Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.2021.v02i02.014

Turk J Agr Eng Res (TURKAGER)
ISSN: 2717-8420
*2021, 2(2), 413-424*

Research Article

# Optimization of Operational Parameters of an Improved Maize Sheller Using Response Surface Methodology

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## ABSTRACT

The research was carried out to optimize parameters for evaluating an improved motorize maize sheller. Statistical analysis was performed using response surface methodology (RSM) with 3 by 3 factorial experiment with 3 replicates. The three parameters are speed (850 rpm, 950 rpm and 1100 rpm), moisture content (12, 15, and 17%) and feed rate (120 kg $h^{-1}$, 130 kg $h^{-1}$ and 140 kg $h^{-1}$) used to illustrate the ability of the machine to shell maize (throughput capacity, shelling rate and machine efficiency). Results obtained showed that for optimum throughput capacity of 630.97 kg $h^{-1}$; shelling rate 485.34 kg $h^{-1}$ and machine efficiency 93.86% of the machine; is maximum for 129.6 kg $h^{-1}$ feed rate and moisture content 16.49% and machine speed of 1026.9 rpm. The machine can be used on commercial farms with these operational results.

**RESEARCH ARTICLE**

**Received:** 12.09.2021
**Accepted:** 20.11.2021

**Keywords:**

- Maize sheller,
- Optimization,
- ANOVA,
- Machine efficiency,
- Throughput capacity
- Shelling rate

**To cite:** Sedara AM, Odediran EO (2021). Optimization of Operational Parameters of an Improved Maize Sheller Using Response Surface Methodology. Turkish Journal of Agricultural Engineering Research (TURKAGER), 2(2), 413-424. *https://doi.org/10.46592/turkager.2021.v02i02.014*

## INTRODUCTION

Maize (*Zea mays*) is an essential cereals crop that have its place to a grass family (Poaceae) creating trivial eatable seeds (Aremu *et al.*, 2015). In maize processing shelling is consider a major operation that is very important to study. Shelled maize grains are important because they are consumed worldwide and are used for different purposes in different industries that's why its shelling is considered to be crucial (Sedara *et al.*, 2020). When maize seeds are removed from cob this is referred to as shelling and it's a postharvest process. It's performed on the farm or processing facilities

(Nwakaire *et al*., 2011). To produce finished products like flour from maize it is important to shell. Maize shelling operation could be performed manually, mechanically or electro-mechanically. The operation is should be able to remove the grain without inflicting damages to the kernels. According to Okure and Ssekanyo (2017), the traditional method of maize dehusking was done manually with hand and shelling was by beating the dehusked cob of maize with sticks, sickle, finger, etc., mostly done by rural women. Olaoye (2004) claimed that appropriate change of functioning condition in motorised thresher has been discovered by scholars to be the best critical success feature in grain threshing. Key variables of notice are mostly categorised as machine factors, crop characteristics and swaying eco-friendly or handling conditions. Nkakini *et al.* (2007) reported that the sheller used abrasion mechanism to strip maize. Manually functioned lever was used to alternate two shafts, one of which explained revolving motion to direct motion a slider crank. Maize cobs are push into the machine by the slider which is a continuous process. Despite the fact that of its operation, it provided constant flow with kernels dropping through the chute. Ojomo and Alemu (2012) reported that most of locally fabricated maize sheller/thresher have low efficiency due to limited knowledge on how to optimize parameters for improve performance. Different designs for maize shelling still the operational conditions still need to be optimized. Nsubuga *et al.* (2020) worked on optimizing the maize shelling operation of a multipurpose maize thresher and got optimum moisture content and speed of 13% and 896 rpm. The aim of the research was to establish optimum performance indicators between operation variables (moisture content, speed and feedrate) and their effect on shelling rate, throughput capacity and machine efficiency using 3D surface response methodology, thereby improving the quality of shelling/threshing and productivity.

## MATERIALS and METHODS

### Principles of Operation

The shelling is achieved by the shearing by the rotating spikes auger, which releases the grains from the maize cobs holding them. Different grain crops and different varieties of the same grain crop have varying characteristics, which require different speeds of the cylinder for achieving the best result of shelling, therefore adjustment of cylinder speed and proper feeding of cobs is essential.

