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Multi-response optimization of bambara nut milling- sieving machine

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Abstract

Response Surface Experimental design was used to investigate the optimal operational parameters and response of bambara nut milling –sieving machine; Performance result revealed particle size of milled flour, number and speed of the paddle as these machine process/operational parameters with significant influence on its performance while throughput and extraction efficiency constitutes its functional performance indicators. Extraction of the grain starch granules from its fiber depends on the particle size of the milled grain and paddle parameters. In addition, the multi-response performance simulation of this machine predict 1080 rpm, 4 paddles and 35 μm respectively for speed of the paddles, number of paddles and particle size of bambara flour as values require for its optimal operation with optimal value of throughput and extraction efficiency of 117.8 kg/h and 98.45% respectively which indicates that the novel bambara nut milling-sieving machine reduced the food loss to chaff in this sector to 1.55% against 15.82% associated with the widely used semi-mechanized system. It also promotes hygiene in this sector because it eliminated human contact with the milled grain during sieving operation. Its operation with the optimal parameters derived in this study is therefore recommended to both small and medium scale bambara flour producers to enhance quantity and quality bambara flour production for food security and poverty alleviation.

Keywords: Bambara flour; Efficiency, Optimization; Response surface methodology; Throughput

1. Introduction

Bambara nut a legume belonging to the family of fabaseae is a crop with a high potential for the attainment of food security and poverty alleviation in Africa, as it shows considerable drought resistance and potentially, high nutritional qualities [1, 2]. The crops contains about 6% other extract therefore could give a cash crop status, a great importance in food industry. Bambara nut can be processed and eaten in many ways, the fresh immature green grains are consumed raw as a vegetable or cooked with salt and pepper while its roasted dry seeds are eaten as snack with coconut. However, processsing of bambara nut to flour makes it more versatile for diverse diet production [3, 4]. Hence, the clamor for a system for its processing by small and medium scale bambara flour producers. According to [5] the milling process is partially mechanized with the latest version of hammer mill while manual sieving operation still prevails in this sector because of unsuccessful fitting/matching of other grain flour milling and sieving machineries for bambara flour production. This is because bambara seed is hard and impermeable with strong binding property unlike other seeds such as soybean and cowpea [6]. As a result multiple milling and manual sieving is witnessed and generally adopted by processor in this sector as the only means of milling and separating the fine bambara flour from its fibrous content. Since [7] revealed its high demand as a result of the unique content, unique taste, flavor and enhanced iron, calcium, phosphorous, magnesium, zinc and copper content also the level of these minerals were higher than those found in commonly consumed legumes. Thus a system specially designed for milling-sieving of the bambara nut is highly desired to curb its incessant scarcity and high cost.

Hence, development of milling- sieving machine for bambara flour production by [5] as shown in Fig. 1 which is of interest and relief to both small and medium scale bambara flour processors.

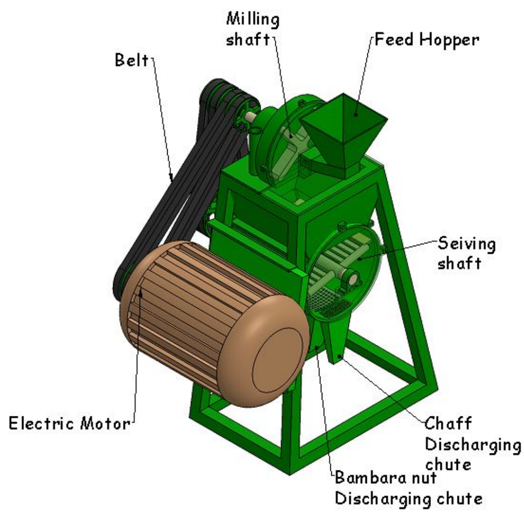

Figure 1: Bambara nut milling-sieving machine.

