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RESEARCH ARTICLE

OPTIMIZATION OF THE EFFICIENT SHREDDING PROCESS OF BIOGAS FEEDSTOCKS FROM CASSAVA PEELS

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ABSTRACT

The operation of a shredding machine is altered by clogging the cutting chamber. In this study, a high rotational clearing speed was developed to minimize damage and enhance the shredder's performance. Three-factor and three-level tests were conducted using the peels' speed, input rate, and moisture content to ascertain the machine's ideal process parameters. Based on the single-factor experiments, the correct shaft speed (2400, 2600, and 2800 rpm), the input of cassava peels (1, 2, and 3 kg/min), and the moisture content (80, 85, and 90%) were then determined. Three stages of L20 (33) orthogonal arrays were performed to optimize the application parameters using I-Optimum. The results showed that the optimal conditions for machine efficiency (96.48%) and throughput (13.32 kg) were 2600 rpm speed; 1.03 kg/min input and 82.9% moisture content with desirability of 0.70. These results can serve as a guide for the shredder using cassava peels.

KEYWORDS

Peels, anti-clogging System, high rotary, I-Optimum.

1. INTRODUCTION

In many tropical regions, cassava (Manihot esculenta, Cranz) is one of the major crops farmed for both industrial and food uses. It is widely planted in all regions and is one of the major food crops in Nigeria (FAOSTAT, 2019; Egbeocha et al., 2016; Tadele and Assefa, 2012; Falade and Akingbala, 2010). A relatively small amount of peels and unwanted tubers are fed directly to ruminants; with increased production of peels and other cassava-derived wastes, constitutes an enhanced risk of environmental pollution. The processing of cassava yields peels, chaff, fibre, and spoilt or otherwise unwanted tubers. The analysis reported that cassava peel is a good substrate for biogas production (Adeleke and Bamgboye, 2009). Thus, there is a pressing need to put the peels to other beneficial uses. Size reduction of cassava peels is required to increase the surface area for bacterial decomposition, thereby increasing gas production (Mshandete et al., 2016). The effective use of peels can support efficient waste management in prosperity by using them as a substrate for biogas production. According to, shredding machinery that operates in the reduction of sizes must meet strict specifications for precision and have a broad range of adjustment capabilities (Yancey et al., 2013). Nevertheless, peels of cassava are capable of being pretreated by employing shredding machinery to split open the cell walls and boost the biomass's specific surface area for an enzymatic attack (Zielinski et al., 2019). As a result, reducing blocking in the shredding chamber is a great way to enhance the machine's functionality.

Few studies have been conducted on the clogging of wet materials, whereas many scientists focus on the shredding technique of crop residues from agriculture and plastic products (Sridhar and Surendrakumar, 2016; Ashwini et al., 2020; Berk, 2013; Shahid et al., 2019; Ayo et al., 2017). Reducing the moisture content of materials, increasing speed, and utilizing a spur gear with both shafts rotated in opposite directions to enhance device performance are some frequently employed solutions to the issue of moist agricultural waste clogging (Sreenivas et al., 2017). Some studies had worked on designing the grinding chambers in various shapes to improve machine performance (Altun, 2018; Qin, 2009; Meier, et al., 2008). In addition, introduced the use of vibrators in the cutting chamber to minimize clogging of the machine (Chen et al., 2008). Some literature work has indicated that the angle and sharpness of the blades, the spacing between the blades are the required variables and the cutting speed, revolutions per minute are considered to be some parameters that can reduce clogging in the cutting chamber and the ejection point (Asmamaw et al., 2019; Bolaji et al., 2017; Aloria et al., 2015; Kumar and Kumar, 2015; Abhilasha and Aruna, 2017). The high-speed cleaning device is currently widely used in crushing machines. With this method, the damp residues can be cut and scattered under the effect of the impact force. Conversely, the moist cassava peel is struck repeatedly and escapes through the sieve in the grinding mechanism, creating a large volume of slurry. This study introduced a low cutting speed test of 1440 rpm (Hande and Padole (2015). The impact of the high-cut process, friction, and increased tensile strength all contributed to the results, which showed that increasing the speed effectively reduced the blockage of the cutting chamber. Nithyananth and Libin (2014) adopted a 240 RPM reduction gear motor to drive the cutting shaft. Although all tests have shown that the processing method can improve machine performance to some extent, studies are complex and time-consuming. According to the ideal operating parameters were demonstrated to offer suggestions for improving the shredding efficiency (Fei et al. (2020).