### Design and Fabrication

The hopper was designed to be a frustum, trapezoidal in shape and has the following dimensions that were chosen based on proportionality and aesthetics. The angle of the base to the vertical is 490 with volume of hopper 0.04749 $m^3$. The total number of spikes on the shelling cylinder 28, and the power required was 1.5753 hp. The shelling/threshing chamber was 65 mm in diameter and length was 750 mm. The overall dimensions of frame were 77 cm length, 42.5 cm width and 128 cm height. Hopper receives and conveys maize cobs to the shelling unit, shelling chamber is where the maize encounters impact force on maize cob during shelling. Shaft and bearing allows the rotation cylinder and spikes and screen receives and screen the shelled grains, while frame supports the weight of the entire machine. V-Belt transmits power from engine to the shaft

The machine was designed using AutoCAD 16 as shown in Figure 1. Shows the side view of the fabricated motorize maize sheller.

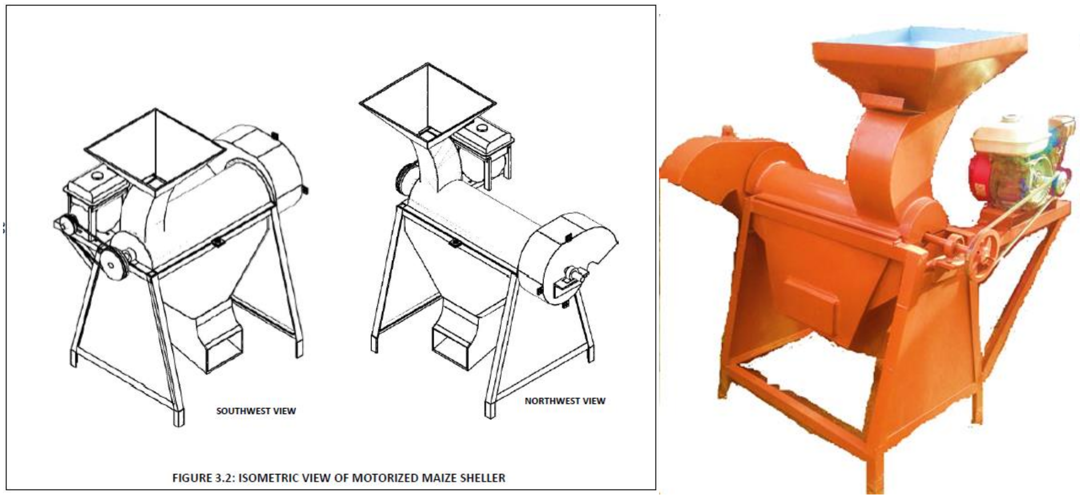


**Figure 1.** Side view of developed motorized maize sheller.

**Experimental design and performance evaluation**

Complete Randomised Design was used in the test as experimental design. A tachometer was used to measure the speed in rpm of the motor and the machine pulleys. The range of instrument was 10-10000 rpm. Stopwatch was used to measure time taken to run the machine during performance test and weighing balance to measure mass of maize. Moisture content was determined gravimetric method, Samples at all levels of moisture contents was randomly assigned to the sequence of test runs. Each test at a particular moisture content was replicated three times. This is carried out to ascertain the efficiency and effectiveness of the machine in terms of throughput capacity, shelling rate and machine efficiency. The developed machine performance was tested using maize at different variables such as moisture content (12, 15, and 17%) with variation in the machine speed (850 rpm, 950 rpm and 1100 rpm) and the feed rates (120 kg h$^{-1}$, 130 kg h$^{-1}$ and 140 kg h$^{-1}$).

The feed rate was calculated using equation 1

(i) Feeding rate (kg h$^{-1}$) $=\frac{W_{mf}}{T_t}$ (1)

where, $W_{mf}$ is total weight of maize cob fed into the hopper, $T_t$ is total time taken

(ii) Shelling rate (kg h$^{-1}$) The weight of the maize kernels (whole + broken) detached from the cobs in unit time was taken as shelling rate. It was calculated using Equation 2:

$$\text{Shelling rate (kg h}^{-1}\text{)} = \frac{W_{mh}}{T_{th}} \quad (2)$$

$W_{mh}$ is total weight of material handled and $T_{th}$ is total time taken.