This machine mills and sieves Bambara flour in a single flow process and its major operational parameters include the electric motor, the milling unit and the sieving unit. The milling unit comprises of the chamber that houses the rectangular shaped cross beater hammer with shaft and a mesh. The chamber houses the beaters and shaft while the cross beater performs a dual purpose of crushing the nut and also as a blower which helps in the separation of the flour and chaff. The mesh regulates the particle size of grain discharged to the sieving unit. The sieving unit comprises of

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the sieving chamber which houses the sieving paddle with shaft, chiffon sieve protected with an aluminum perforated net and a 5.5Hp electric motor. The machine operates at a throughput and extraction efficiency of 117.8 kg/h and 98.45% respectively at the design value of its operational parameters. [5] Further indicated that three operational parameters (particle size of flour, number and speed of the paddle) of this machine affect the throughput and extraction efficiency differently at same level. It is therefore desired that the machine operates with maximum extraction efficiency and throughput possible, therefore the need for the optimal settings of these operational parameters which will simultaneously optimize both responses. According to [8, 9, 10] determination of optimal performance parameters of engineering system has been one of the major areas of international research interests and its beneficial in industrial application of machineries. It is therefore of economic importance to apply a principle that will enable simultaneous assessment of the three operational parameters of the milling-sieving machine on its separation efficiency and throughput. Therefore, application of multi-response surface methodology simulation in this study enabled the establishment of optimal operational parameters of the integrated milling- sieving machine for bambara flour production with small number of experimental runs and thus, strengthening how well it will be embraced. This is because Response Surface Methodology (RSM) gives optimal operational settings that are always or nearly close to the real system's optimal operating conditions [11]. Response surface methodology is very efficient in determining optimal industrial processes involving different factors with antagonist responses and has been successfully applied in many technological problems [12]. It is a confirmed outstanding and widely used industrial research and analytical tool because its predictions are always or nearly close to the optimal operating conditions of the true system. RSM determines and concurrently solves multivariate models using quantitative data from appropriate experimental designs with the objective of finding the optimal settings of design factors relative to a performance indicator or response [13, 14, 15]. Hence, its application by [16, 17] in determining the optimal mix for acid reclamation of used engine oil and optimal design for rice husk-saw dust reinforced polyester ceiling board production respectively. Optimal operational parameters of a *cassava attrition peeling* machines and for optimization of anti-obesity effect in fermented were successfully predicted by [18] and [19] respectively with this technique. RSM was also applied by [20] in determining the operational settings of a centrifugal pump for heavy end recovery. [21] Employed RSM to determine the optimal operating settings of a multistage centrifugal pump used in gas plants. Results revealed a reduction in energy consumption when pump was operated at the optimal factor settings obtained. [22] Established mathematical models for the prediction of thrust force and cutting torque when drilling Al7075 work piece using RSM. Models' predictions showed good accuracy when compared to experimental results. [23] also analyzed the effect of peeling time and operational speed on flesh loss of cassava using RSM. Optimal shaft speed for minimal flesh loss and peeling efficiency was obtained using this technique.

Therefore, this study applied RSM in multi-response optimization of bambara nut milling-sieving machine to enable its optimal performance

2. Methodology

Screening tests were used to determine the significant level/limits within which the operational parameters of the bambara flour milling-sieving machine affect its performance. This entails evaluating the machine' performance indicators when it operates at varied settings of one factor and constant design/normal operating settings of others to ascertain the lowest and highest values within which the varied factor significantly affects the responses simultaneously. *The f*actor values at which any of the responses starts and also when all stops changing value while the factor varies constitutes the respective lower and upper limits of the factor studied at that time. Accounting for the maximum fibre content of the bambara groundnut which according to [24, 25] is 1.4 to 10.3%. The performance parameters of this machine were determined from the experimental results using the following mathematical relations;

Table 1: Factorial design layout for evaluating main effects of the Bambara flour processing machine.

Experimental runs		Coded factors' setting		
Standard order	Run order	X_1	X_2	X_3
7	1	-1	1	1
5	2	-1	-1	1
4	3	1	1	-1
2	4	1	-1	-1
13	5	-1	-1	1
12	6	1	1	-1
3	7	-1	1	-1
1	8	-1	-1	-1
16	9	1	1	1
10	10	1	-1	-1
8	11	1	1	1
15	12	-1	1	1
9	13	-1	-1	-1
11	14	-1	1	-1
6	15	1	-1	1
14	16	1	-1	1

$$\eta = \frac{100M_f}{0.951M_f} \tag{1}$$

$$\text{TP} = \frac{M_g}{t} \tag{2}$$

Where t, M_g, M_f constitutes processing time, mass of bambara groundnut processed and mass of fine flour extracted respectively.

