Influence of Process Variables on a Rice De-stoning Machine

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Authors' contributions

This work was carried out in collaboration between both authors. Authors OAA and DLA designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript, managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

Article Information

Original Research Article

ABSTRACT

Investigation of the effect of processing factors on a rice de-stoner is necessary to address the major challenge of stone pebbles be introduced during harvesting and post-harvest handling of rice production. In this study, three process variables (moisture content, feed regulator, and machine speed) were investigated to determine their effects on a rice de-stoner. Design expert version 11 Response Surface Methodology (RSM) was used to identify the process variables levels yielding optimum rice tray loss, impurity level after separation rice separation efficiency, stone separation efficiency, and capacity of the machine. Feed regulator had a little effect on both the tray loss and impurity level after the separation of rice. Machine speed and moisture content had a little effect on both the rice separation efficiency and the stone separation efficiency while the feed regulator and moisture content in percentage had a little effect on the machine capacity. The rice de-stoner has the optimum machine speed, feed regulator, and moisture content of 189.654 rpm, 7.307 mm, and 11.88% respectively. The tray loss, impurity level after separation, rice separation efficiency, stone separation efficiency and machine capacity have optimum values of 9.366 %, 5.713 %, 90.629 %, 72.448 % and 133.024 kg/h with the corresponding R^2 values of 0.71, 0.97, 0.71, 0.96, and 0.96

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respectively at desirability value of 0.713 which indicates the nearness of the response to the predicted values and adequacy of models established in describing the observed values. The optimization of rice de-stoner showed an optimal processing condition for independent parameters and the machine response variables. This research is a contribution to the improvement of the quality of Nigerian rice.

1. INTRODUCTION

Rice production and consumption has been on a significant increase due to its adaptability in various traditional food recipe, bread and alcoholic drinks [1]. It is a leading cereal crop grown in all the continents of the world [2]. An approximate 5 billion people consume rice globally regularly [3,4]. The rate of rice consumption differs in countries and continents [5]. Rice, which is primarily grown for human consumption, has been imported into West Africa by more than 40 percent (2.75 million per year) [6]. However, over 90 percent of global rice production, especially in Asia, comes from tropical and semi-tropical temperate climates. An estimated 120 million Nigerian depend on rice as a staple food where it is consumed in various forms across localities but most popularly as boiled grains [7]. Similarly, Africa's largest producer of rice in West Africa, with an annual production of 3.2 million tons of paddy rice resulting in approximately 2 million tons of refined rice. Rice consumption in Nigeria has risen to over 10% per annum causing changes to consumer's preferences [8].

Rice importation is continually been encouraged due to exists of a huge gap of about 2 million metric tons annually [9]. The reasons for this identified gap include among others poor production methods, unavailability and high cost of farm inputs, low pace of technology adoption, post-harvest wastage, poor processing methods, and inefficiency in milling, poor marketing strategies, polishing and low-quality packaging and low/substandard mechanization on rice farms which has led to the over-reliance on manual labour for farm operations [10]. The demand for foreign rice in Nigeria had been attributed to the prevalence of impurities in locally produced once [11]. 'Reference[12]' indicated that Nigeria has enormous potential to increase domestic rice production and marketing with high expectations of becoming a self-sufficient rice producer, as this will also have a positive effect on the nation's economy by affecting all key players and stakeholders (paddy farmers and traders, rice millers and processors, haulers, residents, government and exporters).

However, the major challenge in the Nigerian rice industry is poor processing that allows for the introduction of contaminants such as stone pebbles, sticks, and chaff during harvesting and post-harvest handling. For this problem to be solved, the use of durable and sustainable machines must be engaged to enhance the quality of rice being produced [7,13]. The pneumatic method was used to clean the threshed rice paddy with air-lifting light, chaffy and dusty materials from the paddy, with material other than paddy of the same weight separating the paddy by reciprocating screen [14,15]. Aerodynamic properties of a mixture of particles are important for cleaning. When airspeed is high, the cleaning process will transform into an aspiration process, separating grains and chaff by differences in terminal velocity and drag coefficient. At low feed rates, aerodynamic separation of grain from straw and chaff occurs over the sieve, and at a higher feed rate, material particles are no longer aerodynamically assisted, as they form a sieve mat and increase grain losses [16].

