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Development, Testing and Optimization of a Melon (*Citrullus lanatus*) Seed Washing Machine

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ABSTRACT

A melon seed (egusi) washing machine was designed, developed and evaluated for performance in coring edible melon seeds out of the pods, which are strenuous, time-consuming and tedious operation. The machine has a capacity to process 300kg of melon seed pulp in an hour powered by 2 hp, 1410 rpm single-phase electric motor. The melon seed (egusi) washing machine was made up of the following main units; hopper, washing chamber, bearing, screw conveyor, brush, electric motor and main frame which act as supporting base. The performance characteristics of the machine include: cleaning efficiency, output capacity and percentage seed recovery, were evaluated at three operating speeds (282, 325 and 423 rpm) and three feed rates of 2kg/60sec, 2kg/75sec and 2 kg/90sec. Each treatment combination was performed in triplicates making a total of 27 values. The minimum and maximum cleaning efficiency were 63.77 and 81.54 %, while minimum and maximum percentage seed recovery were 40 and 84 %. The minimum and maximum output capacity were 19.33 kg/hr and 44.47 kg/hr. Statistical analysis was performed with the use surface response optimization and all indicated that, the optimal value for speed and feed rate were 423 rpm and 0.033 kg.

1. Introduction

In Nigeria, Melon is a common agricultural produce, for the reason that the edible seeds are generally used in the preparation of indigenous stew or soup and snacks like fried melon seed ball known as "*Robo*" in South Western Nigeria. Recent statistics shows that 100,000 and 488,000 metric tons of melon were produced in Nigeria in 1992 and 1997 respectively [1, 2].

Melon seeds are vastly nutritious, furnishing the human diet with good quality proteins [3]. It contains about 41.51% essential amino acids and other essential nutrients [4]. Melon seed is also a good source of minerals, vitamins, oil and energy in form of carbohydrates [5]. Melon (*Colocynthiscitrullus. L.*) is an extensively cultivated and consumed oil seed crop in Nigeria and West Africa [6]. According to Aguayo [7], melon is the fourth most significant crop in the world in terms of production (18 metric tons), after orange, banana and grape.

Melon fruits mature in about 120-150 days after sowing. Harvesting starts when the fruits begin to enlarge [8]. Melon fruits can last long thus can then be kept numerous months without spoilage. Generally, the traditional method of coring melon seeds in the fruits involves a manual cracking of the fruit with wooden clubs or cutting off the bead or tail portion of the fruit with a knife, all done in order to create access for microorganisms to enter and cause the decomposition of the freshy mesocarp and endocarp (fermentation). The fruit which has been treated is left for about a week to decompose. In view of all this enormous usage of the melon seed, the depodding, washing and shelling makes it difficult to process. The reason is simply that these operations are yet to be effectively and efficiently mechanized.

However, the processing flow chart of melon seed is shown in Figure (1). The washing of melon seed is full of drudgery, time consuming, tedious, inefficient, and require lot of water and also, it is laborious. Presently, over 95% of the melon seeds produced in Nigeria markets is processed using traditional methods [9, 10]. Hence, this results to unswerving outcome on the quantity, quality and price of the melon seeds in the market at any point in time. In order to ensure availability of clean melon seeds in sufficient quantities in Nigeria and World markets at all times, there is need to design and fabricate melon seed washing machine at an affordable cost with high efficiency to alleviate problems associated with the manual way of washing using indigenous technology.

Figure 1: A flow chart of melon processing steps
Source: Giwa and Akanbi [11]

2. Materials and Method

2.1 Description of the Melon Seed *(Egusi)* Washing Machine

The pictorial, orthographic and isometric views of the melon seed washing machine are as shown in Figures (2-4) respectively. The constructional features of the various components are as follow: hopper, washing chamber, shaft and conveyor, discharge chute, vat, and main frame support.

a. **Hopper:** The hopper was fabricated from 1.5 mm thick mild steel of dimension 20 mm x 20 mm inlet and 10 mm x 10 mm base with a height of 28 cm. The hopper base was welded to the 10 mm x 10 mm opening base created on the cylindrical washing chamber housing at the left-hand side. The hopper is the inlet through which the fermented melon seeds pulps are admitted into the washing chamber

b. **Washing Chamber:** A 1.5mm metal sheet of dimension 1100mm x 60mm was cut and shaped into cylindrical form of diameter 26mm. This serves as the housing for the washing of melon. The washing chamber unit consist of the parts that wash and separate the clean melon seeds out of pulp and dirt.