The main effects/linear relation among the operational and performance parameters of the bambara flour milling-sieving machine were experimentally assessed in this study using a randomized single replicate full factorial design with the same test procedure as in factor screening. The sixteen (16) runs, two levels coded factorial design layouts shown in Table 1was developed based on equation (3) using version 18 of Minitab software.

$$n = 2^{k-q} + n_c \tag{3}$$

Where n_c , q, k and n constitutes the number of center points, factors, fractions and runs in the design factor values of -1 and 1 as displayed in Table 2 indicate the low and high factor values

The transformation relation of the coded (x_c) and actual/measured (X_a) levels of each factor was established from equation (4) given by [26]

$$x_c = \frac{X_a - 0.5\,(X_l + X_u)}{0.5\,(X_l + X_u) - X_l} \tag{4}$$

Where $X_l$and X_u constitutes the lower and upper limits of the factor. The data obtained from the experimental assessments of this machine's operation at each actual factor limits combination as contained in the developed factorial design code. Table 2 was analyzed using Minitab 18 software to fit mathematical functions relating the factors and each of the responses based on first-order main effect regression.

Table 2: Response surface design layout for non-linear simulation of the Bambara flour milling-sieving machine.

Standard order	Run order	X_1	X_2	X_3
16	1	0	0	0
18	2	0	0	0
2	3	1	-1	-1
17	4	0	0	0
5	5	-1	-1	1
11	6	0	-1.68	0
19	7	0	0	0
9	8	0	0	0
7	9	-1	1	1
6	10	1	-1	1
1	11	-1	-1	-1
15	12	0	0	0
8	13	1	1	1
12	14	0	1.68	0
13	15	0	0	-1.68
4	16	1	1	-1
10	17	1.68	0	0
20	18	0	0	0
14	19	0	0	1.68
3	20	-1	1	-1

The developed linear response function of this machine was confirmed unfit for approximation using of their exhibited statistical residual diagnostic measures and plots. The measures include regression analysis of model coefficients, analysis of variance (ANOVA) and lack-of-fit tests. The plots used are normal probability plots of residuals, histogram of residuals, dot plots of the residuals versus observation order and that of residuals versus fitted response were model adequacy measures used for the statistical verification of the fitted functions. Residual is the difference between the respective observed responses and their model predicted values. Thus, the factorial design was augmented/simulated to an orthogonal twenty (20) run, central composite circumscribed response surface design for fitting second-order response models of the bambara flour milling-sieving machine

The response surface design comprises of the initial 16 factorial points, center and star points valued at 0 and 1.68 respectively (Table 2). The best fit response functions of this machine were determined from its over approximating second order models using backward elimination method with the aid of residual diagnostic measures and plots.

The reduced nonlinear functions which approximated the machine' responses were selected based of the criteria that a good mathematical model must exhibit less than 0.05 P-values, small SS of Error, R^2 and adjusted R^2 values close to 1(100%) with less than 0.2 difference, ANOVA-Fcal Ftab and insignificant lack-of-fit. Others include that normal probability and histograms of good functions' residuals must approximate straight line and dumb-bell plots while their residuals versus run order and residuals versus fitted response plots remain structure less (scatter feature)

The prediction accuracy of the developed selected response functions of the bambara flour processing machine were confirmed using twenty experimental runs before applying them for this systems optimization. The test conditions were based on actual factor settings within the set limits that are not used for the models' fitting using with the same procedure as in factor screening. Thereafter, the machines responses predicted from the confirmatory set factor combinations were compared with the actual experimental results (at 95% acceptable prediction interval) by computing their residuals and their percentage errors.

The mathematical programming model formulated from the developed models was simulated for the machine's optimal parameters prediction using Minitab response optimizer with maximization of extraction efficiency subject to constrain of throughput TP, greater than or equal to 116 kg/h as objectives, coded factor value of 3 and particle size of flour $\leq 35\ \mu$m.

The model solution or prediction criterion for optimal parameter conditions was based on coded factor settings with maximum overall desirability value close to one. The actual optimal settings of the operational parameters of the machine were derived from the coded solution using their transformation relations before confirming their accuracy with three experimental trails using the same test procedure as factor screening.

Table 3: Functional limits of the particle size of flour, number and speed of paddle.

