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Original Research Article

Performance Characterization and Modeling of Minisett Processing Machine

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ABSTRACT

Taguchi design/optimization tool was used to carry out the performance optimization on the fabricated Yam minisett processing machine. The performance analysis results showed that the crank shaft speed, connecting rod length and the number of blades were used as functional operational parameters while the machine capacity and efficiency are the functional performance indicators of the processing machine. The results show that the machine operates at an optimal efficiency and capacity of 96.24% and 28,888 minisett/hr respectively which were obtained at a crank shaft speed of 10-80 rpm, connecting rod length of 470-540 mm and cutting blade number settings of 13, thus it was economical viable.

1. INTRODUCTION

Yams like the white yam (*Dioscorea rotundata*), water yam (*Dioscorea alata*) or yellow yam (*Dioscorea cayenensis*) are best grown on free draining, sandy and fertile soil. The land is first cleared then fallowed. While preparing the land, mound or ridge of 1.0 meter height are formed in an arranged manner all through the farm. After that, planting is done by seed yam or cut setts fromware tubers. The phrases “yam seed” and “seed yam” can be confusing at times. Most times, people wrongly use them interchangeably, although they represent different things. Yam plants produce flowers which always come in long clusters. Individually these flowers are not notable as they are small, but obvious when they are clustered. It is a greenish flat perianth that encloses some numbers of stamens in the male flowers and three-winged ovary in the female flowers. During maturity, the membranous capsule bursts into valves, liberating numerous flat seeds; these seeds are called yam seeds or botanic yam seeds (Aighewi, *et al.,* 2014). Breeders use these seeds in crossbreeding to produce new varieties of yam. In regular yam production, yam is propagated by planting tubers, which is actually a full edible yam. These tubers are known as "seed yams", since as yams they serve as seeds. Tubers produced from seed yam are always identical to the mother tuber genetically, while those yams produced from yam seeds have an identity that differs from its parent material. Yam is demanding of labour, especially for land preparation and harvesting (Oguntade *et al.,* 2010; Nweke and Ezumah 2012).

The predominant source of planting material (or seed yam) mostly in West Africa are the farmer-saved seeds (Nweke *et al*., 2011). There are basically four ways by which yam farmers obtain their seed yams. The first is called the milking or the double harvesting which involves harvesting the same plant twice (Nweke, 2014). The first harvest is done between the fifth and seventh month of the plant's growth. Here, the farmer carefully cuts the tuber (the growing yam) off below the coronal roots to avoid damage to the root system. After that, the roots are then covered with soil. This first yam is called the ware yam, and it serves as food to the farmer and his family or source of income. Later on, at the end of the season, a second harvest of the same plant is done (Nweke, 2014). This second harvest will be kept and used as seed yam for the next planting season.

Sorting method involves the use of small whole tubers as some yam varieties have the capacity to produce both seed sized tuber and ware sized tubers from a single stand. After the harvest, the farmer separates the big tubers from the small sized tubers. The larger tubers mostly are used for food or sold, while the small sized tubers are retained for planting (Korada *et al*., 2010).The problem with this method is that the farmer is faced with a high risk of selecting a seed sized tuber whose small size is as a result of disease, probably caused by virus, whose symptoms may not be visible on the tubers at that time (Nweke, 2014).

Another method of getting planting material involve cutting large ware tubers of up to 2 kg into seed sized setts of 300 g to 500 g. This is referred to as "junking". It is mostly used when seed sized tubers are in short supply (Nweke, 2014). The disadvantage of this method is that it reduces significantly the quantity of tubers that could be used for food as larger tubers are converted to seed yam by being cut into setts (Oguntade *et al*., 2010) It's worth noting that sometimes such setts do not sprout evenly when planted.

Yam varieties like the "*Macakusa*" which is in high demand in the major yam producing region of the middle belt of Nigeria flourish well when propagating by junking. This is an advantage since this variety of yam is known for its inability to produce many seed yam tubers (Aighewi *et al.,* 2014). Thus, larger tubers are always cut to get enough seeds. Another method of junking which is less widely used involves cutting ware sized tubers during the first harvest of milking, after which they are buried in the soil at the base of the plant. During the second harvest, they are dug up and planted immediately in a newly prepared field for the next planting season, (Aighewi, *et al*., 2014). This production method is practiced by some farmers in the yam growing regions of Nigeria and Ghana.