This study aims to investigate the effects of response surface parameters and regression statistics variance on the shredding mechanism of wet cassava peels under high rotary clear-out. The analysis will take into account the ease with which the cutting shaft's speed can be changed.

2. MATERIAL AND METHODS

Based on a study of the operational crushing rate in shredders by reducing the clogging of wet peels, the research was conducted to validate the

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feasibility of producing shredded cassava peels as a new type of biogas feedstock. The factors that influence the efficient shredding of high moisture cassava peels are the input cassava peel, shredding speed, and moisture content of the material. The experimental shredding equipment was performed using a new fabricated shredded at the Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.

2.1 Sources of the Material and Moisture Content

Fresh cassava peels were obtained at the cassava processing farm at Agbowo, Ibadan North local government. Cassava peels contain a higher dilution of smaller and powdery particles. It is light, which makes it easier to convey, improves porosity and water retention, and helps air circulation.

The conventional technique was used to calculate the moisture content (ASABE Standards, 2003). The small quantity of about 200 g was taken from cassava peels and divided into two samples, 100 g each for determination of the average moisture content of the cassava peels and weighting the samples using the weighing balance. Using equation (1), the sample's moisture content was determined on a percent wet basis.

$$M_S = \frac{100(w_i - w_f)}{w_i} \quad (1)$$

Where:

M_S is the moisture content of the sample (on a wet basis)

w_i is the Initial mass (in grams)

w_f is the final mass after oven drying (in grams)

By adding the necessary quantity of water, Q, as determined by equation 2, the amount of moisture higher than the initial moisture content was reached.

$$Q = \frac{A(b - a)}{100 - b} \quad (2)$$

Where,
A = initial mass of the sample in (g)

a = initial moisture content of the sample in (% w.b)

b = final moisture content of the sample in (% w.b) Q = mass of the water to be added in (g)

2.2 Determination of Shredding Efficiency

The FEXOD 320SBG shredding machine efficiency was determined based on the amount of product unloaded from the machine (Figure. 1) about the mash of raw material introduced. It was calculated from equation 3 according to (Etoamaihe and Iwe, 2014),

$$Q_{fs} = (Q_{shr} - Q_{unshr}) \quad (3)$$

$$S_{eff} = \{Q_d/(Q_{fs} + Q_w)\}\ 100\% \quad (4)$$

Where,

Qshr = Average mass of peels fed into the machine

Qunshr = Average mass of peels not properly shredded

Qd = final product (kg)

Qfs = initial mass of feedstock (kg) Qw = quantity of water (kg)

2.3 Determination of Throughput Capacity

The throughput of the machine at varied feedstock and water loading was estimated as the ratio of input mass to the time required to complete shredding operation. According to equation 5 was used to estimate the throughput capacities of the machine (Agbonkhese et al., 2020).

$$M_{Th} = \{(Q_f + Q_w)/t_{op}\} \quad (5)$$

Where

Qf = initial mass of feedstock (kg) Qw = quantity of water (kg)

Top = time required to complete shredding operation (hr)

2.4 Overall Assembly

Figure 1 illustrates the shredding apparatus used in this investigation. The primary components of the system included a hopper, a housing chamber with a centralized mixing device and a conveying shaft, a stationary plate, and a discharge chute. Peels were introduced from the hopper to the mixing, cutting, and conveying chamber. They flowed through the chamber and then the shredded materials were distributed into collecting points by chute.

