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Development of an NCAM motorized GRAIN GRUEL (Soy Bean) sieving machine

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Abstract

A survey carried out on conventional or traditional method of sieving wet grains showed that the method consumes time, energy, has low output and efficiency and is also hazardous to health due to low level of hygiene involved. A motorized grain gruel machine was developed at the National Centre for Agricultural Mechanization (NCAM), Ilorin Nigeria. The machine consists of four major units which are hopper, seiver, separator and the discharge unit. The machine's performance was evaluated at different water volumes (16.5, 18.5 and 20.5 liters) and at three different operating speeds namely 65.3 rpm, 115.0 rpm and 126.0 rpm. The parameters evaluated are; sieving efficiency, through put and output capacity. The data were analyzed using the New Duncan multiple range test (Post Hoc Test) method and linear regression model was used to establish the relationship between the independent variables with the dependent variable, which was optimized using pulp in python version 2.9 frame work. Results show that the machine performed higher at 20.5litres and 126 rpm to a maximum sieving efficiency of 85.08% and 86.48% respectively, but was optimized to the range of 88.35-92.5% in sieving efficiency and 19.42-23.42kg/hr in output capacity. Also the analysis showed that water volume used had more significant effect on the efficiency and other variables such as the throughput and the output capacity respectively, than the operation speed. It was concluded from the results that the machine saved time and energy, reduced material wastage and hazards and therefore is more efficient than the conventional method. It is recommended that further evaluations should be carried out on the machine using a wider variety and species of grains samples.

Keywords: Development; Performance; sieving machine; Conventional method; Efficiency

1. Introduction

Grains gruel are legumes and cereals crops family, which are vital source vitamins, minerals, protein, carbohydrates, fats, oils, and protein. Grains products include soya milk, and maize pap and kunu products among others [1, 2].

Soya bean which is the most economically and nutritionally significant among the lots and its popularly consumed as a bean has several uses, which includes soy milk, soya cheese (Beske), soy sauce, soy oil etc. It is a highly refreshing milk drink which is rich in nutrients, vitamins and minerals that help in optimal bone health, improved blood cholesterol, protection against cardiovascular diseases, soybean a suppressant for prostate and breast cancer reduces blood pressure and body weight regulation which makes it one of the natural beverage consumed in Nigeria [3, 4].

The final taste and natural flavor of the soy milk is dependent on the processing method used in the extraction of the milk. When processing the soya milk, asides the strenuous process taken to produce the milk and The processing operations involved in the production of soya milk include; Cleaning, steeping, wet milling, wet sieving, mixing, cooking

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and filtering. The milling, mixing and separation of the soy milk from the slurry influence the final output and quality of the product [5, 6].

Fayose [6], Developed a Multi Purpose Wet Food Sieving Machine. The machine consists of a hopper, a mixing compartment, a sieving compartment operated by a crank and spring arrangement, collecting trays and outlets. The volumetric flow rate and the capacity of the machine were 0.0206 m^3/h and 22.45 kg/h respectively. The test concentration was conducted at three levels 12.2 %, 14.44 % and 22.77 %. The study showed that the machine performance coefficients and sieving capacity increased with decreasing concentration. Also, highest performance coefficients of 98% was obtained for sieving of maize while sieving capacity of 16.90g/sm^2 was obtained when the machine was used to sieve cassava.

Ibrahim and Gbabo [7], developed a batched grain beverages processing machine capable of integrating and blending of soaked grains, mixing the slurry and extracting the aqueous liquid together. The results of testing of the machine using soya beans revealed that highest blending efficiency of 81.11% from combination of blade with contact area of $1.32x10^{-3}m^2$, speed of blending of 1100rpm and blending time 540sec, while the lower value of blending efficiency of 52.85% was obtained from combination of blade with contact area $6.8x10^{-4}m^2$, speed of blending of 1000rpm and blending time 420sec. The results of analysis of variance ANOVA also revealed that all the experiment factors have positive significant effects ($p \leq 0.05$) on the blending efficiency.

However, there is a dearth of literatures on modern efficient methods of processing and preservation of soya milk especially in the separation of milk from slurry residue.Hence, the need to develop soya milk production and separating machine. The sieving machine still has a lot to be desired in terms of efficiency and efficacy of the product. In addition, as reported by Faluyi *et al* [8], the hygiene of the product would be assured as there would be no physical contact between the operator and the product during operation so as to avoid contamination. Moreover, Sieving of wet products is often arduous, cumbersome and time consuming, as separating of the fine and coarse particle in water is an indispensable process as the grain biopolymers are extracted and the presence of water aids the separation as the soluble contents become dense and are suspended in water [6].