Double planting is a means to plant the same sett twice and is mostly practiced in Southern Kaduna, Nigeria. After a planted seed yam has formed roots, vines, and leaves, the same seed yam is carefully detached and replanted in a new mound (Maroya *et al.,* 2014). These four methods of obtaining seed yam are recommendable, but their multiplication ratio is low, (at about 1:5). Also, the quality of yam produced is not guaranteed and limited quantity of seed yams is a problem in yam production, (Ogbonna *et al*., 2011).

In a bid to find a lasting solution to the problem of unavailability of good quality seed yam, researchers in National Root Crops Research Institute (NRCRI) Umudike, Nigeria and International institute of Tropical Agriculture (IITA) Ibadan, Nigeria developed a method called the yam minisett technique, but its level of adoption by farmers is low due to laborious features of manual cutting process, prone to accident in using sharp knife for cutting the minisett, tedious, energy sapping and time consuming thus there was a development of yam minisett processing machine by Igbo (2024). Hence, the objective of this paper was to investigate the performance analysis and modeling of minisett processing machine using Taguchi methodology.

2. MATERIALS AND METHODS

The developed yam minisett cutting machine was tested after fabrication to evaluate its performance. Each test performed was carried out in ten (10) different experimental runs for an average weight of 8kg of yam. The test performance indicators evaluated in the tests are capacity (or throughput), C_m and efficiency η_c.Two experiments were carried out on the machine, the first was to determine the effect of speed on the efficiency while the second was to determine the effect of speed on the capacity of the machine. Each test involved operating the machine at constant time duration of five (5) minutes. The length of the connecting rod (i.e. the travel distance of the yam) was also kept constant for each of the experimental run. The speed of the crankshaft was varied from 10rpm to 100rpm using pulleys of different diameter to achieve various speed ratios.

The number of yamminisetts produced during each test was recorded. The numbers of well-cut minisett were recorded, and those with improper cuts were also recorded. Yam minisetts with regular sharp cuts, good finishing and an average weight of 25g or more were considered as good one, while those that did not meet the above criteria were considered as scraps but were used in economic viability analysis, (Bolaji, 2018). Each minisett was weighed on a weighing balance to determine its actual weight. Thereafter, the capacity C_m and efficiency η_c of the machine were computed in each case using the following relations in Equations 1 and 2.

$$C_m = \frac{N_g}{t} \quad (1)$$

$$\eta_c\% = \frac{N_g}{N_T} x\ 100\% \quad (2)$$

Where t = Time of the operation, N_g = Number of well-cut yam minisetts and N_T= Total number of yam minisetts produced

The determination of the optimal settings of the performance and operational parameters of the machine involves model selection, experimental design, data collection, model fitting, model validation and optimization. The empirical relationships between the performance and operational parameters of the machine were evaluated using a taguchi design generated with version 18 of MINITAB. The MINITAB statistical software along with Taguchi design with L9 orthogonal array were employed for the optimization of the capacity and the efficiency of the yam minisett machine. In accordance with the steps that are involved in Taguchi's Method, a series of experiments were conducted while optimizing the machine. The factors that influence the values of these two responses were selected to be rotational speed of the crank shaft (W), length of connecting rod (which is travel distance of the yam carrier in mm) (L), and number of blades (B).

The Taguchi method was applied to the experimental data and the signal to noise ratio (S/N) for each level of process parameters was calculated. Regardless of the category of the quality characteristic, a higher S/N ratio corresponds to a better-quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. S/N Ratio for this function is given in Equation 3.

$$\frac{S}{N} = -10Log\left(\frac{1}{n}\sum_i^n Y_i^2\right) \quad (3)$$

Where, n= Sample size and Y = Efficiency

3. RESULTS AND DISCUSSION

Empirical evaluation of the developed yam minisett processing machine revealed capacity and efficiency as its functional performance indicators (responses). The process/operational parameters with significant influence on these responses include: speed of the crank shaft, length of connecting rod and number of blades. The experimental factor screening result shown in Table 1 revealed the functional limits within which these operational parameters influence the performance of the machine.

