental design with three replicates per treatment was used, resulting in 27 experimental runs. The experiments were conducted at the Nigerian Stored Product Research Institute (NSPRI), Port Harcourt Zonal Office. The machine was tested using mash masses of 30 kg, 60 kg, and 90 kg at operational times of 0.2, 0.4, and 0.6 hours. Data were subjected to statistical analysis, including two-way ANOVA, regression modeling, and response optimization using MINITAB 21 software. The results indicated that both mash mass and time of operation had significant effects ($p < 0.05$) on sifting efficiency. The optimal sifting efficiency was recorded at a mash mass of 30 kg and a time of 0.6 hours. The multiple linear regression model developed showed high predictive accuracy with R^2 = 99.10%, Adjusted R^2 = 98.54%, and Predicted R^2 = 97.45%. The optimization analysis also yielded a high composite desirability value of 0.991, validating the model's reliability. This study for process of optimization in cassava mash sifting operations and offers a framework for improving mechanized food processing systems in developing regions.

Keywords: Patch, Wireless, Substrate, Microstrip, Gain

1. INTRODUCTION

Cassava (Manihot esculenta Crantz) is widely recognized across globe, especially in the developing countries as a source of carbohydrates, calories, vitamin C, thiamine, riboflavin, niacin and several other nutrients that are essential to human (FAO, 1997; Montagnac et al., 2009). In Africa, Nigeria is the largest producer of cassava (Amerije, 2016) which can be processed into several foods and delicacies and any or all its components are either found very useful for human or livestock consumption (Alonge et al., 2012).

Gari is the major products from the numerous products of cassava and it is seen to be the most utilized product (Amerije, 2016). There are several processing steps involved in processing cassava tubers into garri, include peeling, washing, grating, pressing, shifting, frying. The stability of gari when it is finally transformed into the gelatinized form is influenced by each of these processing steps (Oni et al., 2009). Gari sifting reduces the labor-intensive process and drudgery involved in manual sieving, and it ultimately contributes to a better and more consistent final product. Gari processing has been the

Publisher
Faculty of Engineering and Technology,
Kwara State University, Malete. P.M.B. 1530 Ilorin,
Kwara State, Nigeria.

https://doi.org/10.5281/zenodo.18441457

subject of numerous studies, with small and medium-sized processing receiving the majority of the focus. A cassava lump breaker was constructed by Sulaiman and Adigun (2008), but a thorough performance assessment of the machine's efficiency and throughput capacity was not done. Alabi (2009) developed a motorized cassava lump breaker and sifter. It was suggested for the operator's safety, that an outlet be included for materials that weren't sorted, include the hopper, pulley and electric motor be covered. An electric motor-powered motorized cassava mash sifter was developed and evaluated by Kudabo et al. (2012). A motorized dewatered cassava mash sifter was created and assessed by Jackson and Oladipo (2013) in order to ascertain how operation speed affected the sifting effectiveness of the device.