The objective of this study is to developed a modified grain gruel motorized sieving machine which will include a filter in order to reduce stress, by which the operator undertake when extracting milk from the wet grain gruel, having an enclosed sieving mechanism limiting human and atmospheric contamination, using low cost and available material and still having high sieving capacity and efficiency rate for small and medium scale processing of wet agricultural crops.

2. Material and methods

The major components of the equipment's are Sieving screen, Hopper, bearing, shaft, frame, pulley belt, filtering chamber, spring, and a prime mover.

2.1. Design consideration

In the design of the NCAM motorized grain gruel sieving machine following were taken into consideration:-

- Availability of construction materials: materials of adequate strength and durability were used for the fabrication, which were sourced locally.
- Cost: low cost materials that give adequate strength and stability were used for the fabrication.
- Physical and mechanical properties of the said grain: relevant geometric mean diameter of the grain was considered for the design of the machine.
- Basic considerations were given to the design of the size, speed and capacity of the machine.

2.2. Description and Operation of the Developed NCAM Motorized Grain Gruel Sieving Machine

The machine has a mainframe which holds other components of the machine in a rigid position while a reciprocating mechanism sieves the milk from the slurry. It has an overall dimension of 600mm x 600mm x 996.5mm. The seiver is a detachable component which is made up of a food grade stainless steel sieving screen, attached to a square mild steel frame which serves as the hopper. The sieving tray is fixed inside a frame made from 45mx45mm mild steel that holds it in place. This sieving frame has loaded springs attached to it, which sits on ball bearings that enhances easy movement of the sieving frame. The machine has a chute of dimension 590mm x 190mm wide through which the sieving milk is collected. The machine is powered by a prime mover, while the sieving chamber of the machine was designed to be rectangular in shape with a dimension of 500mm x 450mm x 400mm.

The stainless sieving screen was designed to be replaceable so as to allow sieves of different screen sizes to be interchanged so as to fit the consumer/customer's needs.

2.3. Design calculations

All the various parts and components of the motorized sieving machine were designed, using various appropriate equations..

2.3.1. Hopper

The volumetric capacity of the hopper was calculated using

$$V\ (m^3) = \frac{M}{\rho} \qquad 1$$

Where,

M is the mass of cowpea in (kg) and ρ the bulk density of cowpea in (kg/m^3)

Therefore the area and the volume of the rectangular shaped hoper were calculated using the following equations bellow

The Area of the hopper (A) $= L \times B$ 2

Volume of the hoper (V) $= L \times B \times H$ 3

Where L is the length measured in meters (m), B is the breath measured in meters (m),

and H is the height of the hopper measured in meters(m).

2.3.2. Pulley design

The diameter of the pulley of the shaft was calculated to be 320 mm using the expression given by Khurmi and Gupta (2005)

$$N_1D_1 = N_2D_2 \qquad 4$$

2.3.3. Belt design

The belt speed, v (m/s) and its total belt length, (m), were calculated using the expression given by Khurmi and Gupta (2005), respectively

$$V = \frac{\pi N D}{60} \qquad 5$$

Where,

V = Velocity of the belt, N= Revolution of the motor, D= Diameter of the motor pulley

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C + \frac{(D_1+D_2)^2}{4C} \qquad 6$$

$$C = \frac{D_1+D_2}{2} + 0.05 \qquad 7$$

Where,

L= Length of Belt, D_1 = Driver Pulley diameter, D_2 = Driven Pulley Diameter, c = Pulley Centre Distance.

2.3.4. Torque transmitted by the shaft

The torque transmitted by each shaft was calculated using the equation below

$$T = \frac{P60}{2\pi N}$$

2.3.5. Shaft design

The combine twisting moments and bending moments were used to determine the shaft diameter by using the formula given by Khurmi and Gupta (2005)

$$T_e = ((K_B \times M)^2 + (K_T \times T)^2)^{0.5} = \pi \times S_S \times \frac{d^3}{16} \quad (8)$$

Where,

T_e = equivalent twisting moment (Nm) , M = resultant bending moment (Nm)

T = Torque transmitted by the gear shaft (Nm), s = Allowable shear stress with keyway = 45N/mm^2 as given by Khurmi and Gupta, (2005)

d = diameter of the shaft in mm

K_B = combined shock and fatigue factor applied to bending moment = 2.0 for minor shock

K_T = combined shock and fatigue factor applied to torsional moment =1.5 for minor shock.