Table 1: Functional limit of the yam minisett processing machine parameter

S/N	Factor	Levels		
		Lower	Middle	Upper
1	Speed of crank shaft (rpm)	10	40	80
2	Length of connecting rod (mm)	340	470	540
3	Number of blades	5	8	13

The appropriate orthogonal array for conducting the experiments was selected by computing the degrees of freedom, (Taguchi *et al.*, 2005). The orthogonal array for experimentation is the L9 array which implies nine experimental trials as shown in Table 2.

Table 2: Coded orthogonal array experimental design

Experiment No.	Factor level		
	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	1
9	3	3	3

Following the orthogonal array above, experiments were conducted with their factors and their levels as mentioned in Table 2. The experimental layout with the actual values of the factors is shown in Table 3. Each of the 9 experiments was conducted 5 times (45 experiments in all, each lasting for 5 mins) to account for the variations that may occur due to the noise factors. The number of minisetts produced during each test was recorded. The number of well-cut minisetts was recorded, and those with improper cuts were also recorded, and with these values the Capacity and the efficiency of the machine at each experimental run was obtained. Tables 4 and 5 show the obtained values of capacity and the efficiency of the machine respectively, from different experiments.

A model for capacity and efficiency values based on these parameters is offered by MINITAB from which the optimal combination of the process parameters can be then predicted. Then analyses of variance (ANOVA), lack-of-fit test and residual analyses were conducted using MINITAB to check the adequacy of the estimated models to approximate the measured data well at 95% confidence interval (Sylvanus *et al.*, 2015). If $F_{cal} > F_{tab}$ and *p-val*> 0.05, the models are adequate approximation of the measured data; if $F_{calLOF} > F_{tabLOF}$ and *p-valLOF*> 0.05, the models have no significant lack-of-fit.

Table 3: Experimental layout for multiobjective analysis of the yam minisett processing machine

Experiment No.	Actual Factors		
	W(rpm)	L(mm)	N
1	40	470	16
2	40	340	8
3	40	540	22
4	10	470	22
5	10	340	16
6	10	540	8
7	80	470	8
8	80	340	16
9	80	540	22

Table .4: Experimental analysis of the yam minisett processing machine capacity

Experiment No.	Capacity/mins					
	1	2	3	4	5	Mean
1	478.59	478.60	478.90	480.20	480.50	479.36
2	481.45	482.01	479.99	480.57	480.98	481.00
3	481.47	481.47	481.39	481.50	480.99	481.36
4	479.98	479.98	482.01	4481.99	480.99	480.99
5	479.99	480.01	481.11	481.55	480.99	480.73
6	480.55	480.92	480.31	481.49	481.48	480.95
7	481.02	480.57	480.39	481.50	481.49	480.99
8	480.97	481.55	481.50	481.47	480.99	481.30
9	481.49	482.01	481.47	481.45	480.98	481.48

Table 5: Experimental analysis of the yam minisett processing machine efficiency

Experiment No.	Efficiency%					
	1	2	3	4	5	Mean
1	90.6	91.2	90.78	90.26	91.4	90.85
2	71.9	72.04	70.8	71.42	70.4	71.3
3	96.6	95.6	94.8	96.4	97.2	96.12
4	96.20	96.20	95.99	96.19	96.62	96.24
5	87.5	86.8	87.6	88.02	88.1	87.6
6	87.5	87.4	88.2	86.66	88.01	87.55
7	68.7	69.0	68.8	69.02	68.4	68.78
8	65.6	66.03	64.32	65.1	64.90	65.19
9	63.1	62.64	63.42	63.86	62.84	63.17

Finally, coefficients of determination (R^2 and $adj – R^2$) and error standard deviation (S) were determined to check the goodness of fit of the models. The more R^2 and $adj – R^2$ approximate to 100% and the smaller the value of S, the better the models approximate the measured data well. Results from ten experimental runs at varying speeds and the corresponding capacity or throughput obtained are tabulated in Table 6. Factors such as length of connecting rod, number of blades and duration of experiment were kept constant at 470 mm, 16, and 5 mins respectively.

