The performance of a combined dewatered cassava mash lump pulverizer and sifter under some operational factors

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Abstract: A combined dewatered cassava mash lump pulverizingand sifting machine was developed to determine the effect of moisture content, operating speed, and mash quantity on the performance of the machine using historical data experimental design of response surface methodology. The independent variablesof the experimentswere moisture content, operating speed, and mash quantity, while the dependent variables were sifting efficiency, input capacity, and output capacity for both 3 and 5 mm aperture sieves. The results of the analysis revealed that sifting efficiency for 5 mm aperture sieve ranged from 78.8% to 89.0%, sifting efficiency for 3 mm aperture sieve ranged from 62.8% to 79.9%, input capacity ranged from 232.29 to 405.25 kg/hr, output capacity for 5 mm aperture sieve ranged from 56.2 to 97.4 kg/hr, while output capacity for 3 mm aperture sieve ranged from 45.10 to 87.8 kg/hr.Also,the independent variables were significant ($p<0.05$) oneach dependent variable. In addition, from the model summary statistics, the adequacy of best fit of the model was obtained from the highest value of coefficient of determination (R2), and the least value of standard deviation (SD) and Predicted Residual Sum of Squares(PRESS) values.The respective R2, SD, and PRESS values of 0.9759, 0.55, 13.44for sifting efficiency for 5 mm aperture sieve; 0.9165, 1.52, 114.71for sifting efficiency for 3 mm aperture sieve; 0.9828, 6.98, 2440.04 for input capacity; 0.9885, 1.57, 103.41for output capacity for 5 mm aperture sieve; and 0.9847, 1.90, 155.91for output capacity for 3 mm aperture sieve wereobtained.Therefore, from the results obtained, the machine is recommended for small and medium scale gari processors.

Keywords: pulverizing, sifting, model, input capacity, output capacity, efficiency, aperture sieve

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1 Introduction

Cassava (*ManihotesculentaCrantz*) is one of the favored root and tuber crops of the tropics and also a major source of energy in the human diet in the tropics. It is the third most important source of calories in the tropics after cereal crops (FAO, 2008). In addition, it is an important staple, food security, and cash crop that thrive where most other crops fail (Olukunle, 2005).The crop originated in South America, where its tubers have been used throughout the ages as a basic food from where it spread to other regions of the world, its cultivation has spread throughout the humid tropics and subtropics (Nwekeet al., 2002). Adetunji and Quadri (2011) reported that cassava is mostly grown on small farmsin Nigeria and usually intercropped with vegetables, plantation crops, yam, sweet potatoes, melon, maize, beans, and other annual crops.

FAO(2003) reported that highest production is in Africa with 99.1 million tonnes while 51.5 and 33.2 million tonnes are for Asia and Latin America respectively.Cassava production in Nigeria was put at about 33.8 million tons a year (FAO,2006).Nworgu(2006) reported that Nigeria has annual output potential for cassava production of 75.5 million tonnes.Ajao and Adegun(2009) reported that the total area of harvested crop in 2001 was 3.1 million / ha with an averageyield of about 11 t/ha.Katz and Weaver (2003) reported that cassava contains protein and also contain significant amounts of calcium, phosphorus, and Vitamin C.Oluwoleet al.(2004) also reported that edible part of

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fresh cassava root contains 32% – 35% carbohydrate, 2% – 3% protein, 75% – 80% moisture, 0.1% fat, fiber and 0.70% – 2.50% ash.

Cassava is the most perishable of roots and tuber crops and can deteriorate within two or three days after harvesting. Additionally, the cyanide acid content in cassava rootswould need to be reduced to a level that is acceptable and safe for human consumption (Akogun, 2015). For these reasons, cassava is sold as a processed product such as gari, flour, fufu, atieke, to mention a fewwhilst other roots and tubers are most frequently sold as fresh produce.Otiet al. (2010) defined gari as a creamy-white, granular flour with a slightly fermented flavor and a slightly sour taste made from fermented, gelatinized fresh cassava tubers.Itis consumedby either soaking in cold water with sugar, coconut, roasted peanut, fish, or boiled cowpea as complements or as a paste made with hot water and eaten with vegetable sauce (IITA, 2005).

Pulverisation precedes sifting operation in gari production.Sifting produces a quality gari free from fibrous contaminants and having similar sized granules (Akogun, 2015). Pulverizing and mash sifting operations in gari processing causes great challenges in gari production.This is because large percentage of cassava mash lumpsare still been pulverised and sifted manually by rubbing of hands on local sieve/mesh made of raffia mat made from plant materials which is often called "raffia sieve".The cassava lump formed after the dewatering of grated cassava mash is broken down into smaller particles, and ungrated and thread-like cassava mash, remains of roots and back of cassava fiber are been removed.