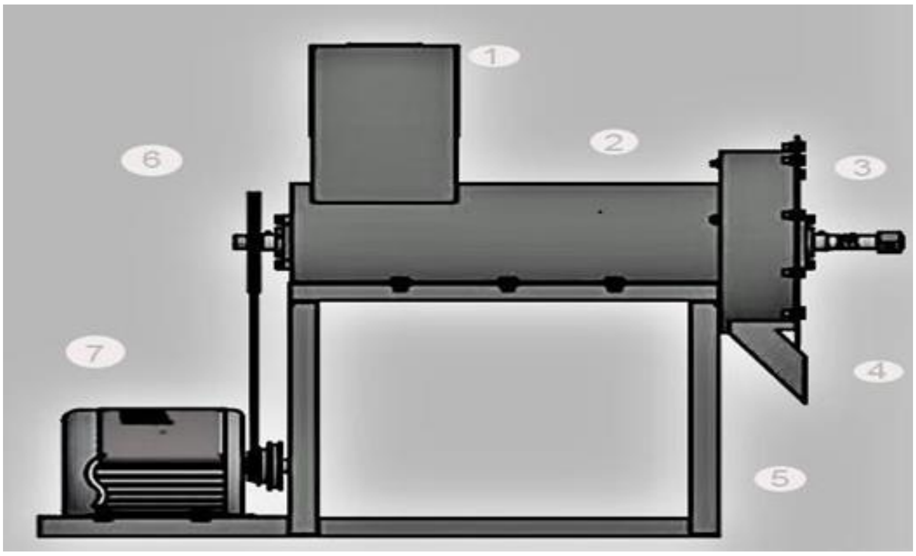

Figure 1: The shredding Machine; 1) Hopper; 2) Housing Chamber; 3) Diaphragm Chamber; 4) Outlet Chute; 5) Frame; 6) Shaft; 7) Electric Motor Experimental design

The three-level, three-numeric factorials central composite experimental design with a categorical factor of "0" was employed to study the effect of cassava peels input, machine speed, and moisture content on the concentration of the shredding efficiency and throughput of the shredding machine (response). To optimize the level of selected variables, such as cassava peel input, machine speed, and moisture level, a total of twenty trials were conducted in duplicate. The design consisted of three levels: low, medium, and high, coded as −1, 0, and +1. The three independent variables were designated as x1, x2, and x3 in the statistical calculations. Table 1 lists the range and levels that were chosen for the experiments based on the preliminary experiments.

Table 1: Independent parameters and their coded levels

Parameters	Code	Unit	Coded parameter levels		
			-1	0	+1
Cassava-peels input	x_1	Kg/min	1	2	3
Shredding Speed	x_2	Rpm	2400	2600	2800
Moisture content	x_3	%	80	85	90

(-1) refers low level; (0) refers to mean level; (+1) refers to high level

Coefficient of determination (R^2), response plots, and analysis of variance (ANOVA) was used to analyze the data. The response estimated using the following form of a second-degree polynomial, Eq. (6), was determined using the central composite design:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2, \tag{6}$$

where Y is the estimated response, b0, (b1, b2, b3), (b12, b13, b23), and (b11, b22 b33) are the regression coefficients for the intercept, linearity, interaction, and square, respectively. The equation expresses the relationship between the predicted response and independent variables in coded values according to Tables 1 and 2. Independent variables (input cassava, speed, and moisture content) and the important design process response (shredding efficiency and throughput) were analyzed using response surface methodology (RSM). Analysis of variance (ANOVA) was performed using the Design-Expert 11.0 software package to find the models with good fits for shredding efficiency and throughput of the machine (Box and Draper, 2007).