2.4. Design Drawings

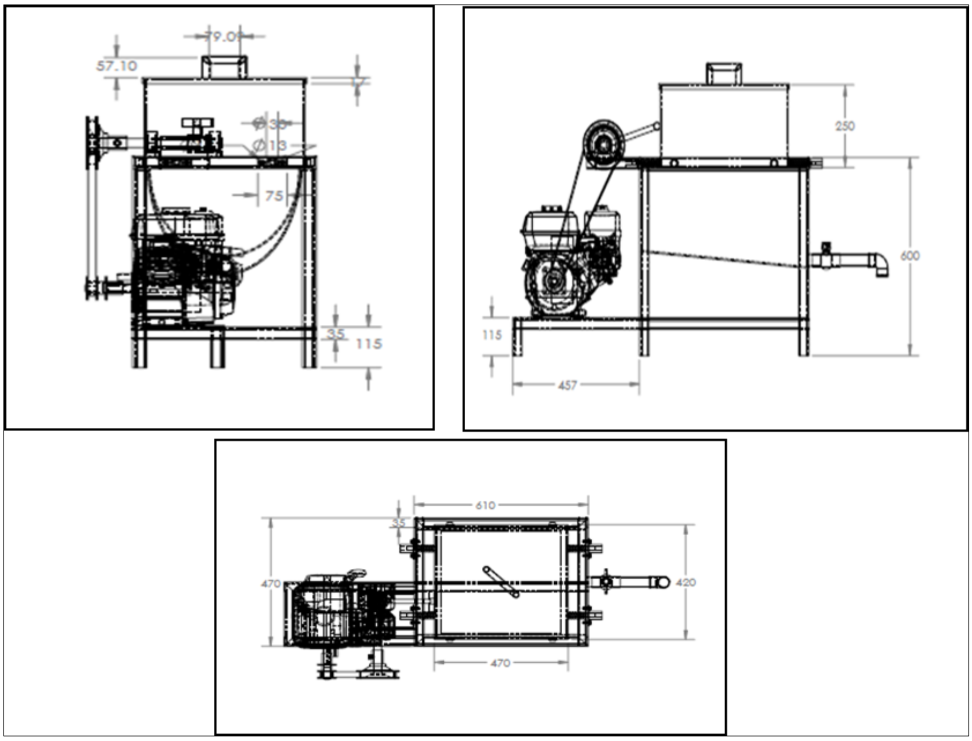

Figure 1 Orthographic view of the machine.