Factor Description	Symbols		Limits	
	Coded	Actual	High (+1)	Low (-1)
Number of paddle	x_1	N_p	4.00	2.00
Paddle speed (rpm)	x_2	n_p	1080.00	444.00
Particle size of flour (μm)	x_3	p_f	35.00	17.00

3. Results and discussion

The factor levels described as the limits below or beyond which there are no observable significant changes in the machine's performance indices were determined during preliminary evaluation of the machine is shown in Table 3. Operation of this machine at these optimal factor settings while varying the number and speed of the sieving paddle revealed the upper limits within which these paddle parameters affects this machine's performance as 4 and 1080rpm respectively while 2 and 444rpm constitutes their respective lower limit. The multiobjective performance evaluation of the bambara processing machine using twenty response surface experimental runs based on a two level of factors and the following transformation equations relating the actual ($N_p,\ n_p,\ P_f$) and coded ($x_1,\ x_2.x_3$) settings of the speed and number of the paddle and milled grain particle size respectively.

$$x_1 = \frac{N_p - 762}{518} \quad (5)$$

$$x_2 = \frac{n_p - 3}{1} \quad (6)$$

$$x_3 = \frac{P_f - 25.5}{8.5} \quad (7)$$

The multiobjective performance test results used for the simulation and optimization of this machine's throughput and extraction efficiency is shown in Table 4.

To this effect, the complete RSM matrix comprising of 8 initial factorial points augmented with 6 center and 6 axial points with the value of 1.68179 was analyzed. The second order models obtained in coded factors are given in equation (8) to (9) using Table 5.

$$\begin{aligned} TP\,(\text{kg/h}) = {} & 85.544 + 4.692x_1 + 2.619\ x_2 \\ & + 6.117x_3 + 4.510x_1x_1 + 3.688x_2x_2 \\ & + 5.207x_3x_3 + 2.038x_1x_2 + 4.688x_1x_3 \\ & + 3.788x_2x_3 \end{aligned} \quad (8)$$

Table 4: Multiobjective evaluation of the bambara flour processing machine.

Standard order	Run order	Coded values			Natural values			Responses	
		X_1	X_2	X_3	N_p (rpm)	n_p	P_f (μm)	Throughput(kg/h)	Extraction efficiency (%)
16	1	0	0	0	762.00	3	25.50	85.21	92.71
18	2	0	0	0	762.00	3	25.50	85.60	91.72
2	3	1	-1	-1	1080.00	2	17.00	96.00	96.31
17	4	0	0	0	762.00	3	25.50	85.65	91.71
5	5	-1	-1	1	444.00	2	34.00	87.40	94.21
11	6	0	-1.68	0	762.00	1	25.50	90.82	98.36
19	7	0	0	0	762.00	3	25.50	85.37	91.74
9	8	-1.68	0	0	-1280.16	3	25.50	90.20	89.46
7	9	-1	1	1	444.00	4	34.00	103.70	96.06
6	10	1	-1	1	1080.00	2	34.00	110.10	95.31
1	11	-1	-1	-1	444.00	2	17.00	92.70	96.46
15	12	0	0	0	762.00	3	25.50	85.72	91.76
8	13	1	1	1	1080.00	4	34.00	115.60	98.03
12	14	0	1.68	0	762.00	5	25.50	101.80	93.46
13	15	0	0	-1.68	762.00	3	-42.84	90.01	97.96
4	16	1	1	-1	1080.00	4	17.00	89.00	98.46
10	17	1.68	0	0	1280.16	3	25.50	107.07	93.66
20	18	0	0	0	762.00	3	25.50	85.60	91.72
14	19	0	0	1.68	762.00	3	42.84	111.20	96.81
3	20	-1	1	-1	444.00	4	17.00	93.20	98.46

$$\begin{aligned}\eta\,(\%) \;=\; & 81.901 + 10.604x_1 + 5.838\,x_2 + 8.859x_3 \\ & - 9.061x_1x_1 - 5.755x_2x_2 - 7.019x_3x_3 \\ & + 3.175x_1x_2 - 2.145x_1x_3 + 2.350x_2x_3\end{aligned} \tag{9}$$

After analyzing each term in the model and eliminating the insignificant term(s) (excluding the main terms) from the function, the reduced model is given in equation (10) to (11). The throughput and extraction efficiency model was converted to actual values using the transformation equations listed in equation (5) to (7).