The washing unit consist basically of screw conveyor that was welded on horizontal shaft which is to be driven by electric motor (single phase) and its attached with brush that aid thorough washing of melon seeds. The entire bottom washing cylinder was perforated to sieve sizes of 7.5 mm to serve as the screen through which the dirt and the pulp materials will be falling out into the lower basin (vat) and the clean melon seed would be falling through the discharge chute outlet for collection.

c. **Shaft and Conveyor:** The shaft used was 25mm diameter and 1100mm length of mild steel. The shaft length was chosen based on the total length of the washing chamber. The shaft was mounted on bearing at two horizontal ends and then to a sheave. The screw conveyor and brush were arranged in a spiral way on the shaft. The screw conveyor was welded on the shaft at 450 attached with hard brush.

d. **The discharge chute:** This is an opening cut at the lower part of the washing cylinder/chamber. The clean seed is conveyed from the cylinder through this opening. The dimension of opening is 300mm x 140mm x 80mm**.**

e. **The main frame:** The main frame was constructed in such a way that the bearing and washing chamber was mounted on it. It was constructed with 40mm x 40mm angle iron. The angle iron offers stability and main frame is the mounting support for all the component of the machine.

Figure 2: Pictorial view of the melon seed washing machine

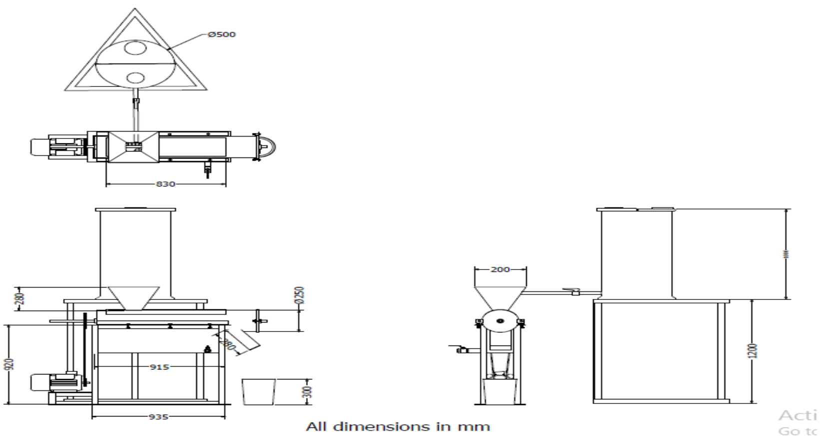

Figure 3: Orthographic view of the melon seed washing machine

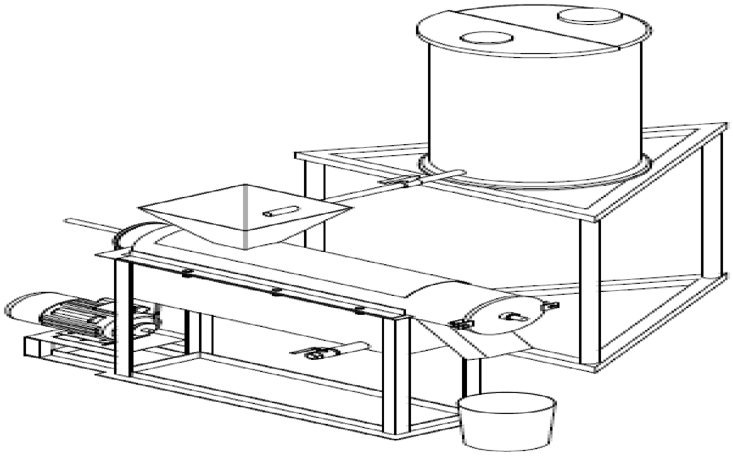

Figure 4: Isometric view of the melon seed washing machine

2.2 Design Considerations

Prior to the design and construction of the melon washing machine, the operations of existing melon washers, shellers and threshers for related agricultural crops like cowpea, okra, melon, maize amongst others were considered. This enhanced the selection of related factors for an effective and efficient design of the melon washer. Engineering and manufacturing simple methods were implemented in the design to produce a fairly inexpensive with low maintenance and easy to operate machine. The spare parts can be accessed easily and would not fail.