Sanniet al.(2008) stated that manual pulverizing and sifting of cassava cake is tedious, slow, unhygienic and hazardous. Francis (1984) also identified the shortcoming of traditional method of sifting to include problem of rubbing ones' hand against palm fiber, which can cause injury to the hand of the operator, problem of the operator having backache because of time of sitting down for the operation and time and energy consumption. Jackson (2011) also reported that it takes about three men an hour to sift one kg of dewatered cassava mash using the traditional methods as an operation that will be efficiently carried out in one minute using the mechanical sifter.

Assessment of the effect of moisture content, operating speed and mash quantity on the performance of cassava mash lump pulverizer/sifterusing the historical data experimental design, is essential to determine the level of efficiency, capacity, and acceptability of the developed machine for usage. In addition, it helpsto stimulate growth,reduction in drudgery and time consumption in traditional method of gari production.

2 Methodology

2.1 Sample preparation

Freshly harvested cassava tubers obtained from a cassava-processing center in Alagodo-Ajibode, Ibadan, were processed according to methods reported by Otiet al.(2010) as shown in Figure 1. The roots weredewatered to moisture content of between 40% and 50% moisture content wet basis Odigbo (1981) and Akande et al. (2004).

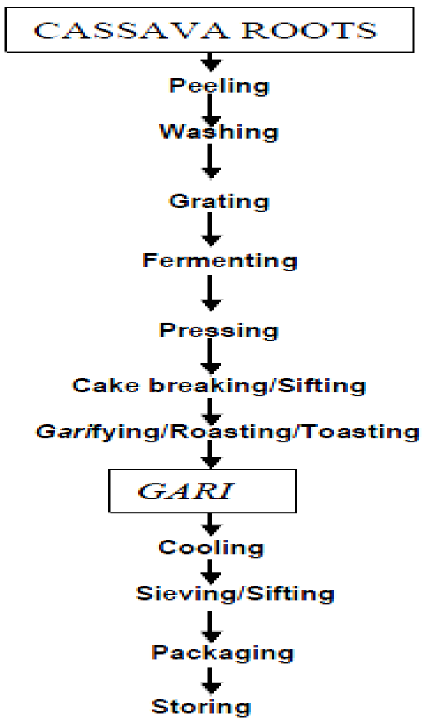

Figure 1Flow chart of gari processing (Source: Otiet al., 2010)

2.2 Moisture content determination

Initial moisture content of cassava mash was determined using ASAE (1990) standardwhere 20g weight of sample was placed in an oven set at 110°C for eight hours. The final weight was taken when the product had cooled down inside a desiccator and the moisture content determined as a ratio of moisture loss to weight of wet material in percentage was recorded as moisture content wet basis.The difference in weight before and after drying was taken to be moisture loss. The dried samples were weighed using a digital compact balance. The average moisture content was calculated using the relationship as reported by Simonyanet al.(2008):

$$MC_{wb}\ \% = \frac{Wi-Wd}{Wi} \times 100 \qquad \ldots (1)$$

Where;

MC_{wb} = moisture content, wet basis(%),

W_i= initial weight of sample(kg),

W_d = dried weight of sample(kg)

2.3 Moisture content variation

The desired moisture content levels was achieved by placing the cassava mash lump samples in an oven where each sample was allowed to dry slowly over a temperature of 60°C as described by Gbasouzor and Maduabum (2012) and Chukwunekeet al.(2013) until the desired moisture content (40%, 43% and 46% wet basis) of the cassava mash lump was achieved. This was carried out as reported by Jackson and Oladipo (2013) using Equation (1).

2.4 Design features and operation of the combined cassava lumppulverizer/sifter

The overall dimension of the machine is 850mm x 390mm x 1250mm. A Honda engine GX 160 model, 5.5hp petrol engine(Yancheng Fujiheng Power Machinery Ltd, China)(selected for its availability, durability and relatively cheap cost) powers the machine. The following materials were used in the development of the machine, they include: 20 mm diameter solid shaft, roller and ball bearing, 150 mm diameter circular plate with external protrusions, $1\frac{1}{2}$by $1\frac{1}{2}$inch angle iron, stainless metal sheet, 5 and 3 mm aperture sieves, bolts and nuts, pulley and belts. The machineis made up of a hopper, lump pulverizing unit, sifting unit and the discharge outlets.The pulverizing unitbreaks down the cassava mash lump by continuous impact of a rotating drum with external protrusions.It then falls down on the sifting unit where the reciprocating and vibrating mechanism of the sieves on the pulverized cassava lump performs the sifting. In addition, 10° angle of inclination of the sieves to the horizontal was used for easy discharge of the sifted products and chaff.