Table 6: Effect of the crankshaft speed on the capacity of the yam minisett processing machine

S/N	Speed of crank shaft (rpm)	Total number of minisett produced	Total number of well-cut minisetts	Total number of poorly cut minisett	Capacity/mins
1	10	1924	1922	2	384.4
2	20	1970	1966	4	393.2
3	30	2151	2147	4	429.55
4	40	2278	2275	3	455.00
5	50	2393	2385	8	477.00
6	60	2415	2405	10	481.00
7	70	2441	2425	16	485.00
8	80	2472	2450	22	490.00
9	90	2490	2460	30	492.00
10	100	2527	2485	42	497.00

From Table 6, it can be seen that at crank shaft speed of 100 rpm, the largest number of yam minisett (2527) were obtained from the machine, and the machines capacity was calculated to be 497 minisett/mins, while at crank shaft speed of 10 rpm, the lowest number of yam minisett (1924) were obtained from the machine, and the machines capacity was calculated to be 384.4 minisett/mins. Table 6 shows that as the speed of the crankshaft increases, the capacity of the machine also increases. Results of the tests carried out to determine the effect of crankshaft speed on the efficiency of the developed machine are displayed in Table 7.

Table 7: Effect of crankshaft speed on the efficiency of the yam minisett processing machine

S/N	Speed of crank shaft (rpm)	Total number of minisett produced	Total number of well-cut minisetts	Total number of poorly cut minisett	Efficiency/%
1	10	16	14	2	87.5
2	20	32	28	4	87.5
3	30	48	44	4	91.7
4	40	64	61	3	95.3
5	50	80	75	5	94.2
6	60	96	86	10	89.5
7	70	112	96	16	85.7
8	80	128	106	22	82.8
9	90	144	114	30	79.2
10	100	176	134	42	76.1

Table 7 shows that machine's efficiency increased as the speed increases from 10 rpm to 40 rpm. From 40 rpm, the machine's efficiency decreased as the speed increased. The machines highest efficiency (which was obtained at 40 rpm) was recorded to be 95.3% while its lowest efficiency was recorded as 76.1 at a speed of 100 rpm. The reduction in the machine's efficiency at 100 rpm, even though it is at this speed that the machine produced at its highest capacity can be explained by the fact that the total number of poorly cut minisett is the highest at this speed.

Generally, the results of the performance tests performed on the machine show that low crankshaft speed is required to produce well-cut minisett and high machine efficiency while a high crank shaft speed is required for better machine capacity (throughput). It also showed that factors like length of the connecting rod and the number of blades also affects the machine's efficiency. For instance, the number of minisett per batch is determined by the number of blades, while the cutting efficiency of the machine is highly influenced by length of the connecting rod. It is therefore necessary to obtain the optimum speed, length of rod and number of blades that which will give the best combination of capacity and efficiency. Hence, the need for the Taguchi optimization.The developed responses equations for the yam minisett cutting machine are given in Equations 4 and 5

$$C = -8.4 + 0.1837W + 0.0251L - 0.067N \quad (4)$$

$$\acute{\eta} = 65.7 - 0.3354W + 0.0415L + 0.666N \quad (5)$$

Where: W = Speed (rpm), N = No of blades and L = Length of rod (mm)

After the regression analysis, the function that relates each response to the three of the factors that were considered were obtained as shown in equation 4 and 5. The analysis of variance, coefficients of determination (R^2 and adj -R^2), error standard deviation (*S*), means and signal to noise ratio for the capacity models developed are shown in Tables 8 to 9 while 10 to 11 constitutes those of the efficiency model.

The main effects plots for means of capacity and efficiency are shown in Figures 1 and 2 respectively, while the signal to noise ratio plots for means of capacity and efficiency are shown in Figures 3 and 4 respectively.

Table 8: Factor signal to noise ratios analysis of the capacity model

Level	Shaft speed (rpm)	Length of rod (mm)	No of Blades
1	7.791	15.342	17.291
2	19.505	17.424	15.933
3	23.331	17.861	17.403
Delta	15.540	2.519	1.471
Rank	1	2	3

Table 9: Factor mean analysis of the capacity model

Level	Shaft speed (rpm)	Length of rod (mm)	No of Blades
1	2.730	7.830	10.307
2	10.920	8.147	9.813
3	15.830	13.503	9.360
Delta	13.100	5.673	0.947
Rank	1	2	3

Table 10: Factor signal to noise ratios of efficiency model

Level	Shaft speed (rpm)	Length of rod (mm)	No of Blades
1	38.94	37.40	37.40
2	38.63	38.34	38.10
3	36.35	38.17	38.42
Delta	2.59	0.95	1.02
Rank	1	3	2

Table 11: Factor means analysis of efficiency model

Level	Shaft speed (rpm)	Length of rod (mm)	No of Blades
1	88.49	74.70	74.93
2	86.09	83.32	81.20
3	65.71	82.28	84.17
Delta	22.78	8.62	9.23
Rank	1	3	2