2.3 Design Calculations

2.3.1. Volume of the Hopper

The hopper has a shape similar to the frustum of a pyramid. The volume of the hopper was estimated using the Equation (1) below:

$$V = \frac{h}{3} \{(A_1 + A_2) + (\sqrt{A_1} + \sqrt{A_2})\} \quad (1)$$

Where;

A = l x b
V = Volume of hopper (m^3), A_1 = Area of Top (m^2), A_2 = Area of Base (m^2), h = Height of the hopper (m), L = Length (m), B = Base (m)

2.3.2. Calculating the Screw Diameter suitable for designing the Shaft Conveyor

This was done in order to determine the minimum screw diameter of the conveyor [11]. The theoretical capacity of a full screw conveyor is given by the expression in Equation 2;

$$C = (D^2 - d^2) \times P \times N \times 60 \quad (2)$$

Where;

$C = C_{VPH} = 0.75m^3/hr$, the capacity of the machine in volume per hour, D = diameter of the screw for the conveyor, d = diameter of the shaft, P = pitch of the conveyor, N = speed of the shaft. Thus, the minimum diameter needed for the conveyor was determined.

2.3.3. Determination of the shaft torque

This was determined using the expression in Equation (3);

$$T_S = \frac{Ps}{\omega s} \quad (3)$$

Where;

T_S = torque of the shaft, P_S = power delivered from the motor to drive the shaft, ω_S = angular speed of the shaft as illustrated in Equation (4)

Such that, $$\omega_S = \frac{2\ x\pi xN2}{60} \quad (4)$$

2.3.3. Torque transmitted to the washing chamber

The torque transmit to the washing chamber was calculated using the formula in Equation (5) below:

$$T = F\ x\ r \quad (5)$$

Where;

T = Torque transmitted to the washing chamber, (N-m), F = Force required to rotate the washing chamber, (N), r = Perpendicular distance from the center of the cylinder to the shaft, (m)

2.3.4. Determination of shaft diameter

Using the standard expression [12] as illustrated in Equation (6), diameter of the shaft was calculated by:

$$d^3 = \frac{16}{\pi\tau}\sqrt{(Mb\ x\ Kb)2 + (Mt\ x\ Kt)2} \quad (6)$$

Mb is Maximum bending moment, Mt is Maximum torsional moment, Kb is Combined shock and fatigue factor for bending, Kt is Combined shock and fatigue factor for torsion, d is Diameter of shaft, τ is Maximum permissible shear stress.

Angular shaft deflection was gotten using Equations (7-8)

$$ɖ = \frac{584\tau l}{D^4} \quad (7)$$

Where;

ɖ = angular shaft deflection (^{o})

l = length of the shaft (mm)

D = modulus of elasticity of steel (N/mm) = $\frac{80000N}{mm}$

Also,

$$D = 2.26\ x\ \sqrt[4]{\tau} \quad (8)$$

$$\tau = \left(\frac{25}{2.26}\right)^4$$

2.3.5. Determination of bending stress

As the machine operates, the shaft is subjected to bending and torsional moment as expressed in Equation (9) [12]

$$W = \frac{mg}{l} \quad (9)$$

$m = w_1 + w_2 + w_3 + w_4$

Where;

m = total mass on the shaft, l = length of the shaft = 1.3m, g = gravitational force constant, w_1 = mass of shaft alone, w_2= mass of screw conveyor, w_3 = mass of wooden brush, w_4 = mass of the pulley

2.3.6. Determination of pulley diameter

The diameter of the shaft pulley was calculated using the expression in Equation (10) [13].

$$N_1 D_1 = N_2 D_2 \quad (10)$$

Where;

N_1 = Speed of the prime mover (rpm), D_1 = Diameter of driver pulley (cm), N_2 = Speed of the pulley shaft (rpm), D_2 = Diameter of shaft pulley (cm)

2.3.7. Determination of Belt length

The length of the belt was determined using the formula given by the expression in Equation (11) [14].

$$\text{Length of open belt } \frac{\pi}{2}(d_1 + d_2) + 2x + \frac{(d1 - d2)2}{4x} \quad (11)$$

Where;

d_1 = diameter of the machine pulley (mm), d_2 = diameter of the prime mover pulley (mm)
x = distance between the center (mm)

2.3.8. Determination of Belt Speed

The speed of the belt was determined according to the expression in Equation (12) [14].

$$V = \frac{\pi \, X \, N1 \, X \, D1}{60} \quad (12)$$

Where;

N_1 = Speed of prime mover (rpm), D_1 = Pulley diameter of the prime mover (m)

2.3.9. Determination of Power Requirements of the washing machine

The power required to operate the machine was calculated using the expression in Equation (13) [12].

$$P = \frac{2\pi NT}{60} \quad (13)$$

Power required to drive the shaft

$$Ps = Ws \times rs \quad (14)$$

Ws = weight of the shaft N,
rs = radius of shaft (m).