'References[17]-[19]' suggested that, to be effective in the mechanization of agriculture in Nigeria, it must be focused on indigenous designs, production and manufacture of most of the machines and equipment required to ensure that they are suitable for crops as well as technical and financial capacities for farmers. This work, therefore, aims to optimize the performance of a rice de-stoning machine with both reciprocating and stationary sieves using locally sourced materials to remove stones and other impurities from locally produced rice.

2. MATERIALS AND METHODS

2.1 The De-Stoning Machine Theory of Operation

The rice de-stoning machine was designed to remove rice from stone. The admixture (rice and

stone mixture) discharges the rice from the hopper by gravity through the feed regulator into the inclined reciprocating sieve with openings depending on the size of rice grain to isolate the rice from the stones larger than it. The bigger stones were discharged through the outlet of stone. Any smaller stones will fall into the collecting tray along with rice. At one end, the collecting tray has a chute that conveys the items to the edge of the second stationary sieve. The sieve makes sand and small stones smaller than rice by gravity only when gathering the clean rice at the inclined outlet chute. A three-horsepower electric motor supplies the reciprocating mechanism with power via the assembly of pulleys and belt (DL Akindahunsi, Federal University of Technology Akure, Nigeria, Unpublished results).
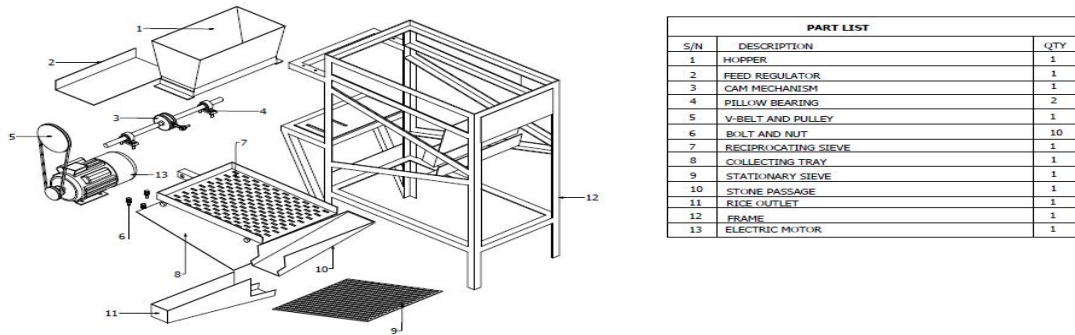

PART LIST		
S/N	DESCRIPTION	QTY
1	HOPPER	1
2	FEED REGULATOR	1
3	CAM MECHANISM	1
4	PILLOW BEARING	2
5	V-BELT AND PULLEY	1
6	BOLT AND NUT	10
7	RECIPROCATING SIEVE	1
8	COLLECTING TRAY	1
9	STATIONARY SIEVE	1
10	STONE PASSAGE	1
11	RICE OUTLET	1
12	FRAME	1
13	ELECTRIC MOTOR	1

Fig. 1. Exploded view of rice de-stoner (DL Akindahunsi, Federal University of Technology Akure, Nigeria, Unpublished results)
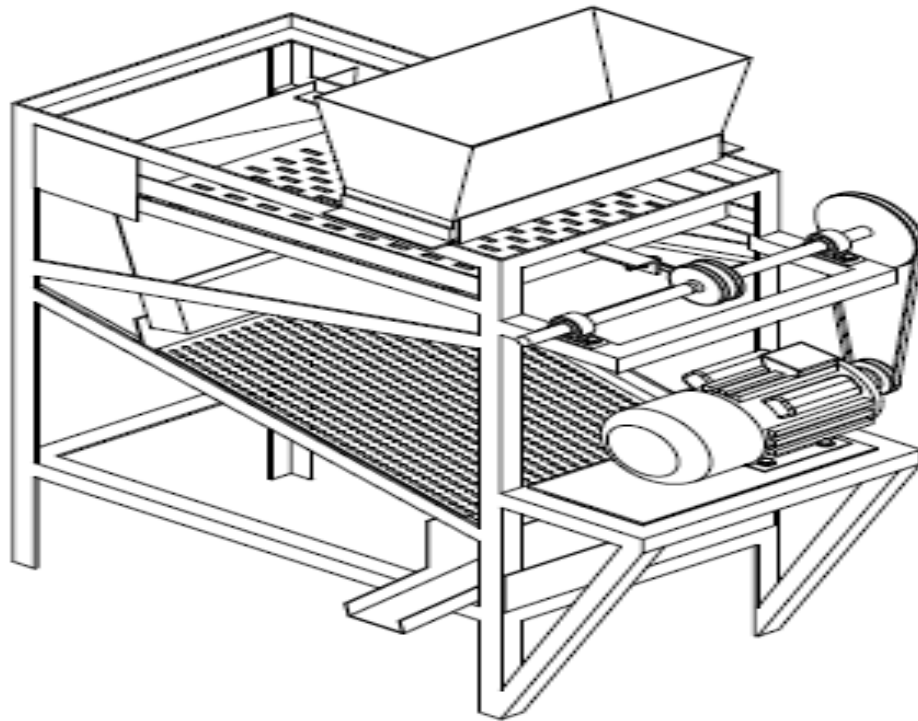