All of the designs discussed were quite on the sieve aperture sizes that were utilized to generate the speeds, outputs, and efficiencies (Ahiakwo et al., 2015). Ahiakwo et al. (2015) evaluated the current state of sieving technology and projected the development of an efficient sieving technology. A motorized garri sieving machine was developed and tested by Ovat and Odey (2018). It included new features like a lump breaking pot, an aluminum sieving chamber to stop corrosion and rust, guards on moving parts to protect the operator and extend machine life, and links in place of cams and followers. The designs by Ovat and Odey (2018) were batch flow oriented, which always has an impact on large-scale manufacturing. An enhanced gari mash sifter was developed and assessed by Ajanwachuku et al. (2021). They stated that the development of this machine has reduced the risks and drudgery involved in the widely used human sifting method while also improving the timeliness of the garri sifting process. As a result, a reciprocating sieve that is intended for high capacity and operational efficiency must be used to optimize an enhanced continuous flow type dewatered cassava mash sifter. Sifting the dewatered mash is an essential step in cassava processing that produces homogeneous granules that improve drying effectiveness and the quality of the finished product (Akinoso et al., 2018). Conventional sifting techniques frequently result in irregular particle sizes, labor-intensive processes, and time commitments, which lower processing efficiency and product standards. Throughput and quality of cassava-based products can be greatly increased by optimizing the design and functionality of sifting machines. To cut down on labor expenses and processing time, automated systems have been integrated into machines in recent years (Omodara et al., 2020). The ideal operating parameters that affect the sifting capacity, such as feed rate, tilt angle, sieve mesh size, and vibration frequency, are still not well understood. The outcome is expected to offer a scientific basis for parameter selection and operational guidelines for enhanced cassava processing. Ajanwachuku and Ekemube (2025) optimized the throughput capacity of cassava dewatered mash sifting machine using general full factorial design in design of experiment. They reported that the optimal desirability of the machine was obtained at cassava mash mass of 90 kg and a time of operation of 0.6 hr. Similar finding was by Ekemube et al. (2025) that carried study on optimization of sifting capacity of an improved dewatered cassava mash sifting machine using design of experiment. Another statistical metric to confirm the accuracy of the optimization plot is the composite desirability (D) (Ciopec et al., 2012). According to Chang et al. (2015), when the composite desirability (D) is near 1.00, the optimization of factors and answers derived from the statistical analysis is extremely precise and dependable.

The efficiency of cassava mash sifting remains a critical bottleneck in small- to medium-scale cassava processing enterprises. Manual sifting techniques are inefficient, leading to low throughput and variability in mash granularity. Although mechanized sifting machines have been developed, they are often operated at suboptimal conditions due to lack of empirical performance data. Consequently, there is a need to determine the optimal combination of machine parameters that significantly enhance sifting capacity and efficiency. Moreover, the absence of a standardized approach to evaluate and optimize the performance of such machines has hindered their widespread adoption. Without proper optimization, machine operations may consume excessive energy or yield poor-quality output. This study leverages the power of Design of Experiment to identify, model, and optimize key factors affecting the performance of an improved cassava mash sifting machine.

Hence, this study aims at establishing optimum performance indicators between operation variables (cassava mash mass, and time of operation) and their effect on machine efficiency using general full factorial design in design of experiment.

2. MATERIALS AND METHODS

2.1 Description of the Machine

The improved motorized cassava mash sifting machine consists of the following components as shown in Figures 1 to 5:

i. Main frame: the main unit of the machine on which all other components of the machine are supported.

ii. Hopper: a trapezoidal shaped pyramid through which lumps of dewatered mash cake are fed into the sieving trough through gravity.

iii. Sieving chamber: a rectangular trough of considerable depth to prevent spilling of agitated particles during operation and length to ensure that the product coming out at the discharge end of the sieve would be chaff alone, that is sieving would have been completed by the time the products get to the discharge end.

iv. Pulley and Belt: The pulley and belts are preferred to this purpose as the distance between the two pulley is short, resulting in negligible slip between pulleys, easy installation, long life, high velocity ratio, high power transmission and its ability to absorb shock.

v. Discharge outlet: this consists of the outlet chute for the fines (under-sized particles). Electric motor: this provides the power needed to operate or run the machine.

vi. Bearings: this is used to provide support for the shaft and reduce friction between moving parts which can cause a loss of available power.

vii. Camshaft: this is used to transmit power from one place to another.