$Ws = mass \times force\ of\ gravity$

Power required to drive the pulley

$$Pp = Wp \times Rp \quad (15)$$

Wp = weight of the pulley (N), Rp = radius of the pulley (m), Mass of the pulley (kg) $Wp=mg$

2.4 The performance behaviour

Among the required gadget for the operation of this machine is the plastic water tank with minimum capacity of 200 liters. The water tank is positioned at certain height to enable free flow of water into the machine-washing chambers by gravity. The fermented melon seed pulp was introduced into the washing chamber through the hopper. The sieve of 7.5 mm diameter in the chamber sifted away the melon pulp-fibers and the clean melon seed was thereby conveyed out through discharge chute with aid of screw conveyor. After the machine had been used to wash 2-3 batches of some quantities of melon-pulp, the dirty water with the sludge is drained away through the water outlet valve in the vat for recycling. This machine washes in batches with the main aim of maximizing the water available.

Two operating factors and four performance parameters were used for the evaluation of the melon seed washing machine. The two operating factors are: Operating speed at three levels (i.e. 282, 325 and 423 rpm), Feed rate at three levels of 2 kg each at (60, 75 and 90 sec). The performance parameters considered were: cleaning efficiency of the machine (%), Output capacity (kg/hr) and Percentage seed recovery (%). The data obtained were statistically analyzed using Mintab 20 software for analysis of variance (ANOVA) and Surface Response Optimization.

2.5 The performance evaluation equations

The performance evaluation equations used for estimating the performance parameters of melon-seed washing machine are stated as follows in Equations (16-18) by exploring some of the useful parameters of the machine using the method of Olotu et al., [15].

$$EC\ (\%) = \frac{W2}{W4} \times 100 \quad (16)$$

$$Oc\ (kg/hr) = \frac{W2}{T2} \times 100 \quad (17)$$

$$Rp\ (\%) = \frac{W_4}{W_o}\ x\ 100 \quad (18)$$

Where;
EC = Cleaning efficiency of the machine (%)
Oc = Output capacity of the machine (kg/hr)
Rp = Percentage seed recovery of melon seed washing machine (%)

3. Results and Discussion

Table 1: ANOVA results for the Effect of Speed, Feed rate on Cleaning Efficiency

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-Value	P-Value
Model	5	207.548	29.58	207.548	41.510	1.76	0.164
Linear	2	141.473	20.16	101.556	50.778	2.16	0.140
A-Feed rate	1	5.092	0.73	4.843	4.843	0.21	0.655
B-Speed (rpm)	1	136.381	19.4	96.950	96.950	4.12	0.055
Square	2	64.945	9.26	64.945	32.473	1.38	0.273
A^2	1	13.322	1.90	13.322	13.322	0.57	0.460
B^2	1	51.624	7.36	51.624	51.624	2.19	0.153
2-Way Interaction	1	1.130	0.16	1.130	1.130	0.05	0.829

AB	1	1.130	0.16	1.130	1.130	0.05	0.829
Error	21	494.084	70.42	494.084	23.528		
Lack-of-Fit	3	95.371	13.59	95.371	31.790	1.44	0.265
Pure Error	18	398.713	56.83	398.713	22.151		
Total	26	701.632	100.00				

R-sq = 0.2958; R-sq(Adj) = 0.1281; R-sq(pred) = 0.00

Table 2: ANOVA results for Speed and Feed rate on Output Capacity of the machine

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-Value	P-Value
Model	5	705.30	63.67	705.300	141.060	7.36	0.000
Linear	2	596.75	53.87	671.996	335.998	17.54	0.000
A – Feed rate	1	434.98	39.27	487.759	487.759	25.46	0.000
B - Speed (rpm)	1	161.76	14.60	187.568	187.568	9.79	0.005
Square	2	38.28	3.46	38.279	19.140	1.00	0.385
A^2	1	17.83	1.61	17.828	17.828	0.93	0.346
B^2	1	20.45	1.85	20.451	20.451	1.07	0.313
2-Way Interaction	1	70.27	6.34	70.274	70.274	3.67	0.069
AB	1	70.27	6.34	70.274	70.274	3.67	0.069
Error	21	402.37	36.33	402.372	19.161		
Lack-of-Fit	3	8.66	0.78	8.659	2.886	0.13	0.940
Pure Error	18	393.71	35.54	393.714	21.873		
Total	26	1107.67	100.00				