Fig. 2. Isometric View of Rice De-stoner (DL Akindahunsi, Federal University of Technology Akure, Nigeria, Unpublished results)

2.2 Sample Preparation

Milled local rice samples were purchased in Ado-Ekiti from rice millers. The experimental procedure consists of the measurement of different weights (quantities) of milled rice and stones. Each rice sample was weighed into 2000 g using electronic weighing balance and 400 g of stones was also measured and mixed with each 2000 g sample of rice. Therefore, the mixture of rice and stones of total weight of 2400 g were fed to the machine. Sample moisture content was determined using a grain moisture meter.

2.3 Experimental Design and Data Analysis

Response Surface Methodology (RSM) of the Design Expert Version 11 software using Central composite design (CCD) with three independent variables was applied for optimizing the quality parameters of the rice. The independent variables were moisture content, feed regulator, and machine speed were adopted for the optimization process by applying the central composite design method for the Analysis of Variance (ANOVA) and optimized responses within the limit of the independent factors tested.

The experimental design had 20 runs. Moisture content (10- 16 % MC_{wb}), feed regulator (5- 15 mm), and machine speed (100- 300 rpm) served as independent parameters, while the responses variables included tray loss (%), impurity level after separation (%), rice separation efficiency (%), stone separation efficiency (%), and capacity of the machine (kg/h). The response surface experimental design that shows the independent variables are provided in Table 1. Equation 1 presents the general formulae for a multiple linear and a quadratic regression model respectively.

$$Y = a + a_1Ms + a_2Fr + a_3Mc + a_{11}Ms^2 + a_{12}MsFr + a_{13}MsMc + a_{21}Fr^2 + \cdots a_pX_{p1} \quad (1)$$

where a, a_1, a_2, a_3, a_{11}, a_{12}, a_{13}, a_{21}, a_p are the coefficients) for testing the effect of the independent variables (machine speed[Ms], feed regulator [Fr] and moisture content[Mc]) on the responses/dependents variables, Y (tray loss, impurity level after separation rice separation efficiency, stone separation efficiency and capacity of the machine, etc), a is a constant (shows the value of Y when the of X=0), a, a_1, a_2, a_3, a_{11}, a_{12}, a_{13}, a_{21}, a_p are the model coefficients (shows how much Y changes for each unit change in X).

Table 1. The response surface experimental design showing the independent parameters and the responses variables

Run	Machine speed (Ms.) [rpm]	Feed regulator (Fr) [mm]	Moisture content (Mc) [%]
1	100	15	16
2	100	10	13
3	100	5	10
4	100	15	10
5	100	5	16
6	200	10	13
7	200	10	13
8	200	15	13
9	200	10	13
10	200	10	10
11	200	10	13
12	200	10	16
13	200	10	13
14	200	10	13
15	200	5	13
16	300	5	16
17	300	15	10
18	300	5	10
19	300	10	13
20	300	15	16