(iii) Machine efficiency (%): It is the percentage by weight of shelled kernels from all outlets of the sheller with respect to total kernel input. It is calculated using Equation 3:

$$\text{Machine Efficiency } (\%) = \frac{T_{ws}}{T_{wc}} \times 100 \quad (3)$$

$T_{ws}$ is total weight of shelled grains from the outlets and $T_{wc}$ total weight of cobs input

(iv) Throughput capacity (kg $h^{-1}$): The weight of the maize cobs with kernels attached attempted by the machine in unit time was taken as rate of throughput and it was calculated using Equation 4;

$$\frac{T_{wgc}}{T_t} \times 100 \quad (4)$$

$T_{wgc}$ is total weight of grains attached with cobs and $T_t$ is total time taken.

**Data analysis**

The analysis entails Response surface methodology (RSM) on Design Expert 12. The factors (speed, moisture content and feed rate) were set in range while the responses (throughput capacity, shelling rate and machine efficiency) were set to maximize. It can be expressed as the dependent variable y is a function of $X_1$, $X_1$ and $X_3$.

$$Y = f(X_1) + f(X_2) + f(X_3) + e \quad (5)$$

where $Y$ is the response (dependent variable), $X_1$ and $X_2$ are independent variables and $e$ is the experimental error.

## RESULTS and DISCUSSION

The factors were optimized to result the level of responses of throughput volume, shelling rate and efficiency. To maximized productivity in terms of shelling the machine operations at different speed, feed rate and moisture content. The RSM (response surface methodology) stayed functional on motorize sheller/threshing with a total of 18 experiments was performed. For accurate results, three-dimensional surfaces representation describing the behaviour of the structure inside the experiment design.

**Throughput capacity (kg $h^{-1}$)**

Table 1 shows that the model established is not significant with F-value of 1.05. This means that the value is large (46.49%) and this could be caused by no-symmetry between the factors to give a better response. The "Prob> F" show model relationships are significant. It was observed that only feed rate that have significant effect on the throughput volume for the machine while the other factors are insignificant, and they can be revisited to improve the model. "Lack of Fit F-value" 3.29 infers it’s not significant with only 10.84% given the model a fit.

**Throughput capacity (kg h$^{-1}$)** = 541.44-23.89*A+1.19*B+5.04*C+15.49*AB-8.57*AC-3.59 *BC+36.34*A$^2$+5.2 *B$^2$6-7.46 *C$^2$ (6)

where A is feed rate, B is moisture content and C is machine speed. Equation 6 shows that speed and moisture content had positive coefficient (little effect) while feed rate was negative showing less effect on throughput capacity. Equation 1 is suitable for classifying the virtual effect of the factors by linking the factor coefficients. Throughput capacity shows a ratio of 5.158 (ratio>4) which indicates an adequate signal as shown in Table 4.3. The model is quadratic in nature which describes the fits. Equation (6) was used to calculate the predicted value and compared with actual value of throughput for the experiment as shown in Figure 2 with a coefficient of determination ($R^2$ = 0.6513) as shown in Table 2. This means the model can significantly explain 65.13% variation in throughput capacity of the machine.