Basically, power generated by the 1-hp electric motor is delivered to the camshaft- a device which converts rotational motion to reciprocating motion. The motion generated because of the
rotation of the camshaft in the pulley and belt arrangement is further transmitted to the sieve
housing thus providing the forward throw while the spring positioned in the opposite direction
returns the sieve on the backward throw. This to and fro linear movement (reciprocating action) of the sieve housing leads to the sifting action of the pulverized garri mash

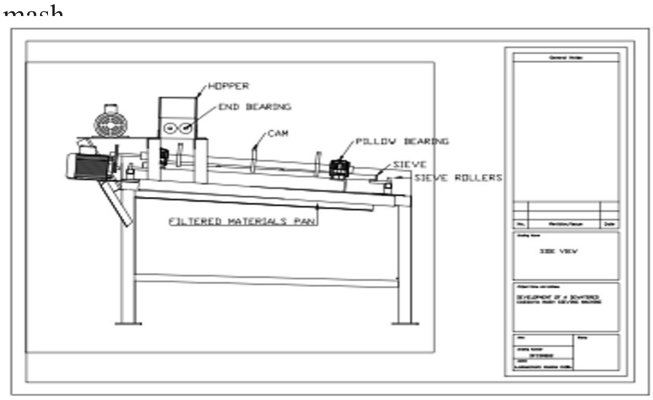

Figure 1: Side View Elevation of Garri Sifting Machine

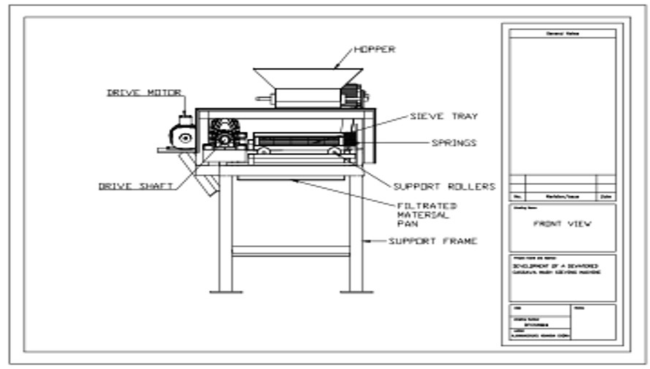

Figure 2: Front View Elevation of the Machine

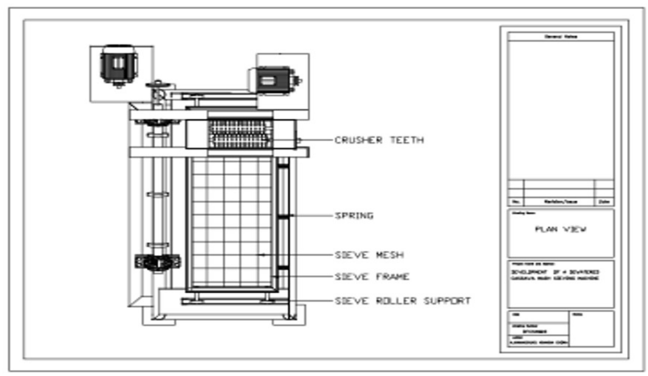

Figure 3: Plan View of Garri Sifting Machine

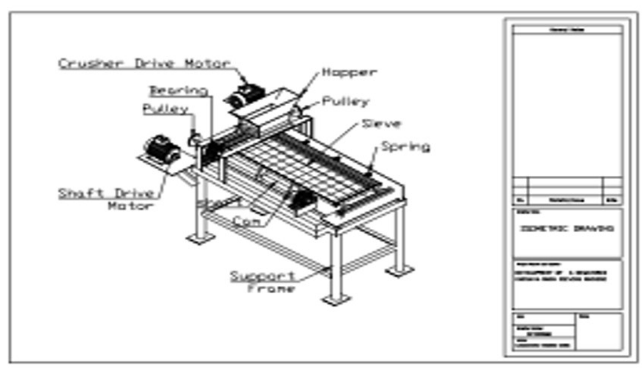

Figure 4: Isometric Drawing of Garri Sifting machine

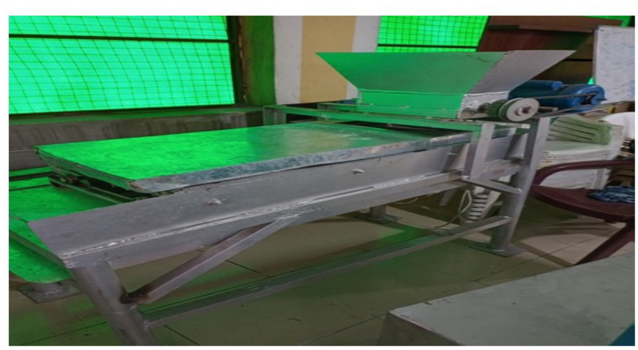

Figure 5: Fabricated Motorised Cassava Mash Sifting Machine

2.2 Experimental Design

Three squared (3^2) full factorial design (two factors at three levels with replicates) was used to examine the effects of two parameters on the garri mash shifter during the sieving of dewatered cassava mash. This design is based on the one response factor and two operational factors as used by Ekemube *et al*. (2023a, 2023b; 2024). The dewatered cassava mash mass (30, 60, and 90 kg) and the time of operation (0.2, 0.4, and 0.6 hr) were the two variables. The response analyzed was sifting efficiency (Se). Based on the reponse variables, the sifting of dewatered cassava mash was separated into three blocks: block 1 was for 30 kg, block 2 was for 60 kg, and block 3 was for 90 kg. Nine experimental treatments with three duplicates were included in the design. In this study, randomization was carried out using the MINITAB 21 program (Minitab Inc, State College, PA, USA).

2.3 Experimental Procedure and Performance Evaluation

The machine was tested at an operational speed of 1725 rpm using 1hp single phase electric motor at 30, 60, and 90 kg loading rate respectively. The different masses of dewatered cassava mash were weighed on a weighing scale and recorded. Each mass of cassava mash beginning with 30 kg was then fed into the hopper, which in turn was properly spread out into the sieving chamber. The machine was running at a