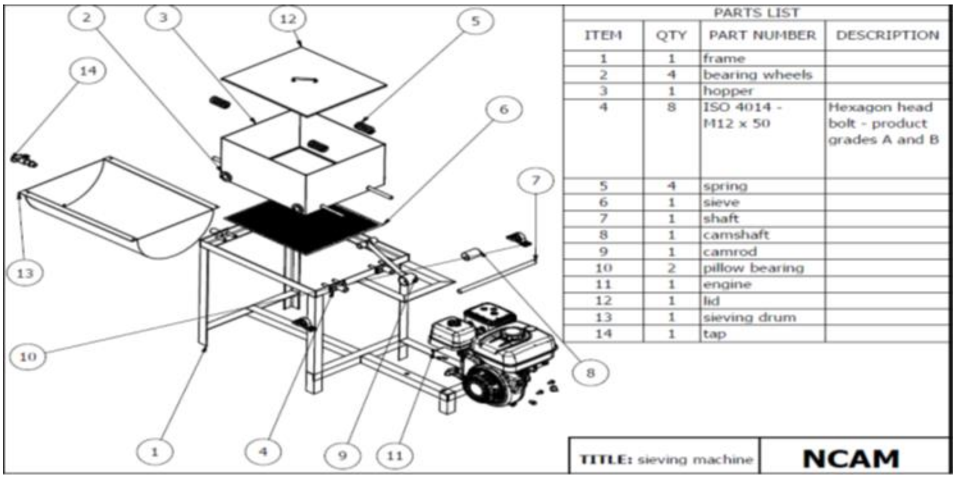

Figure 2 Exploded view of the developed NCAM sieving machine

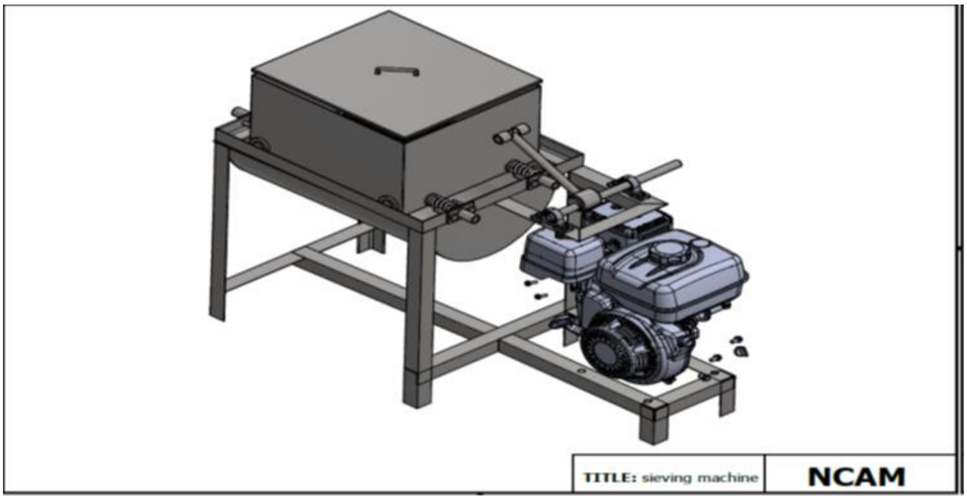

Figure 3 Isometric view of the machine

Figure 4 The Developed NCAM Motorized grain gruel Sieving Machine

2.5. Fabrication techniques

2.5.1. Fabrication Process

The fabrication process of the machine was done at NCAM Engineering services workshop. The basic manufacturing processes include cutting, bending, and primary shaping and joining.

Hopper

*T*he hopper is rectangular in shape, based with a portion attached to the seiver it is made of mild steel of 1.5 mm thickness. The fabrication was done by marking out the measurement on the plate, cutting it into shapes, welding and giving it a finishing touch by grinding.

Frame

The frame which is a rigid rectangular support, gives support to the whole system. it has an overall dimension of 600mmx 600mm x 996.5mm angle iron and the engine seat has a dimension of 280mm × 515mm.The fabrication procedure was done by marking and cutting out the angle iron into its different length using power hack saw. The rectangular angle iron frame was firmly joined together by wielding.

Sieving chamber

The sieving chamber of the machine was cut and welded to a desired /designed dimensions of 500mm x 450mm x 400mm, while the discharge outlet in the halve is situated at the opposite end of the inlet end is 66mm × 40 mm. It was fabricated by marking out 90 mm diameter pipe into the desired length, then cutting off the excess length to the required shape .The finishing was done by grinding.

2.6. Performance Evaluation of the motorized Sieving Machine

2.6.1. Test Methodology

The NCAM motorized grain gruel sieving machine, after Fabrication of the machine, preliminary tests was carried out using corn mill and milled soy beans. The time taken to fully sieve and drain out was recorded with a stop watch, while the weight of the residue was measured and also recorded in 3 replicates.

The corn and Soya beans used was gotten from the local market in Ilorin, Kwara state and were then sorted, cleaned, weighed and milled to ensure only healthy grains was used to evaluate the machine parameters.

2.6.2. Test Parameters

Sieving Efficiency (%): this determines how efficiently the sieving machine carries out the sifting of the wet grain product. it is expressed as

$$S_e = \frac{w_3}{w_3 + w_4} x100 \quad (9)$$

Where w_4 = weight retained in the sieve expressed in kg, and w_3 = weight of sieved wet grains expressed in kg.

Sieved Mash Recovery (%): this indicate the percentage of grain mash that is recovered after the sieving operation. it is expressed as below

$$S_r = \frac{w_3 + w_5}{w_1} x100 \quad (10)$$

Where w_3 = weight of sieved product expressed in kg, w_5 = weight of mash expressed in kg, and w_1 = weight at the outlet expressed in kg.

Output Capacity (Kg/hr): it determines the quantity of sieved grains product that is discharged from the outlet per unit time. it is expressed as

$$O_c = \frac{w_3}{t_1} \quad 11$$

Where w_3 = weight of sieved product expressed in kg, and t_1 = time taken for the given operation

Throughput capacity (Kg/hr): this is the quantity of unsieved product fed into the sieving machine per unit time. it is expressed below as

$$I_c = \frac{w_1}{t_1} \quad 12$$

Where w_1 = weight at the mash outlet expressed in kg, and t_1 = time taken.