$$\begin{aligned}\mathrm{TP} = & 1305.84 - 3.76 * 10^{-2} Np \\ & - 78.73p - 31.26P_f + 4.5 * 10^{-5}\mathrm{Np}^2 \\ & + 3.69p^2 + 0.21{P_f}^2 + 3.14 * 10^{-3} pNp \\ & - 1.3 * 10^{-3} P_f Np + 7.6 * 10^{-1} \eta_{\mathrm{M}}\, p\end{aligned} \tag{10}$$

$$\begin{aligned}\eta\,(\%) = & 1.40Np - 2.5p + 41.33P_f \\ & - 8.88 * 10^{-4}\mathrm{Np}^2 - 5.76p^2 \\ & - 0.28{P_f}^2 + 9.97 * 10^{-3} pNp \\ & - 1.35 * 10^{-3} P_f Np + 0.47P_f p - 1725.51\end{aligned} \tag{11}$$

Where, p N_P, η, TP and P_f represents the number and speed of paddle, extraction efficiency throughput, and particle size of Bambara flour respectively.

Statistical residual analysis (Fig. 2 and Fig. 3) showed that this function is adequate for further investigation of this response because the normal and the scatter points are random indicating that all the necessary terms are adequately represented in the model. The histogram portrayed the requisite dumb-bell shape while the residuals in the normal probability plot follows a straight line and structure less profile indicating that the residuals in the response

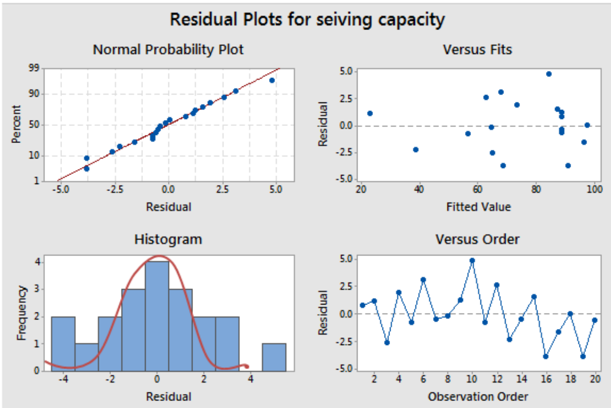

Figure 2: Residual plots of the quadratic model for throughput.

are normally distributed which is expected of a good prediction model. These features imply that the 2nd order response surface model is satisfactory. The prediction adequacy of the extraction model was also confirmed exponentially to over 97% as shown in Fig. 4. Table 6 shows coefficient of determination (regression coefficient) R^2 of the quadratic models for the throughput and extraction efficiency model as 99.69, 99.59 and the adjusted coefficient of determination (adjR^2) as 99.22 and 99.89% respectively which is highly satisfactory also the coefficient of prediction (predicted R^2) of the models is very significant. The insignificant lack of fit of the regression equation implies that the quadratic models for the throughput and extraction efficiency is adequate.

The analysis of variance and regression coefficients shown in Table 7 indicates that this quadratic function is significant and fit. These tables show that the entire main terms as well as the interactions

Table 5: Coded coefficients of throughput and extraction efficiency model.

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Coded Coefficients of throughput						
Constant		85.544	0.338	252.88	0	
X1	9.383	4.692	0.224	20.9	0	1
X2	5.238	2.619	0.224	11.67	0.002	1
X3	12.234	6.117	0.224	27.25	0	1
X1*x1	9.02	4.51	0.218	20.64	0	1.02
X2*x2	7.376	3.688	0.218	16.88	0	1.02
X3*x3	10.413	5.207	0.218	23.83	0	1.02
X1*x2	-4.075	-2.038	0.293	-6.95	0.032	1
X1*x3	9.375	4.688	0.293	15.98	0	1
X2*x3	7.575	3.788	0.293	12.92	0	1
Coded Coefficients of extraction efficiency						
Constant		81.901	0.601	136.38	0	
X1	21.208	10.604	0.398	26.61	0	1
X2	11.677	5.838	0.398	14.65	0	1
X3	17.718	8.859	0.398	22.23	0	1
X1*x2	-18.121	-9.061	0.388	-23.36	0	1.02
x2*x2	-11.51	-5.755	0.388	-14.84	0	1.02
x3*x3	-14.038	-7.019	0.388	-18.1	0	1.02
x1*x2	6.35	3.175	0.521	6.1	0	1
x1*x3	-4.29	-2.145	0.521	-4.12	0.002	1
x2*x3	4.7	2.35	0.521	4.51	0.001	1