specific time a lot for each of the cassava mash sieving evaluation. Important parameters such as the mass of cassava mash which could be sieved, the time taken to complete each sieving operation were taken, and recorded accordingly. This procedure was carried out for three different times with respect to each weight and their averages. At the end of operation, the machine performance criteria based on sifting was determined.

Machine sifting Efficiency: this is the percentage mass of cassava mash separated after sifting. This is calculated as using Equation 1:

$$Se = \frac{Mm - C}{Mm} \times 100\% \quad (1)$$

Where;

Se = Sifting efficiency

Mm = Mass of cassava mash loaded into the sieve

C = Sieved residue (chaff), kg

2.4 Statistical Analysis

Analysis of variance (ANOVA), interaction plot, and response optimizer were the statistical analyses employed in this investigation. In order to ascertain whether there are statistically significant differences between the means of the treatments, the answers in this study were analyzed using a two-way ANOVA. MINITAB 21 software (Minitab Inc., State College, PA, USA) was used to perform statistical analyses. Differences were deemed significant at a 95% confidence level ($p < 0.05$).

2.5 Prediction Equation

As a function of cassava mash mass and time of operation, which is input variable of sifting efficiency. The multiple linear regression model describing the sifting efficiency during machine operations were expressed in Equations 2:

$$T_c = \alpha + \beta_1 Mm_1 + \beta_2 Mm_2 + \beta_3 Mm_3 + \beta_4 T_1 + \beta_5 T_2 + \beta_6 T_3 + \beta_{11} Mm_1 T_1 + \beta_{12} Mm_1 T + \beta_{13} Mm_1 T_3 + \beta_{21} Mm_2 T_1 + \beta_{22} Mm_2 T_2 + \beta_{23} Mm_2 T_3 + \beta_{31} Mm T_1 + \beta_{32} Mm_2 T_2 + \beta_{33} Mm_3 T_3 \quad (2)$$

Where:

S_e = Sifting efficiency, %,

α = Intercept (Average value of the result),

β_1, β_2, β_3, β_4, β_5, β_{11}, β_{12}, β_{13}, β_{21}, β_{22}, β_{23}, β_{31}, β_{32}, and β_{33}, = Interactions' coefficients,

$Mm_{12,3}$ = Cassava mash mass, kg

$T_{1,2,3}$ = Time of operation, hr

2.5.1 Validation of the Multiple Linear Regression Model

By utilizing the model to simulate the experimental data and comparing the experimental and predicted data using standard error, the developed multiple linear regression models were validated (Ekemube *et al*., 2023a, 2023b; 2024, 2025).