**Table 1.** Effect of feed rate, moisture content and machine throughput capacity.
**Response 1. Throughput capacity.**

| Source | Sum of Squares | df | Mean Square | F-value | P-value | |
|---|---|---|---|---|---|---|
| **Model** | 31688.75 | 9 | 3520.97 | 1.05 | 0.4649 | not significant |
| **A-feed rate** | 7797.59 | 1 | 7797.59 | 2.33 | 0.1579 | not significant |
| **B-moisture content** | 19.34 | 1 | 19.34 | 0.0058 | 0.9409 | not significant |
| **C-machine speed** | 346.38 | 1 | 346.38 | 0.1035 | 0.7543 | not significant |
| **AB** | 1918.59 | 1 | 1918.59 | 0.5734 | 0.4664 | not significant |
| **AC** | 587.73 | 1 | 587.73 | 0.1757 | 0.6840 | not significant |
| **BC** | 103.32 | 1 | 103.32 | 0.0309 | 0.8640 | not significant |
| **A²** | 19030.61 | 1 | 19030.61 | 5.69 | 0.0383 | significant |
| **B²** | 398.47 | 1 | 398.47 | 0.1191 | 0.7372 | not significant |
| **C²** | 801.42 | 1 | 801.42 | 0.2395 | 0.6351 | not significant |
| **Residual** | 33459.27 | 10 | 3345.93 | | | |
| **Lack of Fit** | 25664.87 | 5 | 5132.97 | 3.29 | 0.1084 | not significant |
| **Pure Error** | 7794.39 | 5 | 1558.88 | | | |
| **Cor Total** | 65148.01 | 19 | | | | |

Where df is degree of freedom, F-value is critical value and P-value is significant value

**Table 2.** Fit statistics for the throughput capacity of maize sheller.

| | | | |
|---|---|---|---|
| Std. Dev. | 51.80 | $R^2$ | 0.6513 |
| Mean | 517.66 | Adjusted $R^2$ | 0.3374 |
| C.V. % | 10.01 | Predicted $R^2$ | -1.2381 |
| | | Adeq Precision | 5.1576 |

Where Std. Dev. is standard deviation, C.V. % is coefficient of variation, $R^2$ is coefficient of determination, Adjusted $R^2$ is adjusted coefficient of determination, Predicted $R^2$ is predicted coefficient of determination and Adeq Precision is adequate precision.