The F value and p values demonstrate the significance of the coefficient term. The significance of the model under investigation concerning the variance of all terms, including the error term, at the intended significance level is determined by calculating the F-value, defined as the ratio of the regression's mean square to the mean square error of the regression (Oduntan and Bamgboye, 2015). The p-value, also known as the probability value, is used to determine the statistical significance of results at a confidence level. Generally, $F > 4$ indicates that a change in the design parameter has a significant impact on the performance characteristic. The results of this study are validated for a 95% confidence level using a significance level of $\alpha = 0.05$.

Table 2: Designed experiment

Run	Input cassava peels (kg/min)	Speed (Rpm)	Moisture content (%)
1	2.00	2800	80
2	2.00	2800	85
3	2.00	2600	80
4	3.00	2800	80
5	2.00	2600	85
6	1.00	2600	80
7	2.00	2600	85
8	2.00	2400	90
9	3.00	2600	80
10	2.00	2400	80
11	3.00	2800	90
12	1.00	2400	90
13	1.00	2600	90
14	2.00	2800	85
15	3.00	2600	85
16	2.00	2600	85
17	2.00	2400	90
18	3.00	2400	80
19	1.00	2400	85
20	1.00	2800	80

3. RESULTS AND DISCUSSION

3.1 Effects of Experimental Factors on The Shredding Efficiency

The design matrix is followed when conducting the experiments, and Table 3 lists the corresponding outcomes. Shredding efficiency values ranged from 72.2 to 91.7 percent, with an average of 83.9%. The quadratic equation for predicting the optimum point was obtained according to the central composite design and input variables (input cassava peels (x1), shredding speed (x2), and moisture content (x3)). Based on the results of the study, Equation 7 presented an empirical correlation between the response (shredding efficiency) as well as the independent variables in the coded units.

Table 3: Experimental results for efficiency and throughput of the shredder.

Run	Shredding efficiency (%)	Throughput (kg/sec)
1	87.5	3.39
2	93	3.57
3	85	3.17
4	92	1.47
5	90.4	3.9
6	83.3	2.3
7	89.4	3.88
8	80	3.82
9	78	2.17
10	82.5	1.14
11	96.9	4.6
12	97.3	11.25
13	98	8.04
14	97.2	3.26
15	97.7	2.97
16	82	2.15
17	94.5	5
18	87	2.1
19	94.3	9.2
20	91.7	7.9

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$$\text{Shredding Efficiency} = +85.62 - 2.50x_1 + 6.76x_2 + 0.75x_3 + 0.84x_1x_2 + 0.46x_1x_3 + 0.30x_2x_3 + 0.46x_1^2 - 2.29x_2^2 - 0.80x_3^2 \quad (7)$$

$R^2 = 0.834$

From Equation 7, the coefficients of x_2 and x_3 are positives, which implies that with a unit increase in the shredding speed and moisture content, there was an increase in the shredding efficiency by 6.76 and 0.75, respectively. As the coefficient of x1 is negative, efficiency is thought to decrease by 2.5 for every unit increase in input feedstock. Table 4 displays the analysis of variance (ANOVA) results for the quadratic model of cassava peel shredding efficiency. The shredding process was significantly impacted by the terms in the models, as indicated by the p-value for the model being less than 0.05 ($p \leq 0.05$).

Table 4: ANOVA for response surface quadratic model shredding efficiency of the machine.

Sources	Sum of square	Degree of freedom	Mean square	F value	P value
Model	600.70	9	66.74	33.75	0.0001
x_1-Input Feedstock	47.76	1	47.76	24.15	0.0006
x_2-Speed	424.10	1	424.10	214.48	0.0001
x_3-Moisture	5.86	1	5.86	2.96	0.1160
x_1x_2	3.27	1	3.27	1.65	0.2276
x_1x_3	1.33	1	1.33	0.67	0.4313
x_2x_3	0.63	1	0.63	0.32	0.5847
x_1^2	0.83	1	0.83	0.42	0.5315
x_2^2	22.13	1	22.13	11.19	0.0074
x_3^2	1.50	1	1.50	0.76	0.4046
Residual error	19.77	10	1.98		
R^2 =0.968; Adj R^2=0.93		Pred R^2 = 0.85	Adeq Precision =18.92		