3. RESULTS AND DISCUSSION

3.1 Impurity Level after Separation of a Rice De-stoner

The optimum value of 5.713% of impurity level after separation with the desirability of 0.713 indicates the nearness of the observed value to the predicted values. The coefficient of determination (R^2) obtained was found to be 0.9689. This shows that the variation in the independent parameters account for 97% of the total variability in the impurity level after the separation of the rice de-stoner (Table 1). Equation 2 presents the regression model for the relationship between the impurity level after separation and the independent parameters. Figs. 4 & 5 and equation 2 show that the impurity level after separation increases with an increase in the feed regulator and a decrease in moisture content and machine speed. The feed regulator with a small coefficient had a little impact on the impurity level after separation while the machine speed and moisture content with negative coefficients mean the magnitudes were the exact opposite of the impurity level after separation. The demand for foreign rice in Nigeria had been attributed to the prevalence of impurities in locally produced once [11]. At low feed rates, aerodynamic separation of grain from straw and chaff occurs over the sieve, and at a higher feed rate, material particles are no longer aerodynamically assisted, as they form a sieve mat and increase grain losses [16]. This could be because rice - stone mixture has been properly sorted out, because the machine was fed more than it can handle. Similar results reported by [12].

$$ILS = 6.72 - 0.01Ms + 0.28Fr - 0.34Mc + 0.02Mc^2 \qquad (2)$$

Where ILS is impurity level after separation in %; Ms is machine speed in rpm; Fr is feed regulator in mm, and Mc is moisture content in percentage.

Fig. 3 shows the optimization values of independent parameters and the responses variables. The optimization independent parameters of a rice de-stoning machine showed optimum values of 189.654 rpm, 7.307 mm, and 11.881% for machine speed, feed regulator, and moisture content respectively. The tray loss, impurity level after separation, rice separation efficiency, stone separation efficiency, and machine capacity were found to have optimum values of 9.366%, 5.713%, 90.629%, 72.448%, and 133.024 kg/h kg/h with desirability of 0.713.
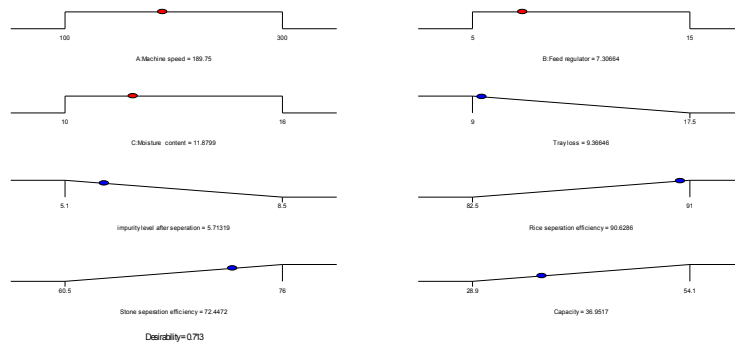

Fig. 3. 0ptimization of independent parameters and response variables

Table 2. ANOVA Model Terms for a Rice Destoner Responses at optimum values of machine speed of 189.654 rpm, feed regulator of 7.307 mm, and moisture content of 11.881%

Response	F Value	Prob > F	Lack of Fit F value	Prob > F Lack of Fit	R^2	Optimum value (%)
ILS (%)	34.616 (S)	0.000 (S)	0.927 (NS)	0.532 (NS)	0.969	5.731
SSE (%)	23.440 (S)	< 0.0001 (S)	1.760 (NS)	0.275 (NS)	0.955	72.448
MCA (kg/h)	25.220 (S)	< 0.0001 (S)	0.890 (NS)	0.548 (NS)	0.958	133.024