2.7. Statistical Analysis

New Duncan multiple range test (Post Hoc Test) method was used to determine the effect of the operational speed (65.3,115.0,and126.0rpm respectively) and the volume of water used on all parameters during the sieving operation. While the linear regression model was used to establish the relationship between the independent variables (operational speed, and volume of water used) with the dependent variable (sieving efficiency and output capacity).Pulp optimization model in python was used to optimize the process. The test was subjected into triplicates during data collection.

3. Results and discussion

Table 1 shows that the volume/quantity of water used during the sieving operation on Corn Mill had a significant effect on the through put, output and the sieving efficiency of the machine. Increasing the volume of waters from 16.5, 18.5 and 20.5litres made the through put of the machine to increase from13.57 to 19.57kg/hr, output capacity from 12.37 to 18.95kg/hr and the sieving efficiency from 78.49 to 85.08% respectively.

The significant difference observed at the through put was even, but at the output capacity it was discovered that the difference was more at 16.26 (18.5litres), while it was also observed that was a shoot-up in the efficiency difference at 20.5 liters (85.08%) compare to the others. This is possibly due to the continuous increase in water volume during the operation aided the adequate dissolution of the wet milled grains which made more of them to pass through the sieving pores of the machine..

Table 1 Effect of Quantity Water for Sieving on Grain Gruel Sieving Machine Using Corn Mill

S/No	Quantity of Water (Litre)	Throughput Capacity (kg/hr)	Output Capacity (kg/hr)	Sieving Efficiency (%)
1	16.5	13.57_a	12.37_a	78.49_a
2	18.5	16.57_b	16.26_b	80.99_b
3	20.5	19.57_c	18.95_c	85.08_c
Sig	1.000			

Table 2 shows that the operational machine speed used during the sieving operation on Corn Mill, had a significant effect on the through put, output and the sieving efficiency of the machine

Increasing the machine operational speed from 65.3, 115.0 and 126.0 rpm had no significant difference on the through put of the machine which remains constant at 16.57kg/hr, same as the output capacity which became significant at 126.0 rpm given rise from15.7 to 16.19kg/hr, there was a significant difference observed at the sieving efficiency from 77.28 to 86.48% respectively.

The result explains that the change in speed had no effect on the through put capacity but made an impact on the output capacity when more speed of 126rpm was applied resulting to a higher sieving efficiency of 86.48%.

Table 2 Effect of Operating Speed on the Grain Gruel Sieving Machine using Corn Mill

S/No	Operating Speed (rpm)	Throughput Capacity (kg/hr)	Output Capacity (kg/hr)	Sieving Efficiency (%)
1	65.3	16.57_a	15.64_a	77.28_a
2	115.0	16.57_a	15.74_a	80.80_b
3	126.0	16.57_a	16.19_c	86.48_c
Sig	1.000			

Table 3 shows that the volume/quantity of water used during the sieving operation on Soybean Mill, had a significant effect on the through put, output and the sieving efficiency of the machine

Increasing the volume of waters used from 16.5, 18.5 and 20.5litres made the through put of the machine to increase from19.34 to 23.30kg/hr, 18.49 to 22.30kg/hr and the sieving efficiency from 78.49 to 85.07% respectively.

The significant difference observed at the through put was even, but at the output capacity it was discovered that the difference was also even, while it was also observed that was a shoot-up in the efficiency difference at 20.5 liters (85.07%) compare to the others. This possibility buttresses the facts that more water volume introduction during the operation supports the total dissolving of the products ,thereby easing the sieving enhancing operation.

Table 3 Effect of Quantity Water for Sieving on Grain Gruel Sieving Machine Using Soybean Mill

S/No	Quantity of Water (Litre)	Throughput Capacity (kg/hr)	Output Capacity (kg/hr)	Sieving Efficiency (%)
1	16.5	19.34_a	18.49_a	78.49_a
2	18.5	21.20_b	20.19_b	80.99_b
3	20.5	23.30_c	22.30_c	85.07_c
Sig	1.000			

Table 4 shows that the operational machine speed used during the sieving operation on Soybean Mill, had a significant effect on the through put, output and the sieving efficiency of the machine.

Increasing the machine operational speed from 65.3, 115.0 and 126.0 rpm made the through put of the machine to increase from 19.29 to 22.61kg/hr, the output capacity from 18.39 to 21.46kg/hr and the sieving efficiency from 78.49 to 85.07% respectively.