R-sq = 0.6367; R-sq(Adj) = 0.5503; R-sq(pred) = 0.381

Table 3: ANOVA results for the Effects of Speed and Feed rate on Percentage seed recovery

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-Value	P-Value
Model	5	1279.75	41.32	1279.75	255.950	2.96	0.036
Linear	2	773.31	24.97	886.17	443.087	5.12	0.015
A – Feed rate	1	13.97	0.45	0.49	0.494	0.01	0.941
B - Speed (rpm)	1	759.35	24.52	885.42	885.422	10.23	0.004
Square	2	276.39	8.92	276.39	138.195	1.60	0.226
A^2	1	162.55	5.25	162.55	162.549	1.88	0.185
B^2	1	113.84	3.68	113.84	113.840	1.32	0.264
2-Way Interaction	1	230.05	7.43	230.05	230.047	2.66	0.118
AB	1	230.05	7.43	230.05	230.047	2.66	0.118
Error	21	1817.21	58.68	1817.21	86.534		
Lack-of-Fit	3	71.21	2.30	71.21	23.738	0.24	0.864
Pure Error	18	1746.00	56.38	1746.00	97.000		
Total	26	3096.96	100.00				

R-sq = 0.4132; R-sq(Adj) = 0.2735; R-sq(pred) = 0.0039

Table 1, 2 and 3 respectively show that there is no significant difference in cleaning efficiency, Ec of melon seed washing machine. The data obtained from the tests were also subjected to analysis of variance (ANOVA) and the test of significance using Mintab 20 Surface Response Optimization. However, results of the analyses carried out indicated that there is significant difference in Output capacity, percentage seed recovery. Similarly, the analysis shows the significant effects of the factors as well as the interaction effects.

Also, the result in Table 2 shows that the factors (speed and feed rate) and interaction between them all are not significant on cleaning efficiency of the machine at p-value greater than 0.05. Further analysis was carried out on the surface plot of the factors and response to know the relationship between them.

Furthermore, Table 3 shows that the factor (speed is significant with p-value less than 0.05 and feed rate is not significant with p-value greater than 0.05) and interactions between them are not significant on the percentage seed recovery of the machine with p-value greater than 0.05. Further analysis was also carried out on the surface plot of the factors and response to know the relationship existing between them.