where ILS is impurity level after separation in %, SSE is stone separation efficiency in %, MCA is machine capacity in kg/h, NS means not significant and S means significant.
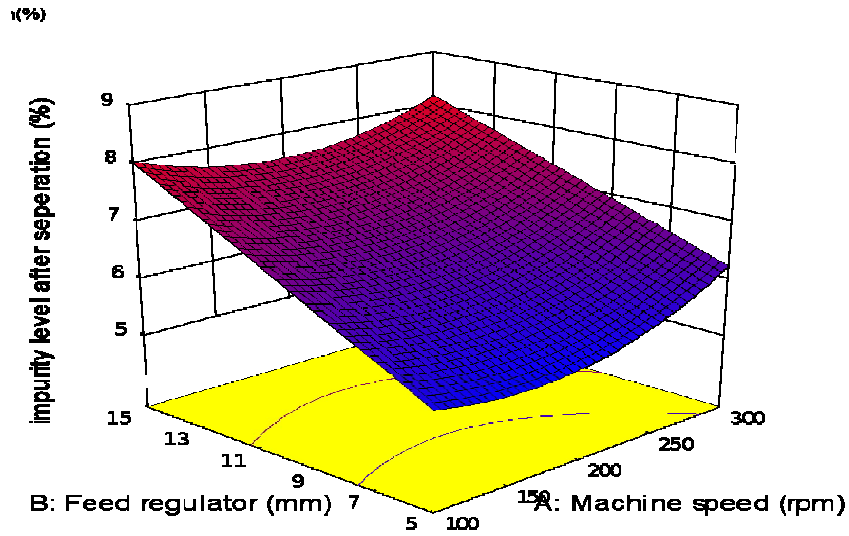
ι(%)

Fig. 4. Contour plot of impurity level after separation as a function of machine speed and feed regulator
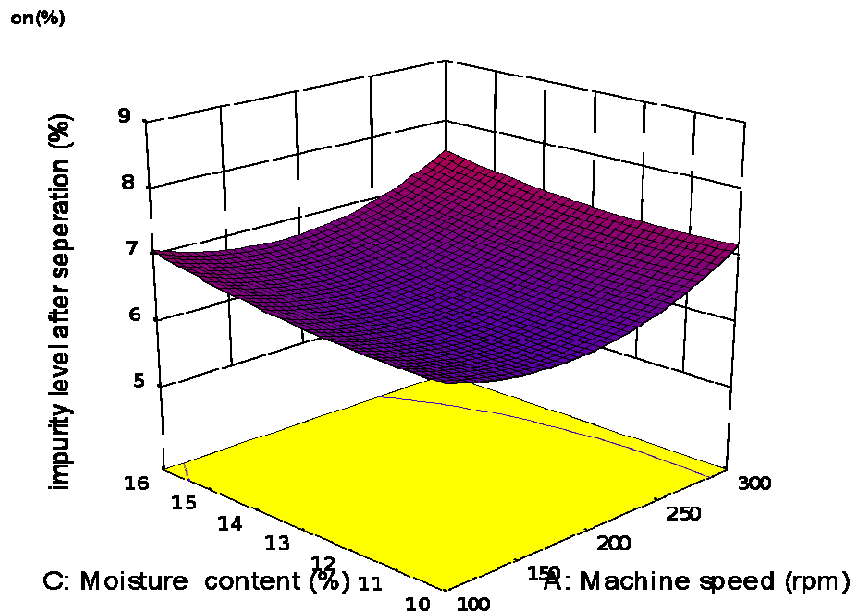
on(%)

Fig. 5. Contour plot of impurity level after separation as a function of machine speed and moisture content

3.2 Stone Separation Efficiency of a Rice De-stoner

Table 2 shows that the response factor has an optimum value of 72.448% of stone separation efficiency with the desirability of 0.713 which indicates the nearness of the observed value to the predicted values. The results for the regression model variance analysis relating the efficiency of stone separation to the independent parameters are described in Table 1. The overall model probability value of 0.0001 implies the model is significant as the value is lesser than 5%. The coefficient of determination (R^2)

obtained was found to be 0.9547. This shows that the variation in the independent parameters account for 95% of the total variability in the stone separation efficiency of the rice de-stoner. The lack of fit of the stone separation efficiency was found to be insignificant. Equation 3 presents the regression model for the relationship between stone separation efficiency and the independent parameters. Equation 3 and Figs. 6 & 7 show that the stone separation efficiency increases with an increase in machine speed and moisture content and decreases in feed regulator. The variation of stone separation efficiency with feed regulator opening in Figs. 6 & 7 shows that, the higher the feed regulator opening, the lower the stone separation efficiency. The machine speed and moisture content with small coefficients had little impact on the rice separation efficiency while the feed regulator with a negative coefficient means the magnitude was the exact opposite of the rice separation efficiency. The major challenge in the Nigerian rice industry is poor processing that allows for the introduction of contaminants such as stone pebbles, sticks, and chaff during harvesting and post-harvest handling. For this problem to be solved, the use of durable and sustainable machines must be engaged to enhance the quality of rice being produced [7], [13]. A similar observation was made by [19]. The higher stone separation efficiency at higher machine speed was possible due to the grains attaining higher reciprocating force and discharge velocity [20]. The stone separation efficiency of rice de-stoning machines increased with decreasing angle of inclination. The more

the feed regulator opening, the lower the de-stoning efficiency of the machines [21].