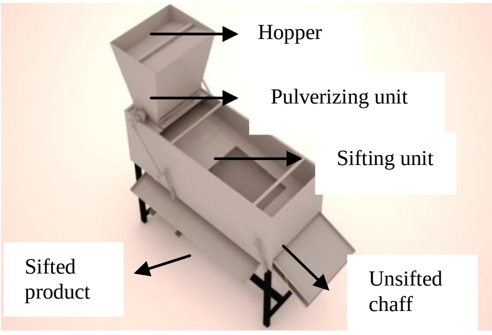

Figure 2Pictorial view of the dewatered cassava mash lump pulverizer and sifter

2.5 Experimental design

Historical data design of response surface methodology were employed as described by Cornell (2005). The variables and levels were fixed based on information from literatures Simonyanet al.(2010), Adejumo and Ola (2010) and Jackson and Oladipo (2013)and trial experiments. The independent variables used for the study were moisture contents (40%, 43% and 46% wet basis), speed of shaft rotation (550, 600, and 650 rpm) and mash quantity (500, 1,000 and 1,500 g),as shown in Table 1, while the responses were the input and output capacity, and sifting efficiency for 3 and 5 mm aperture sieves.

Table 1Independent variables for the pulverizing and sifting process

Factor Name	Units	Type Low Actual	High Actual	Low Coded	High Coded
A	speed rev/min Numeric	550.00	650.00	-1.000	1.000
B	moisture content % Numeric	40.00	46.00	-1.000	1.000
C	mash quantity kg Numeric	0.50	1.50	-1.000	1.000

Where;

A is operating speed (rpm), B is moisture content in wet basis (%), C is mash quantity (kg),

2.6 Test procedure

The combined cassava mash lump pulverizing and sifting machine was operated empty for three minutes in order to stabilize the speed as described by Ahemen (2008), before introducing the dewatered cassava mash lump into the machine through the hopper. The output from thedischarge chutes collected after each operation was weighed using a digital balance. The desired speed was achieved by using a tachometer and a variable speed petrol engine (Honda engine GX 160 model, 5.5hp petrol engine) selected for its availability, durability and relatively cheap cost as described by Ahemen (2008), until the desired operating speed was attained on the machine. Mash quantity was controlled by varying the amount of feed inputted through the hopper as described by Kudaboet al. (2012) and Jackson and Oladipo (2013) while the moisture content was variedby the use of oven as described by Chukwunekeet al. (2013).This experimentwas thereby conducted by the use of three machine speeds of 550, 600 and 650 rpm, against three-mash quantity of 500, 1,000 and 1,500 g and moisture content of 40%, 43%, and 46%.

2.7 Performance evaluation

1) Sifting efficiencyE_s(%): This determines how efficient the machine performs after sifting as described by Jackson and Oladipo (2010),

$$E_s\ (\%) = \frac{W3}{W1} x\ 100\%\ \ (5\text{ mm sieve}) \qquad (2)$$

$$E_s\ (\%) = \frac{W2}{W1} x\ 100\%\ \ (3\text{ mm sieve}) \qquad (3)$$

Where;

E_s= Sifting efficiency(%), W_1= Initial weight of cassava mash lump (kg), W_2= Weight of sifted cassava mash from the 3 mm sieve (kg), W_3= Weight of sifted mash from the 5 mm sieve.

2) Input capacity (kg/hr): This determines the quantity of dewatered cassava mash lump inputted into the lump pulverizing section per hour. It is expressed as described by Hung et al. (1995):

$$Q_i\ (\text{kg/hr}) = \frac{W1}{T1} \qquad \ldots (4)$$

Where;

Q_i= Input capacity (kg/hr), W_1= Initial weight of cassava mash (kg), T_1= Time of pulverizing (hr)

3) Output capacity (kg/hr**):** This determines the quantity of mash sifted per hour and it is expressed as described by Kudaboet al. (2012) and Jackson and Oladipo (2013):

$$Q_0\ (\text{kg/hr})(5\text{ mm sieve}) = \frac{W3}{T2} \qquad \ldots (5)$$

$$Q_0(\text{kg/hr})(3\text{ mm sieve}) = \frac{W2}{T2} \qquad \ldots (6)$$

Where;