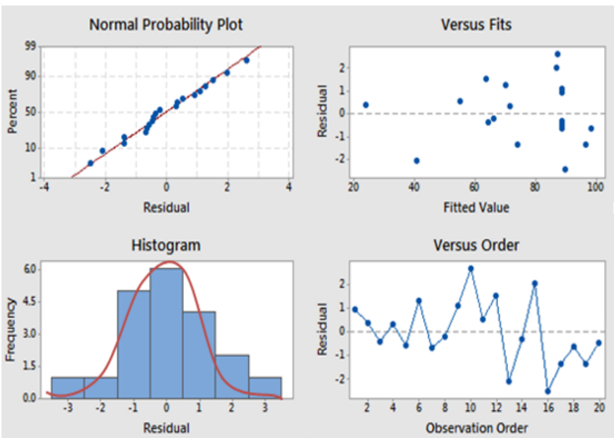

Figure 3: Residual plots of the quadratic model for extraction efficiency.

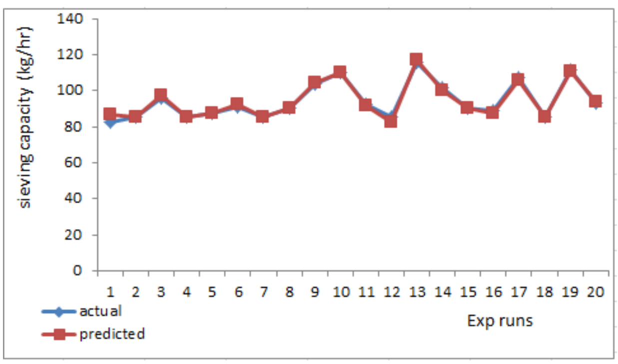

Figure 4: Confirmatory test for extraction efficiency.

Table 6: Fit statistics for main effect quadratic response models of bambara flour processing machine.

Source	Standard Deviation	R^2 (%)	Adjusted R^2 (%)	Predicted R^2 (%)
TP-model	1.4725	99.59	99.22	96.96
η_s-model	0.8973	99.9	99.81	99.17

and square terms are all significant with very high F-values. The sign of each term or combination of terms shows the relationships between the terms and the responses. The model was very significant with a p-value of 0.000 also the linear, square terms and the 2-way interaction terms contained in the models were all significant with similar p- values. Therefore, the empirical models developed are reasonably accurate since the results of the confirmation runs (actual values of the responses) are within 95% prediction interval. With the quadratic model's having proved to be adequate and satisfactory it was then optimized to determine the best settings of the operational parameters of the integrated Bambara flour processing machine. In order to verify the adequacy of the quadratic models developed and to estimate the ability of the quadratic models to correctly predict the responses, the experimental results obtained from the experimental runs were compared with the fitted responses generated on the quadratic models and the residuals was evaluated at 95% confidence interval and at 95% predictive interval as shown in Table 8.

The global solution of the optimization models as displayed in the optimization plot shown in Fig. 5 indicates that x_1 (0.8664), x_2 (1.1722) and x_3 (0.9534) in coded optimal values and the composite desirability for the universal solution is 0.9749 indicating that the universal solution of the variable settings is satisfactory for both the throughput and the extraction efficiency.

The individual desirability of 0.9749 for extraction efficiency and 1.0 for the throughput also substantiate the adequacy of the optimization result. The corresponding actual optimal values of the

Table 7: Analysis of variance for the quadratic model of the throughput and extraction efficiency.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Throughput					
Model	9	1967.6	218.629	317.8	0
Linear	3	905.25	301.75	438.63	0
x1	1	300.6	300.596	436.95	0
x2	1	93.67	93.668	136.16	0.002
x3	1	510.99	510.986	742.78	0
Square	3	738.66	246.218	357.91	0
x1*x1	1	293.14	293.141	426.11	0
x2*x2	1	196.02	196.023	284.94	0
x3*x3	1	390.67	390.672	567.89	0
2-Way Interaction	3	323.75	107.918	156.87	0
x1*x2	1	33.21	33.211	48.28	0.032
x1*x3	1	175.78	175.781	255.52	0
x2*x3	1	114.76	114.761	166.82	0
Error	10	6.88	0.688		
Lack-of-Fit	5	6.69	1.338	5.56	0.197
Pure Error	5	0.19	0.038		
Total	19	1974.54			
Extraction efficiency					
Model	9	5234.37	581.6	268.24	0
Linear	3	3073.02	1024.34	472.44	0
x1	1	1535.64	1535.64	708.26	0
x2	1	465.53	465.53	214.71	0
x3	1	1071.85	1071.85	494.35	0
Square	3	1999.71	666.57	307.43	0
x1*x1	1	1183.08	1183.08	545.65	0
x2*x2	1	477.28	477.28	220.13	0
x3*x3	1	709.95	709.95	327.44	0
2-Way Interaction	3	161.63	53.88	24.85	0
x1*x2	1	80.64	80.64	37.19	0
x1*x3	1	36.81	36.81	16.98	0.002
x2*x3	1	44.18	44.18	20.38	0.001
Error	10	21.68	2.17		
Lack-of-Fit	5	4.86	4.17	2.53	0.201
Pure Error	5	0.82	0.16		
Total	19	5256.05			