The determined R^2 value is 0.9681, which indicates that the models explained 96.8% of the variation in their original data and correlation exists between the actual and predicted responses. To the Adjusted R^2 of 0.9394 in Table 4, "The Predicted R^2" of 0.8527 was in appropriate agreement. "Adequacy Precision" calculates the signal-to-noise ratio. According to Table 4, the ratio of 18.928 suggests a sufficient signal. These models act as a guide through the design space, as was previously examined.

To further elucidate the analysis, Figure. 2 displays the variation in the curve of the experimental value that represents the optimum shredding efficiency, the distribution illustration of the test value, and the corresponding fitting precision of the system model. Fig. 3 displays the expected value that was achieved. The residual value ranges from 0.173 at the lowest to 1.817 at the largest maximum. According to the regression model may very well show the correlation of the factors because the statistically significant shredding performance of the experiment as well as the predicted values are in a straight line (Nakai et al., 2006).

From the three-dimensional (3D) surface diagrams shown in Figure 4, the efficiency of the machine response surface opens upwards and shows the interactive influence of the speed and the feed input on the efficiency when the moisture content is 88%. The shredding efficiency increases with increasing shredding speed and decreases with increasing input material. At any level of shredding speed, the efficiency of the machine first decreases and then increases as the feed rate increases. The figure illustrates how the feedstock input affects the machine's efficiency when the shredding speed is minimal. The efficiency in the figure has a steep quadratic shape. The impact of feedstock input on machine efficiency is visible at low shredding speeds, as illustrated in the figure, where the efficiency's quadratic shape is steep. As the shaft speed increases when the feedstock input is at its lowest point, the shredding efficiency shows an increasing trend, and the impact of speed on the efficiency is evident, as demonstrated by the figure's smooth curve. The shredding efficiency increases from 89 to 100% when the shredding speed increases from 2400 to 2800 rpm and decreases with increasing feedstock input material at a moisture content of 88%. This is because as the material input increases, the machine speed is decelerated thereby reducing the machine power. In additiona, reported similar results on the shredding efficiency of garden waste shredders, which increased as the speed of the machine increased (Nakai et al., 2006). As a reported similar results on the shredding efficiency of kitchen waste shredders for fruit waste, which increases with increasing speed and decreasing input rate (Gurudatta, 2015).

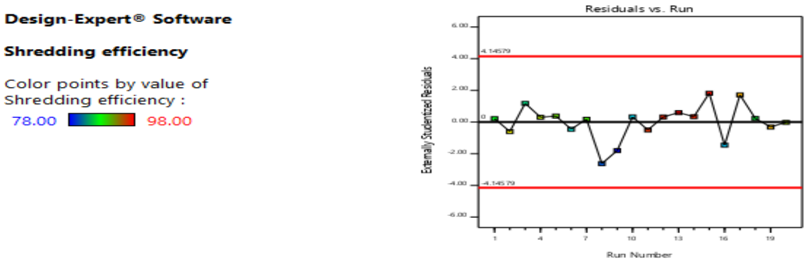

Figure 2: Maximum shredding efficiency residual distribution of cassava peel

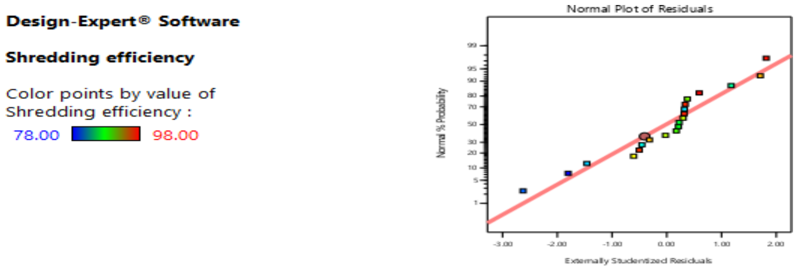

Figure 3: Distribution of the test and predicted values of the shredding efficiency