2.5.2 Evaluation of Model Prediction Ability

To determine whether the measured and predicted results have a good agreement to assess their validity, the 95% confidence interval and prediction interval, coefficient of determination (r^2), adjusted r^2 (Adj r^2), and predicted r^2 [r^2 (Pred)] were employed. Minitab-21 software (Minitab Inc., State College, PA, USA) was used (Ekemube *et al.,* 2023a, 2023b; 2024, 2025).

2.6.1 Optimization of the Quality

The response variables (sifting efficiency) were optimized within the 95% confidence and prediction intervals using an optimization graph. With the combination of operational conditions (cassava mash mass and operationg time), the response optimizer's desired point was reached at the best appropriate maximum sifting efficiency. Minitab-21 was used for the optimization procedure (Minitab Inc., State College, PA, USA).

3. RESULTS AND DISCUSSIONS

3.1 Experimental Results

Figure 6 displays the sifting efficiency of the dewatered cassava mash sifting machine (Table 1). The experimental results show that the increase in the levels of cassava mash mass (30, 60 and 90 kg) and time of operation (0.2, 0.4, and 0.6 hr), respectively, increased the throughput capacity. From Figure 6 and Table 1, that displayed the experimental results of this study. It showed that the maximum sifting efficiency of utilizing this machine under study can be achieved by 90 kg of cassava mash and 0.6 hr time of operation.

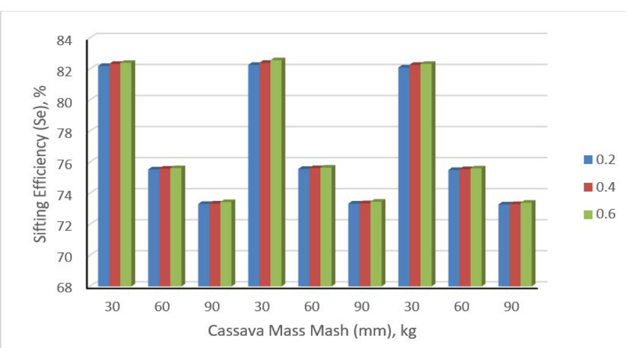

Figure 6: Plot of Sifting Capacity vs Sifting Efficiency

3.2 Effects of Cassava Mash mass and Operating Time on Sifting Efficiency

Cassava mash mass and time of operation were the primary variables assessed in this investigation. As seen in Figures 7 and 8, the single and interaction plots demonstrate the individual and combined effects of both main components (with three distinct levels) on the specific response (sifting efficiency. Plots showing the relative strength of the effects of the components (cassava mash mass and time of operation) with a slope. By adding a center point to the design, it was possible to determine that there was a curvature between the levels. An optimal sifting efficiency can be achieved at the middle point of the factors. A maximum sifting efficiency was achieved at 90 kg for cassava mass mass and 0.6 for time of operation as presented in Figure 7. As the cassava mash mass increases from 30 to 90 kg, with the time of operation from 0.2 to 0.6 hr, according to the results. The findings demonstrated that a significant sifting effieciency was achieved during the operation of the machine by increasing mash mass and and reducing the time of operation. The sifting efficiency can be raised by raising the mash mass and reducing in time of operation, according to the interaction plots (Figure 8). On the other hand, the lines are not parallel to one another, according to the interaction plots. These suggested that the variables (mash mass and time of operation) interact.