The main effects plots for capacity and efficiency in Figures 1 to 2 respectively were plotted from the results of the Taguchi analysis. These main effect plots show the mean effects of the selected factors on the responses. Similarly, Figures 3 and 4 also show the signal to noise plots for means of capacity and efficiency respectively. The contribution of each of the factors to the machine's capacity and efficiency was calculated using the sum of squares values obtained from the ANOVA as shown in Tables 12 and 13 respectively. Tables 12 and 13 show the percentage contribution of each of the factors (speed, number of blades and length of rod) to the responses (capacity and efficiency). From Table 12, it can be seen that the capacity of the machine is greatly influenced by speed, followed by the length of rod, and lastly the number of blades as was observed in Onwuka et al. (2019). Table 13 on the other hand shows that the machine's efficiency is influenced mostly by the speed of the crankshaft, followed by the number of blades and lastly the length of the rod.

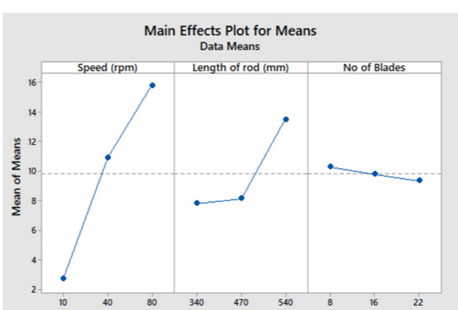

Figure 1: Main effects plot of capacity model of yam minisett processing machine

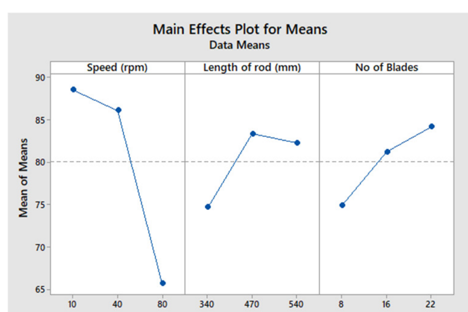

Figure 2: Main effects plot of efficiency model of yam minisett processing machine

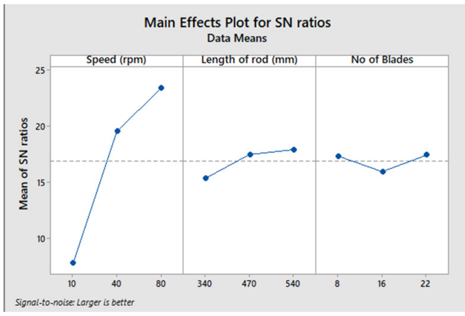

Figure 3: Signal to noise ratio plot for capacity

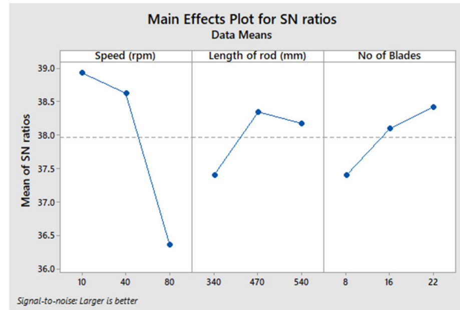

Figure 4: Signal to noise ratio plot for Efficiency

Table 12: Analysis of the effects of each factor on capacity of yam minisett processing machine

Sources	Degree of freedom	Sum of squares	Mean squares	% contribution
Speed	2	393.346	0.673	70.4
Length of rod	2	10.872	5.436	1.94
No of blades	2	4.02	0.010	0.72
Residual error	2	150.910	0.455	26.94
Total	8	559.149		100

Table 13: Analysis of the effects of each factor on efficiency of the yam minisett processing machine

Sources	Degree of freedom	Sum of squares	Mean squares	% contribution
Speed	2	12.0022	6.0011	74.49
Length of rod	2	1.5204	0.7602	9.42
No of Blades	2	1.6407	0.8203	10.1
Residual Error	2	0.9668	0.4834	5.99
Total	8	16.1300		100

The developed model's adequacy measures shown in Table 14 implies that the model exhibits good fitness since the R^2 and Adj R^2 of capacity is more than 95%, and small value of s tend towards zero as desired. Thus, the model is very apt for the machine simulation and optimization.