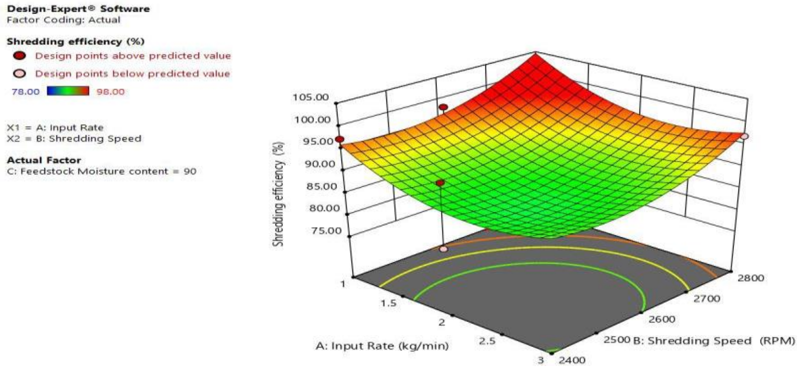

Figure 4: Shredding efficiency as a function of input feedstock and speed

3.2 Effects of Experimental Factors on Machine Throughput

The design matrix is followed when conducting the experiments, and Table 3 lists the corresponding outcomes. The values of the machine throughput varied in the range of 1.14 to 11.25 kg/min with the ratio of minimum to maximum value of 9.87kg/min. The quadratic equation for predicting the optimum point of machine throughput was obtained from input variables such as input feedstock (x1), shredding speed (x2), and Moisture content (x3). The empirical relationship between the response (throughput) and the independent variables was presented based on the experimental results in Equation 8

$$\text{Throughput} = +7.58 - 0.80x_1 + 2.91x_2 + 1.04x_3 - 0.70x_1x_2 + 0.78x_1x_3 - 0.3 + 0.75x_1^2 + 0.87x_2^2 - 0.21x_3^2 \quad R^2 = 0.834 \tag{8}$$

From equation 8, the coefficients of x2 and x3 are positives, which implies that a unit increase in shredding speed and moisture content increases the machine throughput by 2.91 and 1.04 respectively. While the coefficient of x1 is negative, which implies that a unit increase in input feedstock decreases machine throughput by 0.8. As demonstrated in Table 5, the model was significant and the terms in the models had a significant impact on the shredder's machine throughput, as indicated by the p-value being less than 0.05 ($p \leq 0.05$).

Table 5: ANOVA for response surface quadratic model machine throughput

Sources	Sum of square	Degree of freedom	Mean square	F value	P value
Model	129.13	9	14.35	5.58	0.006
x_1-Input Feedstock	4.84	1	4.84	1.88	0.1999
x_2-Speed	78.71	1	78.71	30.63	0.0002
x_3-Moisture	11.20	1	11.20	4.36	0.0634
x_1x_2	2.29	1	2.29	0.89	0.3672
x_1x_3	3.82	1	3.82	1.49	0.2509
x_2x_3	0.61	1	0.61	0.24	0.6363
x_1^2	2.26	1	2.26	0.88	0.3700
x_2^2	3.21	1	3.21	1.25	0.2895
x_3^2	0.11	1	0.11	0.011	0.8417
Residual error	25.70	10	2.57		
R^2 =0.83; Adj R^2=0.68		Pred R^2 = -0.308	Adeq Precision =8.440		