The ANOVA results in Table 2 revealed that both mash mass (Mm) and time of operation (T) had significant effects on sifting capacity at the 95% confidence level, as their calculated F-values (401.83 and 443.21) exceeded the corresponding table F-values (3.63 and 6.23). Similarly, the interaction between mash mass and time (MmT) was also significant, with an F-value of 33.06 greater than the table value (3.63). Additionally, the p-values for the linear factors (Mm and T) and their interaction (MmT) were effectively zero, indicating a highly significant influence on sifting capacity. A factor is considered to have a more substantial impact on the response when the p-value is less than 0.05 (Prakash et al., 2008). ANOVA results based on the study indicated that the p-value (0.00) for both Mm and T factors is below the probability level ($P < 0.05$), and their combined values were also less than the probability level ($P > 0.05$). It can be infered that the sifting capacity generated by the machine was greatly impacted by the cassava mash mass (Mm) and time of operation (T) operational variables.

Table 1: Sifting Efficiency (%) Experiment Results

Cassava Mass Mash, mm (kg)	Operation Time, T (hr)		
	0.2	0.4	0.6
30	82.2	82.333	82.4
60	75.533	75.583	75.617
90	73.311	73.333	73.433
30	82.267	82.4	82.567
60	75.567	75.617	75.65
90	73.333	73.356	73.456
30	82.1	82.267	82.333
60	75.5	75.55	75.6
90	73.278	73.3	73.389

Table 2: Observed and Model Prediction Results

Observation	Mm	T	S_e, %, observed	S_e, %, Predicted	SE Fit
1	30	0.6	73.4560	73.4766	0.028
2	30	0.4	75.6170	75.6339	0.028
3	30	0.2	73.3330	73.3579	0.028
4	60	0.6	82.5670	82.4839	0.028
5	60	0.4	75.6500	75.6729	0.028
6	60	0.2	82.4000	82.3839	0.028
7	90	0.6	73.3560	73.3803	0.028
8	90	0.4	75.5670	75.5839	0.028
9	90	0.2	82.2670	82.2396	0.028
10	30	0.6	73.3110	73.3057	0.028
11	30	0.4	73.3330	73.3280	0.028
12	30	0.2	82.3330	82.3317	0.028
13	60	0.6	75.5830	75.5817	0.028
14	60	0.4	73.4330	73.4244	0.028
15	60	0.2	82.2000	82.1874	0.028
16	90	0.6	82.4000	82.4317	0.028
17	90	0.4	75.5330	75.5317	0.028
18	90	0.2	75.6170	75.6207	0.028
19	30	0.6	75.6000	75.5734	0.028
20	30	0.4	75.5000	75.4844	0.028
21	30	0.2	82.1000	82.1400	0.028
22	60	0.6	82.3330	82.3844	0.028
23	60	0.4	73.3890	73.3770	0.028
24	60	0.2	73.3000	73.2807	0.028
25	90	0.6	75.5500	75.5344	0.028
26	90	0.4	73.2780	73.2584	0.028
27	90	0.2	82.2670	82.2844	0.028

Table 3: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	10	392.337	100.00%	392.337	39.234	33756.81	0.000
Blocks	2	0.045	0.01%	0.045	0.022	19.20	0.000
Linear	4	392.268	99.98%	392.268	98.067	84377.24	0.000
Mm	2	392.166	99.95%	392.166	196.083	168710.52	0.000
T	2	0.102	0.03%	0.102	0.051	43.97	0.000
2-Way Interactions	4	0.024	0.01%	0.024	0.006	5.19	0.007
Mm*T	4	0.024	0.01%	0.024	0.006	5.19	0.007
Error	16	0.019	0.00%	0.019	0.001		
Total	26	392.356	100.00%				