$$SSE = 74.62 + 0.02Ms - 0.92Fr + 0.79Mc - 0.02Fr^2 - 0.04Mc^2 \qquad (3)$$

where, SSE is stone separation efficiency in %; Ms is machine speed in rpm; Fr is feed regulator in mm, and Mc is moisture content in percentage.

3.3 Machine Capacity of a Rice De-stoner

Table 2 presents the optimum values of machine speed of 189.654 rpm, feed regulator of 7.307 mm, and moisture content of 11.881%. "Reference [21]" observed that the operating speed of the rice destoners range from 200 – 2980 rpm. The overall model probability value of 0.0001 is significant. Equation 4 presents the regression model for the relationship between machine capacity and the independent parameters. It was evident in equation 4 that the feed regulator as independent parameters had the highest influence on the machine capacity followed by the moisture content but machine speed is insignificant, i.e. does not influence it. The response factor has an optimum value of 133.024 kg/h of machine capacity with the desirability of 0.713 which indicates the nearness of the observed value to the predicted values. The coefficient of determination (R^2) obtained was found to be 0.9578. This shows that the variation in the independent parameters account for 95% of the total variability in the capacity of the rice de-stoner while the lack of fit of the machine capacity was found to be insignificant which indicates the reliability of the model.
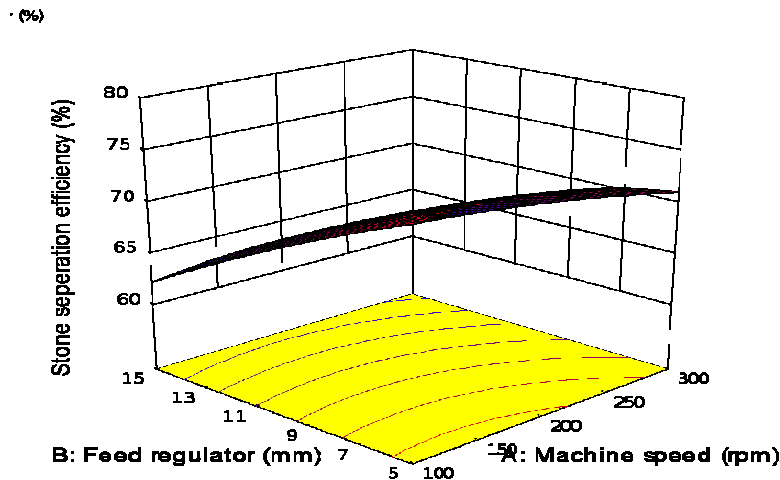

Fig. 6. Contour plot of stone separation efficiency as a function of machine speed and feed regulator
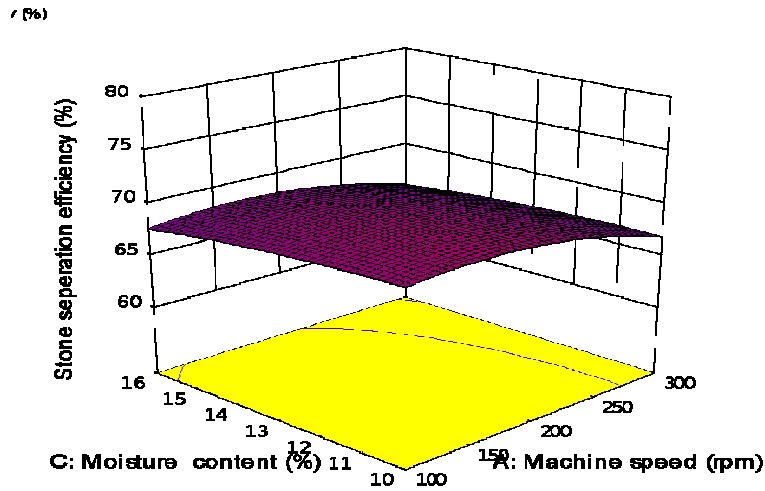
Fig. 7. Contour plot of stone separation efficiency as a function of machine speed and moisture content