Q_0= Output capacity (kg/hr), W_2= Weight of sifted cassava mash from the 3 mm sieve (kg), W_3= Weight of sifted mash from the 5 mm sieve,

T_2=Time of sifting (hr)

2.8 Statistical analysis

The results obtained were subjected to regression analysis and analysis of variance by using Design -Expert 6.0 version (Stat ease Inc; Minneapolis, USA). Level of significance was fixed at 5% ($P< 0.05$).Visual illustrations(graphs)were also generated. Adequacy of the models adopted was tested by highest value of the coefficient of determination, R^2, and least value of standard deviation and Predicted Residual Sum of Squares (PRESS) test.

Table 2 Design summary of the response surface experiments

Response	Name	Units	Obs.	Min.	Max.	Trans.	Model
Y1	Sifting efficiency (5mm)	%	27	78.80	89.00	None	Quadratic
Y2	Sifting efficiency (3mm)	%	27	62.80	79.90	None	Quadratic
Y3	Output capacity (5mm)	kg/hr	27	56.20	97.40	None	Quadratic
Y4	Output capacity (3mm)	kg/hr	27	45.10	87.80	None	Quadratic
Y5	Input capacity	kg/hr	27	232.29	405.25	None	Quadratic

3 Results and discussion

The design summary of the response surface experimentsis shown in Table 2.

Where; Y1 is sifting efficiency (5mm aperture sieve)(%), Y2 is sifting efficiency (3mm aperture sieve)(%), Y3 is output capacity (5mm aperture sieve)(kg/hr), Y4 is output capacity (3mm aperture sieve)(kg/hr),Y5 is input capacity)(kg/hr).

3.1The effects of moisture content, operating speed and mash quantity on the dependent variables

The effects of moisture content, operating speed and mash quantity on sifting efficiency, input capacity and output capacity for 5 and 3 mm aperture sieves were visually illustrated using response surface methodology. These illustrations were shown in Figure 3 to 17.

3.1.1The effects of moisture content, operating speed and mash quantity on the sifting efficiency for a 5 mm aperture sieve

For 5 mm sized aperture sieve, sifting efficiency, which determines how efficient the machine performs after sifting using a 5 mm aperture sieve, ranged from 78.8% to 89.0%. The sifting efficiencyobtained was similar to the result recorded by Jackson and Oladipo (2013) which was reported to be at a range of 73.29% to 86.51%.Sifting efficiency for 5 mm aperture sieve increase with increase in mash quantity and decreases with increase in moisture content and increase in speed, however, operating speed has more effect, followed by mash quantity and moisture content, as shown in themathematical expression of the relationship between the speed, moisture content and mash quantitywith the sifting efficiency for 5 mm aperture sieve presented in Equation (7) and the response surface plots as shown in Figure 3 to 5.The model that gives the best fit from the model summary statistics is a quadratic relationship. The effects of operating speed(A), moisture content(B), mash quantity(C) and were significant on sifting efficiencyfor 5 mm aperture sieve ($p < 0.05$).The goodness of fit for the model was expressed by the coefficient of determination R^2 and was found to be 0.9759, indicating that 97.59% of the variability in the response could be explained by the model. This suggests that the predicted value exhibits a good correlation with the experimental data and that the model is suitable and practicable as described by Gunjanet al.(2013).Also, adequacy of the modelwas testedwhere the least value of standard deviation and PRESS were obtained at 0.55 and 13.44 respectively at this model.

$$\text{Sifting efficiency (5mm)} = 85.72 - 2.97A - 0.67B + 1.32C - 1.40A^2 - 0.15C^2 - 0.18AB - 0.14AC - 0.00833BC \quad (R^2=0.9759) \qquad (7)$$

Where;A= Operating speed (rpm), B= Moisture content (%), C = Mash quantity (g)

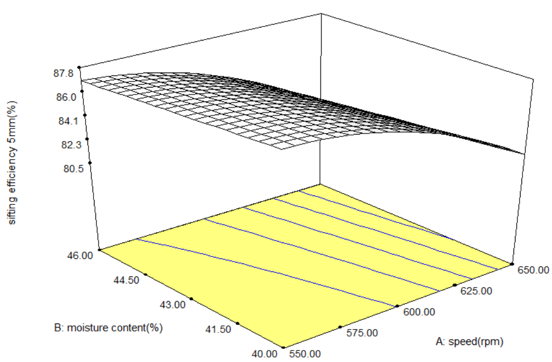

Figure3 Effect of moisture content and speed on sifting efficiency for a 5mm aperture sieve