3.3 Prediction Equation

Table 4 displays the estimated coefficients for the regression analysis and multiple linear regression model for the sifting capacity of dewatered cassava mash sifting machine. The multiple linear regression model (Equation 2) revealed that the sifting capacity of the machine was significant, with a constant value of 186.26 and a SE of 2.83, along with a p-value of zero (0.000). However, component Mm (cassava mash mass) had coefficients with p-values less than 0.00, with the exception of 60 kg, while factor T (time of operation) had p-values of zero (0.00). The multiple linear regression analysis showed that the model developed for sifting capacity was highly accurate and reliable. The coefficient of determination (r^2) was 99.10%, indicating that the model explained 99.10% of the variation in the experimental data. The adjusted r^2 (98.54%) and predicted r^2 (97.45%) values were also very close, with a difference of only 1.09—well below the 20% threshold for model reliability. These results confirm that the regression model effectively represents and predicts the sifting capacity of the machine, explaining over 95% of the data variability and demonstrating a high level of statistical significance.

Table 4: Estimated Coefficients for S_c Multiple Linear Regression Model

Term	Coefficient	SE Coefficient	P-Value
Constant	186.26	2.83	0.000
Blocks			
1	5.41	4.00	0.195
2	-5.81	4.00	0.165
3	0.41	4.00	0.920
Mm			
30	-94.93	4.00	0.000
60	-3.37	4.00	0.411
90	98.30	4.00	0.000
T			
0.2	-78.04	4.00	0.000
0.4	-36.26	4.00	0.000
0.6	114.30	4.00	0.000
Mm*T			
30 0.2	36.37	5.65	0.000
30 0.4	20.26	5.65	0.002
30 0.6	-56.63	5.65	0.000
60 0.2	-5.19	5.65	0.373
60 0.4	3.04	5.65	0.598
60 0.6	2.15	5.65	0.709
90 0.2	-31.19	5.65	0.000
90 0.4	-23.30	5.65	0.001
90 0.6	54.48	5.65	0.000

r^2 = 99.10%, Adj r^2 = 98.54%, r^2(Pred) = 97.45%

3.4 Optimal Response (Sifting Efficiency)

The response optimizer in MINITAB 21 was used to identify the ideal state of controllable factors or variables in order to achieve desired operating conditions for sifting efficiency, based on the multiple linear regression model that was developed. The response (sifting capacity) was the focus of this investigation.

Figure 9 displays the sifting efficiency optimization plot, and Table 5 displays the findings of the best possible solution. The maximum throughput capacity was estimated to be 82.433% based on the analysis. At a cassava mash mass of 30 kg and time of operation of 0.6 hr, the required reaction was obtained, and the composite desirability (D) was 0.991057, which was higher than 0.90 and near 1.00. Another statistical metric to confirm the accuracy of the optimization plot is the composite desirability (D) (Ciopec et al., 2012). According to Chang et al. (2015), when the composite desirability (D) is near 1.00, the optimization of factors and answers derived from the statistical analysis is extremely precise and dependable. As a result, the optimal conditions were largely trustworthy and completely consistent with the multiple linear regression model that was created.

Table 5: Optimization Simulation Result

Solution	Mm	T	Sc, kg/hr Fit	Composite Desirability
1	90	0.6	453.333	0.991057
2	60	0.6	299.333	0.615447
3	90	0.4	225.000	0.434146
4	90	0.2	175.333	0.313008
5	60	0.4	149.667	0.250407
6	30	0.6	149.000	0.248780
7	60	0.2	99.667	0.128455
8	30	0.4	75.333	0.069106
9	30	0.2	49.667	0.006504