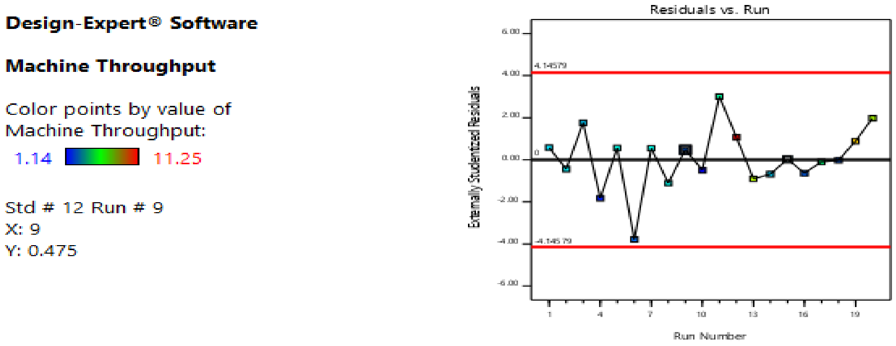

Figure 5: Maximum throughput residual distribution of cassava peel

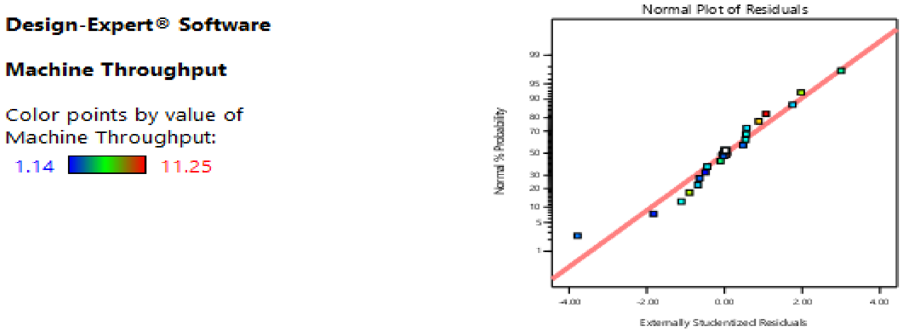

Figure 6: Distribution of The Test And Predicted Values Of The Machine Throughput

In Figure.7, the throughput response surface opens upwards and shows the interactive influence of the speed and the feed input on the machine throughput when the moisture content is 88%. From the contour map, it can be seen that the influence of the machine speed on the throughput is more significant than that of the input rate of the cassava peels. When the shredding speed is at any level and the material input increases from 1-3 kg min-1 the throughput decreases. When the input rate is low, the impact of the shredding speed on throughput is obvious, as shown in the figure. At all input stages with increased speed from 2400 to 2800 rpm, the throughput first decreases and then increases. The machine throughput increases with increasing shredding speed and decreases with increasing material input. The machine throughput increases from 4.1 to 9.45 kg/min when the shredding speed increases from 2400 to 2800 rpm and decreases with increasing input material at a moisture content of 88%. That's because; increasing the load slows the engine speed and thereby reduces machine performance. In input reported similar results for the working machine throughput of the shredder, which increased with increasing shredding speed and decreased with increasing input rate (Aloria et al., 2015). It has been discovered that raising the cassava peels' moisture content boosts machine performance. In addition also documented an opposing impact of moisture on the effectiveness of mechanically shredding switchgrass, straw, and corn burner (Nurek et al., 2019).

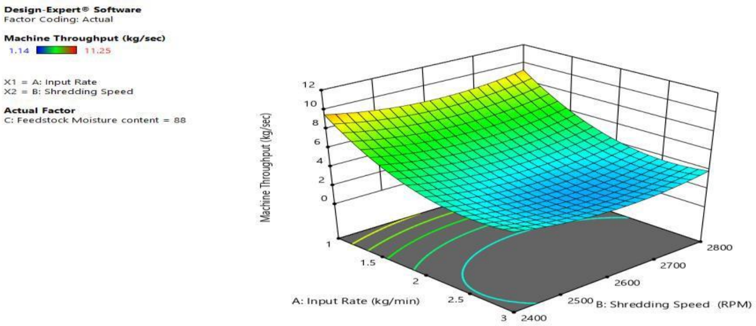

Figure 7: Response surface plot of the capacity of biogas feedstock shredder as a function of speed and input feedstock at the moisture content of 88%.