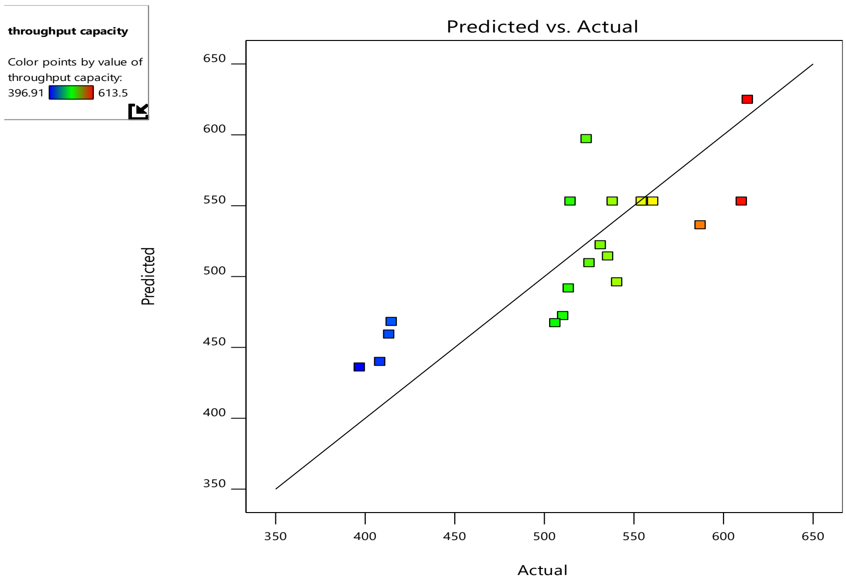


**Figure 2.** Predicted against actual values of throughput of maize sheller.

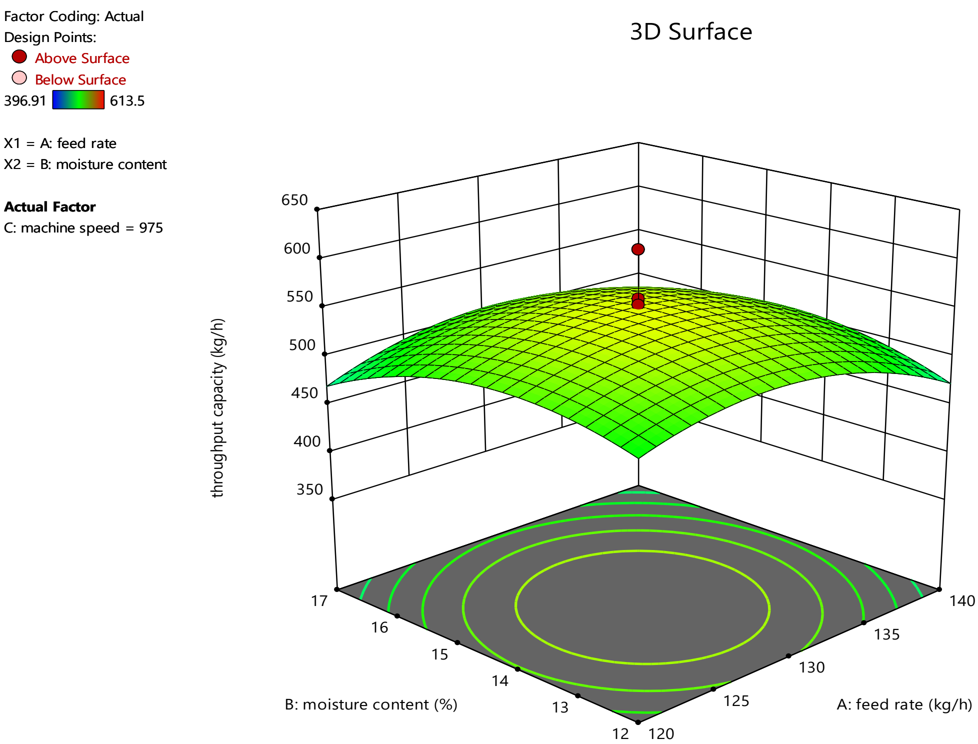


**Figure 3.** Effect of feed rate and moisture content on throughput capacity of machine.

Figure 3 depicts the interaction feed rate and moisture content on throughput capacity of machine. It is clear that the throughput capacity of machine to be minimum at 520 kg h$^{-1}$ and maximum at 580 kg h$^{-1}$ i.e., as the feed rate and moisture increased. This may be due to the reduction in the resistance to detachment from the cobs and the operational energy required to remove the grains from the cobs as moisture content reduced which agrees with Oriaku *et al.* (2014) and Ogunlade *et al.* (2014), when the moisture content reduced, it resulted into increase in throughput capacity.

**Shelling rate (kg h$^{-1}$)**

Table 3 shows the analysis of the variance (ANOVA) of the shelling rate, it was observed that the three conditions have no significant effects on shelling rate. However, the most effective of the factors was the feed rate with a contribution of 35.5%. The model is significant with **p-value** of 0.0236. The product of (federate)$^2$, (moisture content) $^2$, (speed)$^2$ are significant model terms compared to other terms having a lower contribution to 0.05.

$$\textbf{Shelling rate} = 426.626 + -1.8713 * A - 2.94736 * B - 12.5042 * C + 0.1575 * AB - 2.2525 * AC + -4.04 * BC + -30.7692 * A^2 + -28.4711 * B^2 + 21.8749 * C^2 \quad (7)$$

where A is feed rate, B is moisture content and C is machine speed. The model for shelling rate is given by Equation 7 and can be used to calculate the predicted value and compared with actual value of shelling rate for the experiment as shown in Figure 4 with a coefficient of determination ($R^2$ = 0.7759) as shown in Table 4