Table 14: Adequacy summary of the developed model for the the yam minisett processing machine

Response	S	R-Sq	R-Sq(adj)
Capacity	0.0953	98.91%	98.97%
Efficiency	0.0687	98.86%	98.02%

The contour plots using the values of the functional operational parameters which are the crank shaft speed, connecting rod length and the number of blades, are shown in Figures 5 to 10. Figures 5, 6 and 7 respectively show the contour plots for: capacity as a performance indicator on number of blades vs speed, capacity as a performance indicator on length of rod vs speed, and capacity as a performance indicator on number of blades and length of rod respectively. Similarly, Figures 8, 9 and 10 respectively show the contour plots for: efficiency as a performance indicator on number of blades vs speed, efficiency as a performance indicator on length of rod vs speed, and efficiency as a performance indicator on number of blades vs length of rod respectively. The contour plots in Figures 5 to 10 respectively display the 3-dimensional relationship in two dimensions between two factors (speed and number of blades, speed and length of rod, no of blades and length of rod) plotted on the x- and y- axis. Therefore, the contour profile analysis depicts that the capacity increases as combine speed and number of blades increases while efficiency reduces as combine speed increases and no of blades reduces.

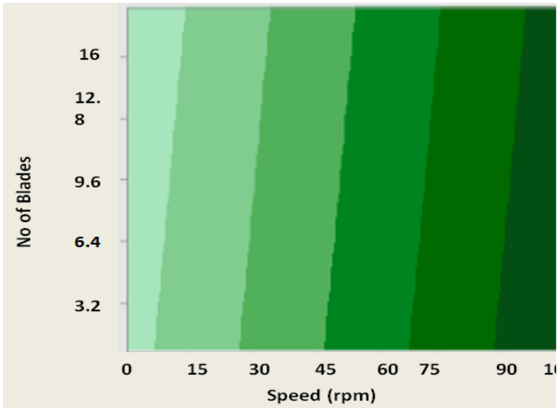

Figure 5: Dual effects profile of no of blades/speed on capacity

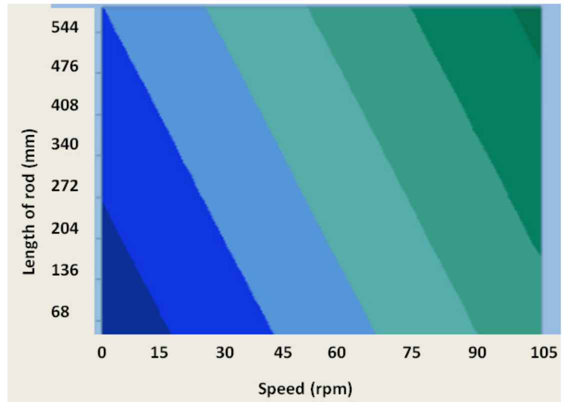

Figure 6: Dual effects profile of Length of rod/speed on capacity

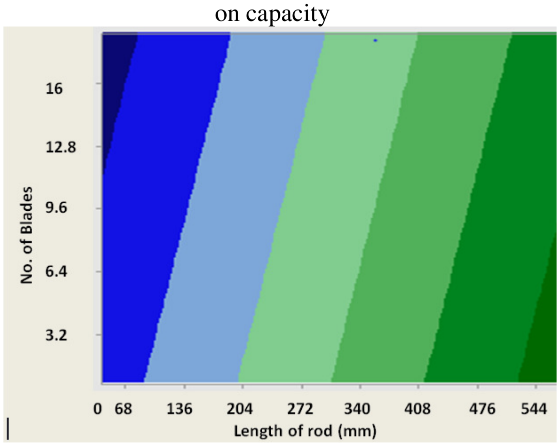

Figure 7: Dual effects profile of blade number/rod length on capacity

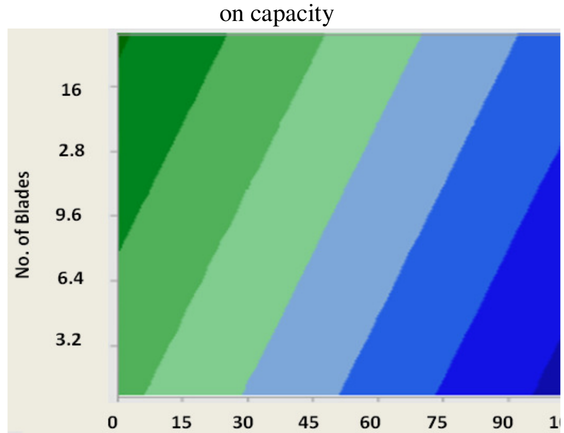

Figure 8: Dual effects profile of blade number/speed on efficiency

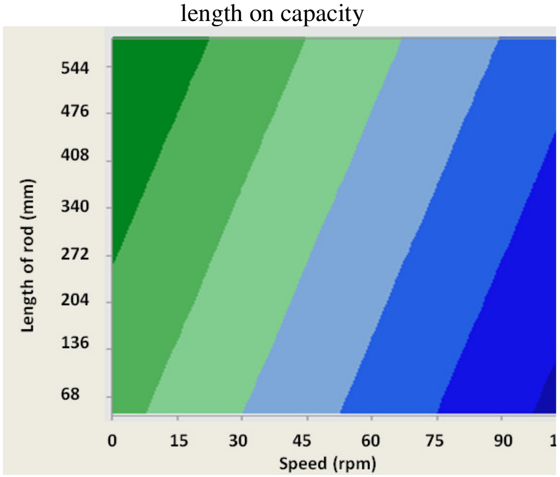

Figure 9: Dual effects profile of length of rod/speed on efficiency

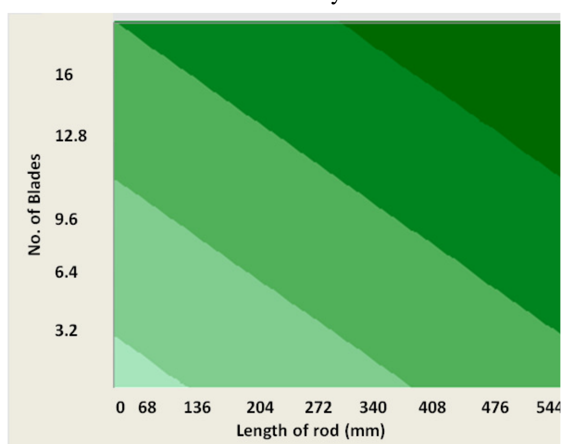

Figure 10: Dual effects profile of no of blades /length of rod on efficiency