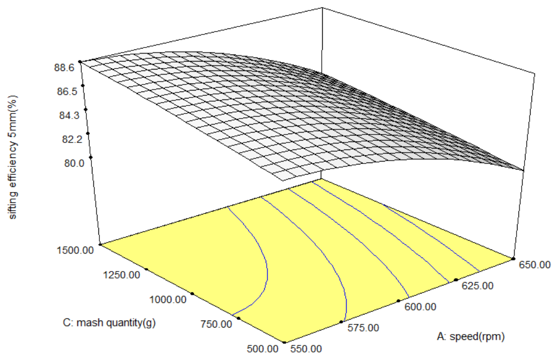

Figure4 Effect of mash quantity and speed on sifting efficiencyfor a 5mm aperture sieve

3.1.2 The effects of moisture content, operating speed and mash quantity on the sifting efficiency for a 3mm aperture sieve

Figure 6 to 8 are plots of treatments against sifting efficiency, whichdetermines how efficient the machine performs after sifting using 3mm aperture sieve. Percentage of sifting efficiency for 3mm aperture sieve ranged from 62.8% to 79.9%. Jimoh and Oladipo (2000) reported an operating efficiency of 61%, which is close to the range obtained. Orojinmi (1997) also reported an efficiency of 76%, which is also within the range obtained. Sifting efficiency for 3 mm aperture sieve increase with increase in mash quantity and decreases with increase in moisture content and increase in speedas shown in the quadratic relationship between the speed, moisture content and mash quantity with the sifting efficiency for 3 mm aperture sieve presented in Equation (8).The effects of speed, moisture content, and mash quantitywere significant on sifting efficiencyfor 3 mm aperture sieve ($p < 0.05$).The goodness of fit for the model was expressed by the coefficient of determination R^2 and was found to be 0.9165.In addition, the least value of

standard deviation and PRESS were obtained at 1.52 and 114.71 respectively at this model.

$$\text{Sifting efficiency (3mm)} = 72.37 - 1.83A - 2.50B + 3.52C - 2.02A^2 - 0.39B^2 + 0.89C^2 - 0.11AB - 0.55AC - 0.008333BC \quad (R^2 = 0.9165) \quad \ldots \quad (8)$$

Where;

A= Operating speed (rpm), B= Moisture content (%), C = Mash quantity (g)

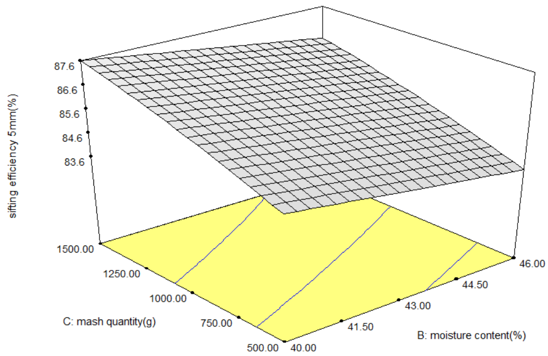

Figure5 Effect of mash quantity and moisture content on sifting efficiency for a 5mm aperture sieve

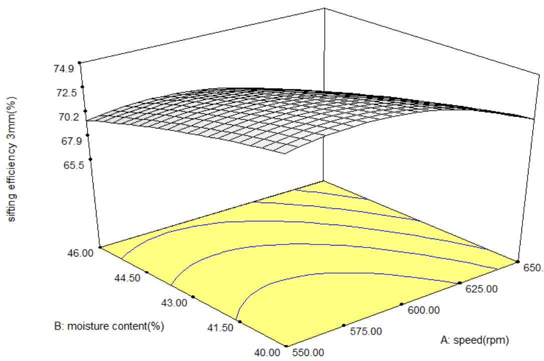

Figure 6 Effect of moisture content and speed on sifting efficiency for 3mm aperture sieve