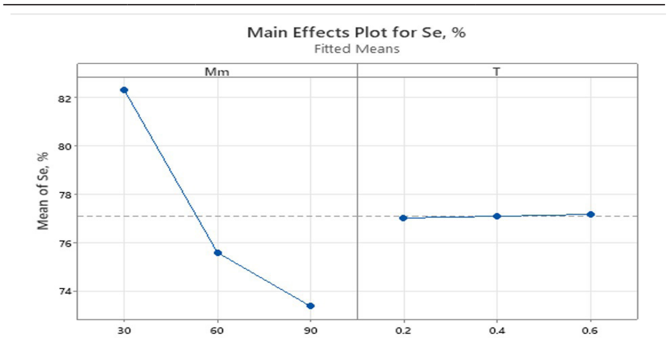

Figure 7: Plot of Main Effects (Mm and T) on P_R

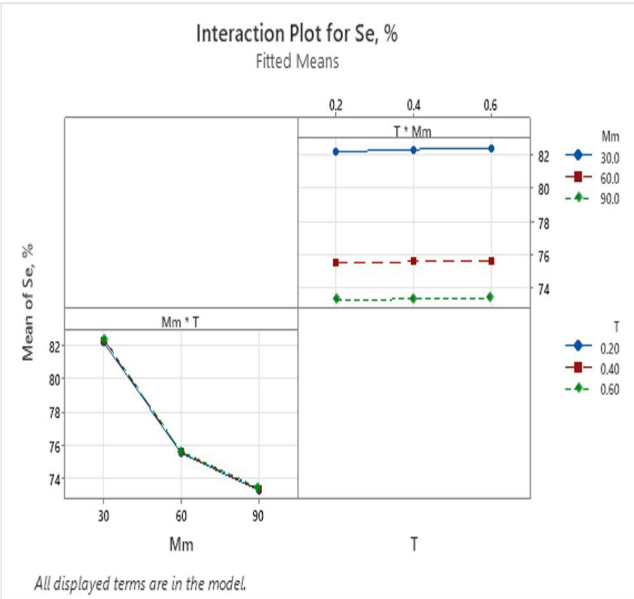

Figure 8: Plot of Interaction (Mm and T) on S_e

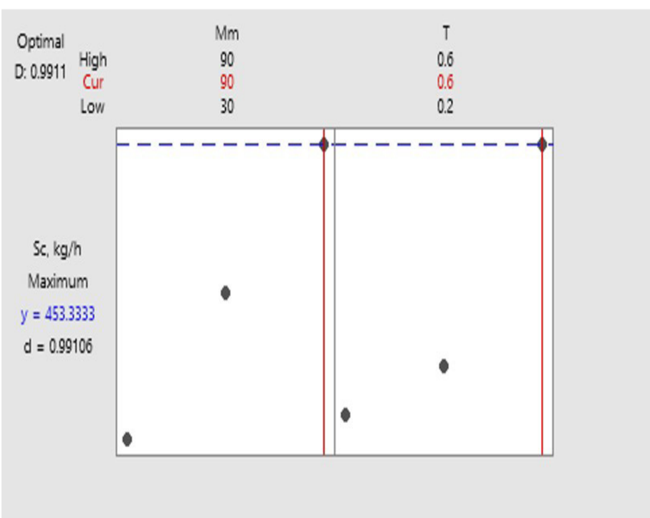

Figure 9: Optimization Plot

4. CONCLUSION

General full factorial design (GFFD) has been successfully used in the design of experiment (DOE) to optimize the sifting efficiency in order to maximize the utilization of an improved dewatered cassava mash sifting machine and set optimal operating conditions. The following findings were drawn from the GFFD analysis: The analysis of variance (ANOVA) revealed that the mass of cassava mash and operating duration had a significant effect on sifting capacity ($P<0.05$). This implies that changes in cassava mash mass of 30, 60, and 90 kg had an impact on the sifting capacity when using developed machine operation Additionally, variations in operation time of 0.2, 0.4, and 0.6 hours had an impact on the sifting capacity. Additionally, the interaction between cassava mash mass and operating duration had a substantial ($P<0.05$) effect on the sifting capacity. It was confirmed that the models have a prediction accuracy of over 95%. The ideal sifting efficiency during sifting was reached at a 30 kg cassava mash mass and a 0.6 hr operating period.

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