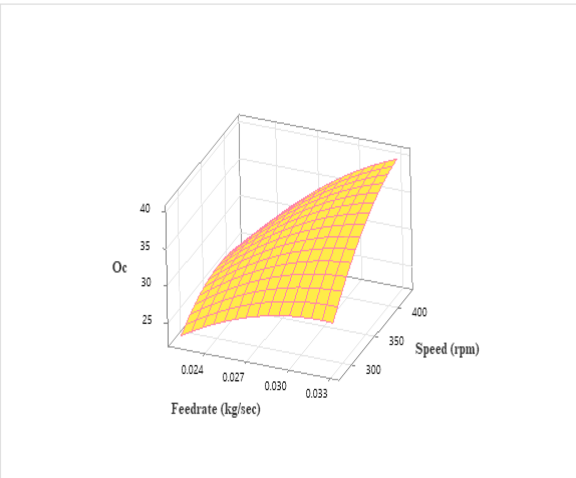

Figure 1: Surface plot of the factors against cleaning efficiency

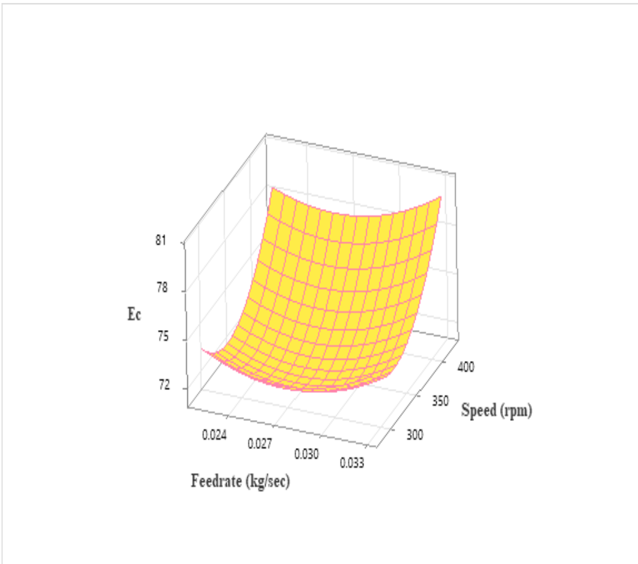

Figure 2: Surface plot of Output capacity against Speed and Feed rate

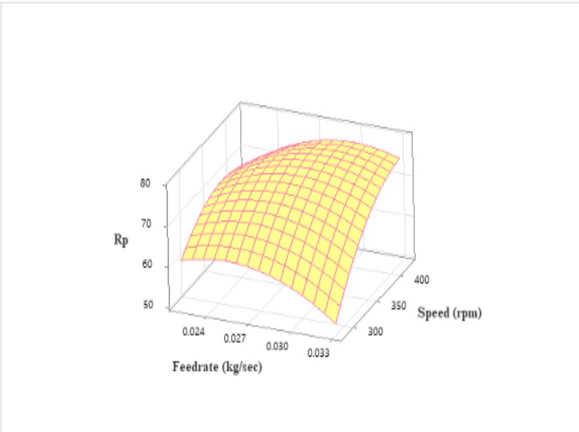

Figure 3: Surface plot of Percentage seed recovery against Speed and Feed rate

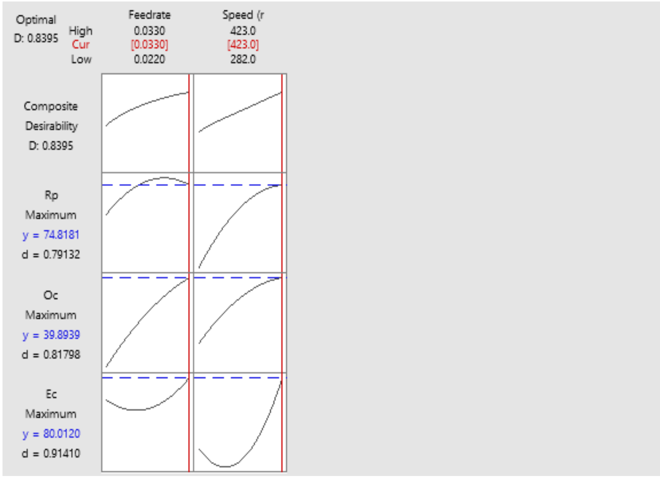

Figure 4: Response Optimization

Figure 1 shows the surface plot of the factors and the response (cleaning efficiency). It can be depicted from the plot that the efficiency increases with less effect of feed rate and increase in speed. The figure also shows a slight curve in the relationship of factors and the response variable.

The illustration in Figure 2 demonstrates the surface plot of the factors and the response (output capacity). Also, it can be described from the plot that the increase in speed leads to increase in output capacity with the slight effect of feed rate. The figure also shows a slight curve in the relationship of factors and the response variable.

Figure 3 expresses the surface plot of the factors and the response (percentage seed recovery). However, it can be depicted from the plot that the less effect of feed rate leads to increase in speed with increase seed recovery. The figure also shows a slight curve in the relationship of factors and the response variable.

Furthermore, Figure 4 shows the optimal response plot. From this plot, the optimal value for speed and feed rate for maximum cleaning efficiency, Output capacity and percentage seed recovery were 423 rpm and 0.033 kg/sec respectively. In addition, the cleaning efficiency, output capacity and percentage seed recovery were 80.01 %, 39.89 kg/hr and 74.82% respectively. It can thus be depicted that the high speed and moderate feed rate can improve efficiency of the machine.

4. Conclusion

In this paper, a machine for washing melon seed has been designed, fabricated and evaluated for performance. The minimum cleaning efficiency and maximum cleaning efficiency were 63.77% and 81.54 respectively, while the minimum and maximum output capacity were 19.33 kg/hr and 44.47 kg/hr respectively. The minimum and maximum seed recovery of 40% and 84.0% was found respectively.

More so, the result obtained shows that the melon seed washing machine has high cleaning efficiency of 80% at operating speed of 423 rpm and feeding rate of 0.033 kg/sec. Also, moderate feed rate and high-speed level shows an optimal cleaning efficiency of the machine. The machine performed smoothly during the operation. All the materials used for fabricating the machine were sourced locally.

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