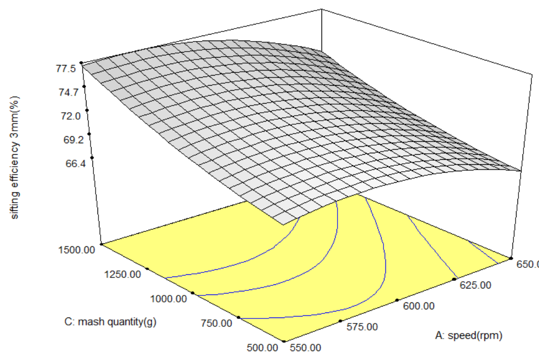

Figure 7 Effect of mash quantityand speed on sifting efficiency for 3mm aperture sieve

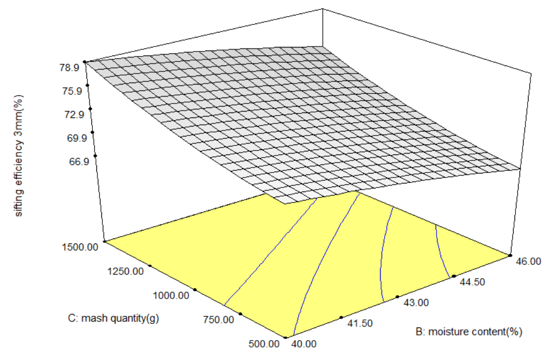

Figure 8 Effect of mash quantityand moisture content on sifting efficiency for 3mm aperture sieve

3.1.3 Effects of operating speed, mash quantity and moisture content on output capacity for a 5 mm aperture sieve

It varied from 56.2 to 97.4 kg/hr. This is similar to the range recorded by Kudaboet al.(2012). Output capacity for 5 mm aperture sieve increases with increase in mash quantity and speed and decrease with increase in moisture content, as shown in the quadratic relationship between the speed, moisture content and mash quantity with the output capacity for 5 mm aperture sieve presented in Equation (9) and the response surface plots as shown in Figures 9 to 11.The coefficient of determination (R^2) is 0.9885. The effects of speed (A), moisture content (B), and mash quantity (C) were significant on the output capacity for 5 mm aperture sieve ($p < 0.05$). The goodness of fit for the model was expressed by the coefficient of determination R^2 and was found to be 0.9885, indicating that the predicted values exhibit a good correlation with the experimental data. In addition, adequacy of the model was tested where the least value of standard deviation and PRESS were obtained at 1.57 and 103.41 respectively at this model.

$$\text{Output capacity (5mm)} = 82.87 + 2.98\,A - 6.18\,B + 11.92\,C - 0.40\,A2 + 0.73\,B2 - 5.22\,C2 - 0.38\,AB - 1.27\,AC + 0.64\,BC \quad (R2 = 0.9885) \quad \ldots (9)$$

Where;

A= Operating speed (rpm), B= Moisture content (%), C = Mash quantity (g)

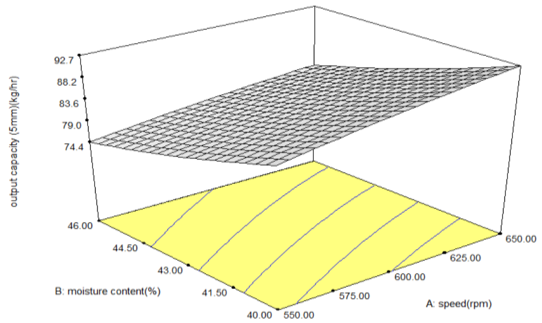

Figure 9Effect of moisture content and speed on output capacity for 5mm aperture sieve

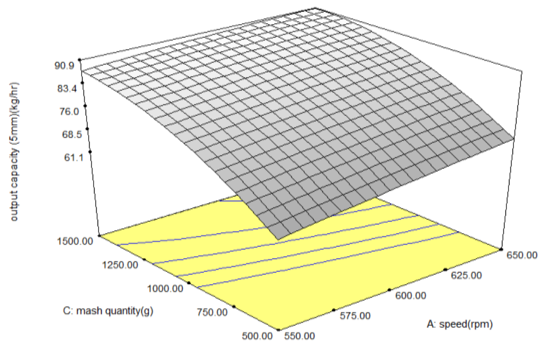

Figure 10Effect of mash quantity and speed on output capacity for 5mm aperture sieve

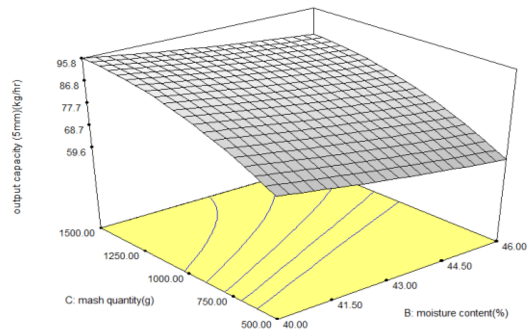

Figure 11 Effect of mash quantity and moisture content on output capacity for 5mm aperture sieve