3.3 Optimization by Response Surface Modeling

The desired set goal was minimum for input feedstock, maximum shredding speed, and minimum for moisture content. The responses (shredding efficiency and machine throughput) were set to be maximized to achieve the highest performance. As indicated in Table 4, the optimum conditions were achieved at a process combination of feedstock input, 1.03 kg, shredding speed of 2600 rpm, and moisture content of 82.9%. Therefore, for the three materials processed, the speed of the machine can be established at 2400 rpm at low input of material (1 kg) at every operational loading point.

To optimize all results with different goals, an evaluation approach with several criteria such as a numerical optimization technique through the desirability function and a graphic optimization technique employing the overlay diagram was used (Figure.8). The optimized process was achieved by applying constraints to the response. From the range examined, the shredding values of 75 to 95% were selected as the optimum, the high shredding resulting in a large cut of the peels and the low shredding values leading to an improvement in the quality of the end products with reduced clogging of the machine. The throughput of 4-15 kg/min was selected as a suitable device throughput to keep the production and the shaft speed constant. From the overlaid contour (Figure. 8) by adding a confidence interval to the selected criteria. The robustness of the design space has been kept away from the edges. The yellow area consistently showed good conditions for the preparation of the starting material

Table 4: Optimum Values of The Process Parameter and Their Response

Factors/Responses	Goal	Experimental range		Optimum/predicted value	Desirability
		Max	Min		
Input cassava peels (kg)	Maximum	1	3	3.08	0.70
Machine speed (rpm)	Maximum	2400 2800		2600	
Moisture content (%)	Minimum	90	80	82.9	
Shredding efficiency (%)	Minimum	72	91.7	96.48	
Throughput (kg/min)	maximum	1.14	13.3	13.32	

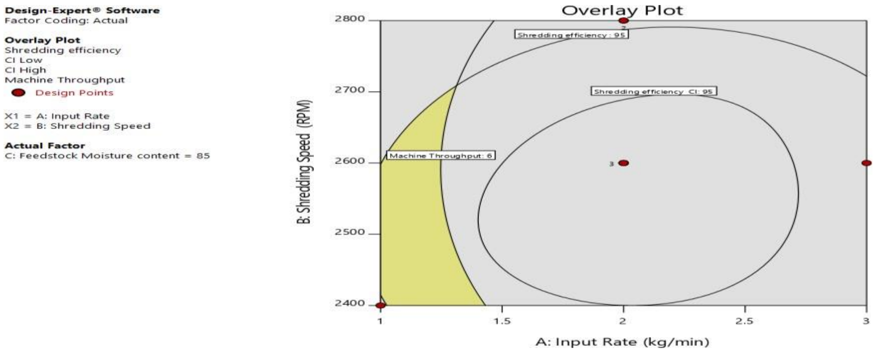

Figure 8: Overlay contour for optimization of the variable parameters Conclusion

In this study, shaft speed (2400, 2600, and 2800 rpm), the input of cassava peels (1, 2, and 3 kg/min), and the moisture content (80, 85, and 90%) were then determined on machine shredding efficiency. The results from the combinations of the factors at different levels were compared to obtain the optimal process parameters. The following conclusions were generated:

- The shredding efficiency of the cassava peel shredder varied from 72 to 91.7 % with an average value of 83.9 %.
- The throughput varied from 1.14 to 11.25 kg/min with an average value of 9.87 kg/min with reduced machine clogging.
- Shredding efficiency and machine throughput increased with an increase in speed and decreased with an increase in feedstock input.
- The optimum values for input feedstock, shredding speed, and moisture content were 1.03 kg, 744.41 rpm, and 88 %, respectively, and predicted values for shredding efficiency and machine throughput were 92.06 % and 13.32 kg/min, respectively, with the desirability of 0.87.

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