**Table 3.** Effect of feed rate, moisture content and machine throughput capacity on **shelling rate.**

| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| **Model** | 36396.23 | 9 | 4044.03 | 3.85 | 0.0236 | significant |
| **A-feed rate** | 47.82 | 1 | 47.82 | 0.0455 | 0.8354 | not significant |
| **B-moisture content** | 118.64 | 1 | 118.64 | 0.1128 | 0.7439 | not significant |
| **C-machine speed** | 2135.31 | 1 | 2135.31 | 2.03 | 0.1846 | not significant |
| **AB** | 0.1985 | 1 | 0.1985 | 0.0002 | 0.9893 | not significant |
| **AC** | 40.59 | 1 | 40.59 | 0.0386 | 0.8482 | not significant |
| **BC** | 130.57 | 1 | 130.57 | 0.1242 | 0.7318 | not significant |
| **$A^2$** | 13643.77 | 1 | 13643.77 | 12.98 | 0.0048 | significant |
| **$B^2$** | 11681.82 | 1 | 11681.82 | 11.11 | 0.0076 | significant |
| **$C^2$** | 6895.98 | 1 | 6895.98 | 6.56 | 0.0283 | significant |
| **Residual** | 10514.11 | 10 | 1051.41 | | | |
| **Lack of Fit** | 9835.22 | 5 | 1967.04 | 14.49 | 0.0054 | significant |
| **Pure Error** | 678.89 | 5 | 135.78 | | | |
| **Cor Total** | 46910.34 | 19 | 135.78 | | | |

Where df is degree of freedom, F-value is critical value and P-value is significant value

**Table 4.** Fit statistics for the throughput capacity of maize sheller.

| | | | |
|---|---|---|---|
| Std. Dev. | 32.43 | $R^2$ | 0.7759 |
| Mean | 401.11 | Adjusted $R^2$ | 0.5741 |
| C.V. % | 8.08 | Predicted $R^2$ | -0.6080 |
| | | Adeq Precision | 7.5486 |

Where Std. Dev. is standard deviation, C.V. % is coefficient of variation, $R^2$ is coefficient of determination, Adjusted $R^2$ is adjusted coefficient of determination, Predicted $R^2$ is predicted coefficient of determination and Adeq Precision is adequate precision.