3.1.4 Effects of operating speed, mash quantity and moisture content on output capacity for a 3 mm aperture sieve

The output capacity, which is the quantity of cassava mash sifted per hour for 3 mm aperture sieve obtained, varied from 45.1 to 87.8 kg/hr. This is within the result of 69.15 kg/hr obtained by Orojinmi (1997). This variation can be as a result of mash quantity, speed and variety of cassava mash as reported by Malomoet al. (2014). Output capacity for 3 mm aperture sieve increases with increase in mash quantity and operating speed and decrease with increase in moisture content as shown in the mathematical expression in Equation (10) and the response surface plots as shown in Figure 12 to 14. The coefficient of determination (R^2) is 0.9847. The model that gives the best fit from the model summary statistics is a quadratic relationship. The effects of the independent variables were significant on output capacity for 3 mm aperture sieve ($p < 0.05$). The goodness of fit for the model was expressed by the coefficient of determination R^2 and was found to be 0.9847, indicating that 98.47% of the variability in the response could be explained by the model and also by the least value of standard deviation and PRESS were obtained at 1.52 and 114.71 respectively at this model.

Output capacity (3mm) = 69.99 + 3.18 A - 7.18 B + 12.26 C - 0.24 A2 + 0.94 B2 -3.74C2 -1.64 A

B - 1.16 A C - 0.067 BC (R2 = 0.9847) … (10)

Where;

A= Operating speed (rpm), B= Moisture content (%), C = Mash quantity (g)

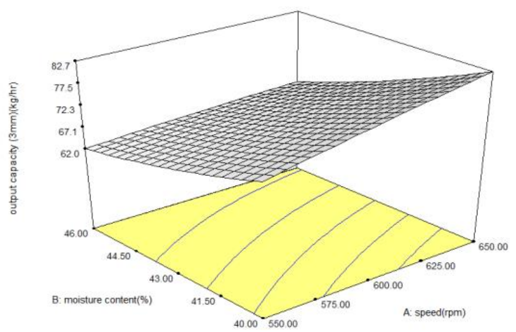

Figure 12Effect of moisture content and speed on output capacity for 3 mm aperture sieve

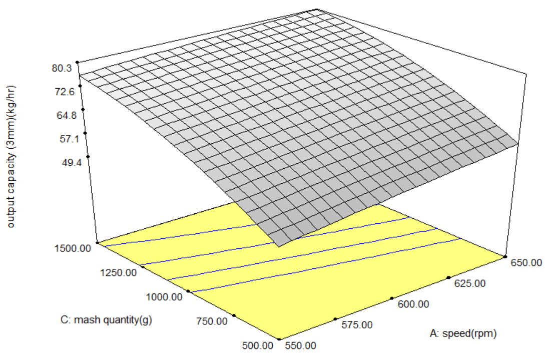

Figure 13Effect of mash quantity and speed on output capacity for 3 mm aperture sieve

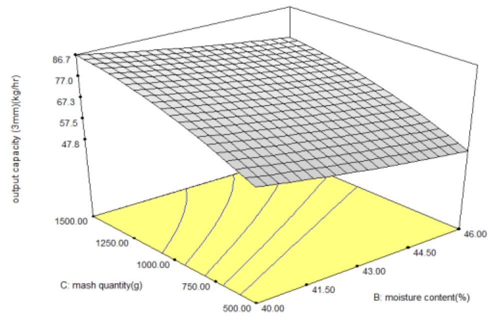

Figure 14Effect of mash quantity and moisture content on output capacity for 3 mm aperture sieve

3.1.5 Effect of operating speed, moisture content and mash quantity on the input capacity

The input capacity obtained varied from 232.29 to 405.25 kg/hr. This is within the range of 300 kg/hr and 1000 kg/hr reported by Hung et al. (1995). Input capacity increases with increase in mash quantity and operating speed and decrease with increase in moisture content, as shown in the quadratic relationship between the operating speed, moisture content and mash quantity with the input capacity presented in Equation (11) and the response surface plots as shown in Figures 15 to 17. The effects of the independent variables weresignificant on input capacity ($p < 0.05$). The coefficient of determination R^2 is 0.9828, suggesting that the predicted value exhibits a good correlation with the experimental data.In addition, the adequacy of the model was tested where the least value of standard deviation and PRESS were obtained as 6.98 and 2440.04 respectively at this model.