Figs. 8 & 9 show that the machine capacity increased with an increase in moisture content and the opening of feed regulator on the hopper. The feed regulator and moisture content large coefficients had greater effect on the machine capacity of the rice de-stoner while the machine speed with negative coefficient means the magnitude was the exact opposite of on the machine capacity of the rice de-stoner. This could be because more grains are being released to the de-stoning chamber and increased weight due to an increase in moisture content. "Reference [21]" observed that machine capacity of rice de-stoning machines ranges from 1.8 – 7500 kg/h. "Reference [12]" also observed that, a variation of the feed gate opening to capacity is highly correlated and polynomial. As the feed gate opening was increased, the capacity being handled per second was also increasing.

$$MCA = 2.39 - 0.07Ms + 3.65Fr + 2.88Mc - 0.1Fr^2 - 0.14Mc^2 \qquad (4)$$

where, MCA is machine capacity in kg/h; Ms is machine speed in rpm; Fr is feed regulator in mm, and Mc is moisture content in percentage.
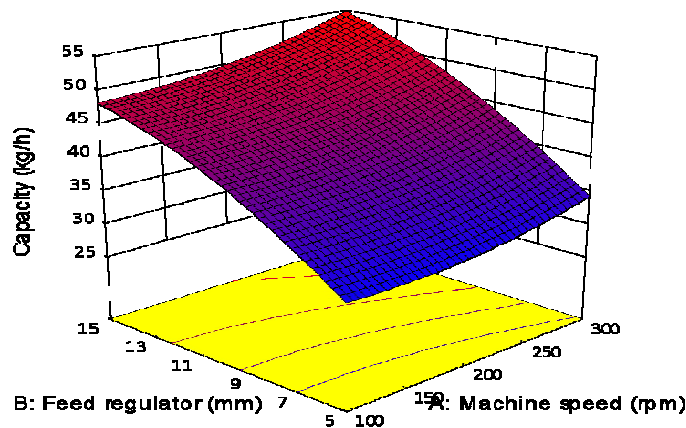

Fig. 8. Contour plot of machine capacity as a function of machine speed and feed regulator
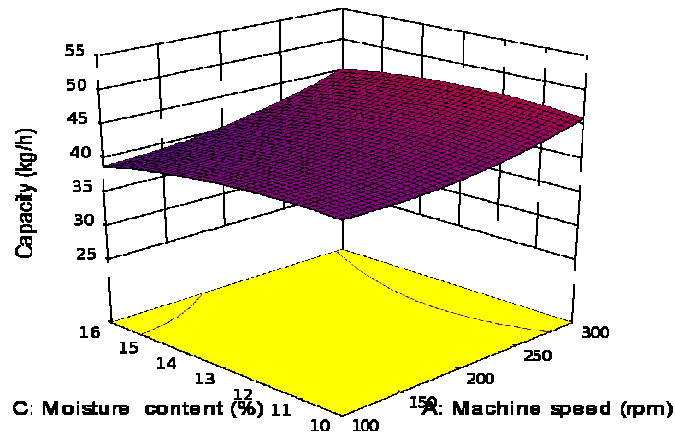
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Fig. 9. Contour plot of machine capacity as a function of machine speed and moisture content

4. CONCLUSIONS

The optimization independent parameters of a rice de-stoning machine showed optimum values of 189.654 rpm, 7.307 mm, and 11.881% for machine speed, feed regulator, and moisture content respectively. The impurity level after separation, stone separation efficiency, and machine capacity were found to have optimum values of 5.713%, 72.448%, and 133.024 kg/h kg/h with desirability of 0.713. An increase in machine speed resulted in increased stone separation efficiency but decreased in impurity level after separation, and machine capacity. As the feed regulator increases, impurity level after separation, and machine capacity increased whereas stone separation efficiency decreased. Moisture content increase led to an increase in stone separation efficiency, and machine capacity but decreased in impurity level after separation. The models obtained for the de-stoning process was adjudged to adequately describe the observation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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