No significant difference on the through put of the machine was observed, which remains constant at 16.57kg/hr, same as the output capacity which became significant at 126.0 rpm given rise to increase from15.7 to 16.19kg/hr, there was a significant difference observed at the sieving efficiency from 77.28 to 86.48% respectively.

The result explains that the change in speed on this specific operation had made a significant effect on all the variables, though minimal but was more pronounced on the efficiency especially when 126rpm operational speed was applied resulting to a higher sieving efficiency of 86.48%.

A Linear regression model was used to establish the relationship between the independent variables (speed and volume of water used) with the dependent variable (sieving efficiency and output capacity) for the soy bean operation in equation 13 (sieving efficiency) and equation 14 (throughput), optimization of the model using pulp model frame work in python shows that the highest sieving efficiency and output capacity achievable using soy bean in operation is 92.5% and 23.42kg/hr respectively with an operational speed of 126rpm and water volume of 20.5liters.

Table 4 Effect of Operating Speed on the Grain Gruel Sieving Machine using Soybean Mill

S/No	Operating Speed (rpm)	Throughput Capacity (kg/hr)	Output Capacity (kg/hr)	Sieving Efficiency (%)
1	65.3	19.29_a	18.39_a	77.28_a
2	115.0	21.95_b	21.13_b	80.80_b
3	126.0	22.61_c	21.46_c	86.48_c
Sig	1.000			

The sensitivity of the system suggests increasing the optimum speed by 0.09 rpm and the volume of water used by 1.23 kg/hr will improve the optimum sieving efficiency of the machine during soy bean operation, also suggesting that increasing the optimum speed by 0.05rpm and the water volume by 0.95 kg/hr will increase the output capacity of the machine during the soy bean operation.

The linear regression equation for the sieving efficiency and output capacity is given in Equation (13 and 14), and it indicates the importance of increased in the quantity of water needed for an effective and efficient sieving process.

$$S=0.09V_o+ 1.23W_u + 59.27 \quad (13)$$

$$O_p=0.05V_o+ 0.95W_u -2.61 \quad (14)$$

Linear regression model was used to establish the relationship between the independent variables (speed and volume of water used) with the dependent variable (sieving efficiencies and output capacity) for the corn operation in equation 15 (sieving efficiency) and equation 16 (output capacity)), optimization of the model using pulp model frame work in python shows that the highest sieving efficiency and output capacity achievable using corn in operation is 88.35% and 19.42kg/hr respectively with an operational speed of 126rpm and water volume of 20.5liters.

The sensitivity of the system suggests increasing the optimum speed by 0.13 rpm and the volume of water used by 1.65 kg/hr will improve the optimum sieving efficiency of the machine during corn mill operation, also suggesting that increasing the optimum speed by 0.007 rpm and the water volume by 1.65 kg/hr will increase the output capacity of the machine during the soy bean operation.

The optimization equation for the sieving efficiency and output capacity is given in Equation (15 and 16), and it indicates the importance of increased quantity of water needed for an effective and efficient sieving process same as soy bean operation.

$$S=0.13V_o+ 1.65W_u + 38.14 \quad (15)$$

$$Op=0.007V_o+ 1.65W_u -2.61 \quad (16)$$

Where S is the sieving efficiency measured in %, O_p is the output capacity measured in kg/hr, V_o is the machine operation speed in (RPM), and Wu is the water used during the sieving operation in (liters).

4. Conclusion

The motorized grain gruel (soy bean) sieving machine was designed, fabricated and evaluated to ascertain its performance. The higher sieving efficiency was recorded using both speed and water volume as varying factors. The maximum sieving efficiencies achieved were 85.07% and 86.48%, this values were achieved at the sieving machine operational speed of 126rpm and water volume of 20.5litres.

A regression model was established for the processes and was optimized; the optimized results showed that the machine operation could achieve efficiency in the range of 88.35-92.5% and an output capacity of 19.42-23.42kg/hr respectively using optimum independent variables of speed 126rpm and water volume used of 20.5litres.

From the analysis it could be deducted that the quantity of water used during the sieving operation had more significant effect on the efficiency than the speed, though the speed had an effect, it was be minimal

The machine would therefore eliminate the constraints involved in the manual processing and reduced operational losses associated to grain gruel sieving operations as it's tends to provide an improved quality product.

Recommendation

Further evaluations should be carried out on the machine using a wider variety, weights and species of grains samples.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare there have no conflict of interest.

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