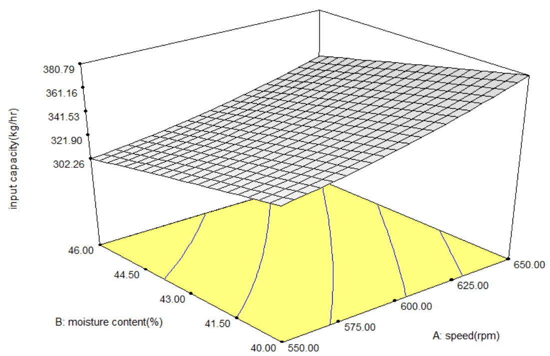

Figure 15 Effect of moisture content and speed on input capacity

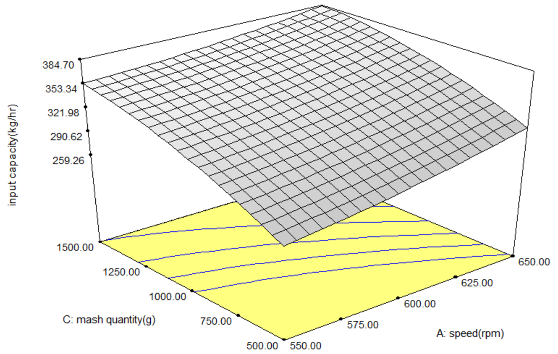

Figure 16 Effect of mash quantity and speed on input capacity

Input capacity = 335.66 + 20.92A - 18.34B +41.80 C+ 4.67A2 -0.41B2 - 12.63 C2 -1.60 AB - 5.73AC +4.78B C (R2= 0.9828) … (11)

Where;

A= Operating speed (rpm), B= Moisture content (%), C = Mash quantity (g)

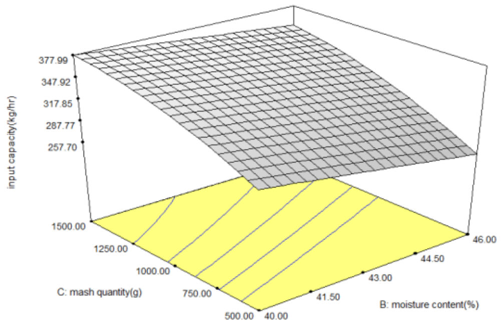

Figure 17Effect of mash quantity and moisture content on input capacity

4 Conclusions

Based on the results of the analysis obtained from the evaluation of the performance of a dewatered cassava mash lump pulverizer and sifter, it was concluded that:

1. The sifting efficiency for 5 mm aperture sieve ranges from 78.8% to 89.0% while it ranges from 62.8% to 79.9% for 3 mm aperture sieve. That is, sifting efficiency is higher for 5 mm aperture sieve than that of 3 mm sieve. Sifting efficiency for 5 and 3 mm aperture sieves increase with increase in mash quantity and decreases with increase in moisture content and increase in speed.This variation was as a result of specie, mash quantity, and moisture content of cassava mash and also the operating speed of the machine.
2. The output capacity for 5 mm and 3 mm aperture sieves obtained respectively varied from 56.2 to 97.4 kg/hr and from45.1 to 87.8 kg/hr. That is, output capacity is higher for 5 mm aperture sieve than that of 3 mm sieve. Output capacity for both 5 mm and 3 mm aperture sieves increases with increase in mash quantity and speed and decrease with increase in moisture content.This variation can be as a result of mash quantity, speed and variety of cassava mash used as reported by Malomo et al. (2014).
3. The input capacity obtained varied from 232.2 to 405.25 kg/hr. This is within the range of 300 kg/hr and 1000 kg/hr reported by Hunget al. (1995). Input capacity increases with increase in mash quantity and speed and decrease with increase in moisture content.
4. The effects of the moisture content, mash quantity and speed were significant ($p < 0.05$) on input and output capacity, and sifting efficiency for both 3 and 5 mm aperture sieves. Also, the model with the highest R^2 value and least value of standard deviation and Predicted Residual Sum of Squares (PRESS) gave the best model from the model summary statistics.

The traditionalmethod of pulverizingand sifting of cassava mash lump in developing countries with hand is tedious, slow, unhygienic and hazardous as reported by Igbeka et al. (1992). Therefore, the machine is recommended for small and medium scale processors that are involved in pulverizingand sifting of dewatered cassava mash lump in gari production.

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