The developed models were used to predict signal to noise ratio values of capacity and efficiency and these predicted values were compared with the actual values derived experimentally as shown in Tables 15 and 16. This was done by selecting a combination of the factors randomly among 18 experiments conducted for capacity and efficiency values. Using the response table of signal to noise ratio, (while applying the “larger is better” condition) the optimal level combination for speed, length of rod and no of blades to be used for the confirmation test were selected as 80, 540 and 13, this machine as a novel invention, is the first fabrication for Yam minisett cutting machine.

Tables 15 and 16 show the initial and optimal values for capacity and efficiency respectively, as obtained from the analysis conducted. Tables 15 and 16 show the comparison between the values obtained for the capacity and efficiency respectively b the initial process parameters and another from the optimal process parameters selected through the response tables of signal to noise ratio. The optimal capacity was obtained as 28,888 minisett/hr. while the efficiency was obtained as 96.42%. The optimal capacity was obtained experimentally at speed: 80 rpm, length of rod: 540 mm, and number of blades: 13. Similarly, the optimal efficiency was obtained at speed: 10 rpm, length of rod 470 mm, and number of blades: 13.

Table 15: Capacity comparison

S/N	Initial process parameters	Optimal process parameters	
		Prediction	Experiment
Level	40, 540, 13	80, 540, 13	80, 540, 13
Capacity	416.66	481.47	481.46
S/N ratio	24.4335	24.8445	24.9556

Table 16: Efficiency comparison

S/N	Initial process parameters	Optimal Process Parameters	
		Prediction	Experiment
Level	40, 540, 13	10, 470, 13	10 ,470, 13
Efficiency	96.12	96.40	96.42
S/N ratio	39.6563	39.7578	39.8542

4. CONCLUSION

Performance models developed shows the responses equation of capacity and efficiency with its constants and variables, also revealed the crank shaft speed, connecting rod length, number of blades, capacity and efficiency as functional operational parameters of the yam minisett processing machine. The machines operate optimally, reduces drudgery and enhance yam production.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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