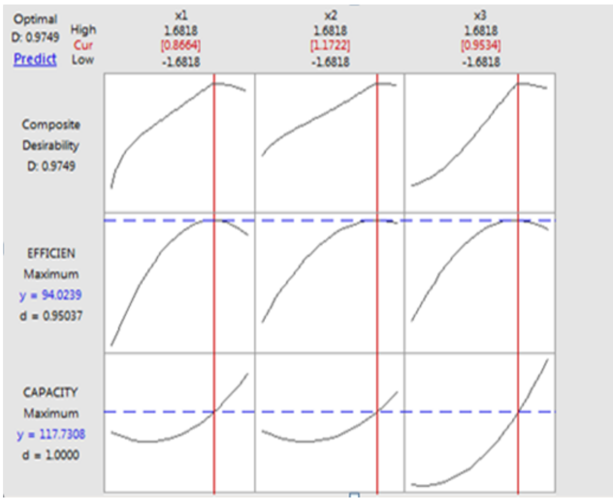

Figure 5: Optimization plot for the performance parameter model.

speed of the paddles, number of paddles and particle size of bambara flour were determined using the transformation equations to be approximately 1038 rpm, 4 paddles and 35 μm respectively. The optimal values of the response from the developed models were determined to be extraction efficiency and throughput with corresponding values of 98.45% and 117.8 kg/h respectively. The obtained values amount to 1.55% improvement in extraction efficiency using this machine against 15.82% obtained from the semi-mechanize method used in the sector. Reduction in particle size of bambara flour and increase in number and speed of paddle improved the throughput and extraction efficiency and the improvement associated with this systems optimization encouraged milling-sieving of quality bambara flour at low cost.

4. Conclusion

Performance optimization results revealed particle size of milled flour, number and speed of the paddle of this machine as process/operational parameters (factors) with significant influence on its performance while throughput and extraction efficiency constitutes its functional performance indicators (responses). Sieving (extraction) of the grain food/starch granules (flour) from its fibre (chaff) depends on the particle size of the milled grain and paddle parameters. In addition, the multi-response performance simulation of this machine predict 1038 rpm, 4 paddles and 35 μm respectively for speed of the paddles, number of paddles and particle size of bambara flour as values require for its optimal operation with optimal value of throughput and extraction efficiency of 117.8 kg/h and 98.45% respectively which shows bambara nut milling-sieving machine reduced the food loss to chaff in this sector to 1.55% against 15.82% associated with the widely used semi-mechanized system. Reduction in particle size of bambara flour and increase in number and speed of paddle improved the throughput and extraction efficiency. The improvement associated with this systems optimization encouraged milling-sieving of quality bambara flour at low cost. Development and operation of this machine using the optimal parameters derived in this study is therefore recommended to both small and medium scale bambara flour producers to enhance quantity and quality bambara flour production for food security and poverty alleviation.

Table 8: Comparison of the experimental and fitted values of the responses.

S/N	X_1(rpm)	X_2	X_3	Throughput (kg/hr)			Extraction efficiency (%)		
				Actual	Predicted	Residual	Actual	Predicted	Residual
1	444	4	80	103.70	104.13	-0.43	96.06	95.48	0.58
2	1080	2	80	110.10	110.07	0.02	95.31	96.02	-0.71
3	1080	4	80	115.60	116.81	-1.21	96.73	98.04	-1.31
4	1211	3	75	107.07	106.19	0.87	93.66	94.10	-0.44
5	762	5	75	111.20	110.55	0.64	96.81	96.44	0.37

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