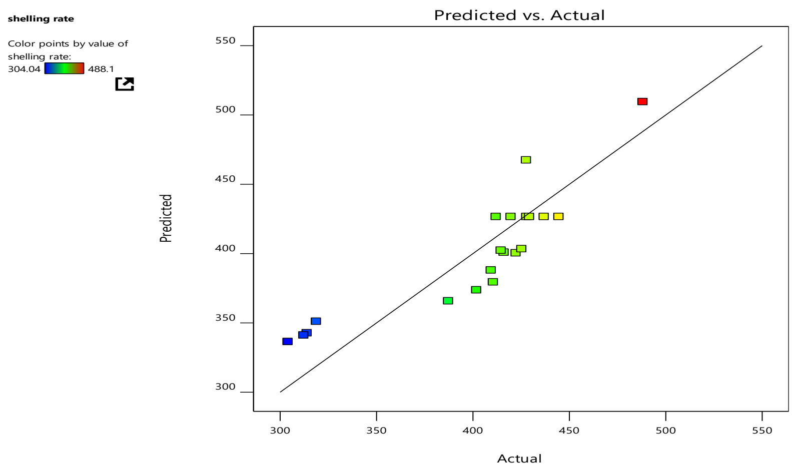


**Figure 4.** Predicted against actual values of throughput of maize sheller.

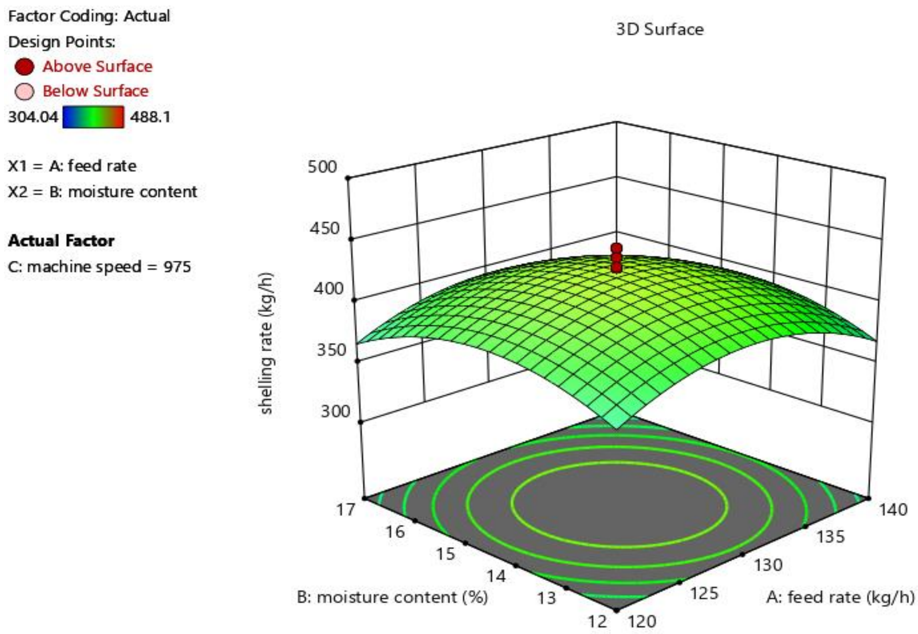


**Figure 5.** Feed rate and moisture content effect on shelling rate.

Figure 5 shows the interaction of feed rate and moisture content on shelling rate. It was observed that shelling rate was highest at 130 kg $h^{-1}$ and minimum at 120 kg $h^{-1}$ which means as shelling rate of grain from cob improved with feed rate and vice-versa, this shows shelling rate slightly improved with increased in moisture content. Also increased shelling speed increased the shelling rate. This may be due to the increased ease of detachment of the maize grains from the cobs with higher impacts and friction created between the shelling drum and the concave as the shelling speed increases which is in agreement with Oriaku *et al.* (2014).

## Machine Efficiency

Table 5 shows the ANOVA for the machine efficiency, it was observed that the three conditions have significant effect on the efficiency of the machine **($p<0.05$).** the product of (feed rate)², (moisture content)², (speed)² also shows they significantly contributes to model terms.

**Machine Efficiency (%)** = $90.0015 + 0.23421 * A + -0.220268 * B + 0.120386 * C + 0.35 * AB + -0.0975 * AC + -0.095 * BC + 1.13928 * A^2 + 1.33197 * B^2 + 0.74684 * C^2$ (8)

Equation 8 was used to calculate the predicted value and compared with actual value of machine efficiency for the experiment as shown in Figure 6 with a coefficient of determination ($R^2$=0.5905) as shown in Table 6.

**Table 5.** Effect of feed rate, moisture content and speed on **machine efficiency.**

| Source | Sum of Squares | df | Mean Square | F-value | P-value | |
|---|---|---|---|---|---|---|
| Model | 47.09 | 9 | 5.23 | 3.94 | 0.0219 | Significant |
| A-feed rate | 0.7491 | 1 | 0.7491 | 0.5637 | 0.04701 | Significant |
| B-moisture content | 0.6626 | 1 | 0.6626 | 0.4986 | 0.04963 | Significant |
| C-machine speed | 0.1979 | 1 | 0.1979 | 0.1489 | 0.04076 | Significant |
| AB | 0.9800 | 1 | 0.9800 | 0.7374 | 0.4106 | not significant |
| AC | 0.0761 | 1 | 0.0761 | 0.0572 | 0.8158 | not significant |
| BC | 0.0722 | 1 | 0.0722 | 0.0543 | 0.8204 | not significant |
| $A^2$ | 18.71 | 1 | 18.71 | 14.07 | 0.0038 | Significant |
| $B^2$ | 25.57 | 1 | 25.57 | 19.24 | 0.0014 | Significant |
| $C^2$ | 8.04 | 1 | 8.04 | 6.05 | 0.0337 | Significant |
| Residual | 13.29 | 10 | 1.33 | | | |
| Lack of Fit | 8.70 | 5 | 1.74 | 1.90 | 0.2494 | not significant |
| Pure Error | 4.59 | 5 | 0.9171 | | | |
| Cor Total | 60.38 | 19 | | | | |

Where df is degree of freedom, F-value is critical value and P-value is significant value

**Table 6.** Fit statistics for the machine efficiency of maize sheller.

| | | | |
|---|---|---|---|
| Std. Dev. | 1.67 | $R^2$ | 0.5905 |
| Mean | 91.69 | Adjusted $R^2$ | 0.2220 |
| C.V. % | 1.82 | Predicted $R^2$ | 0.0340 |
| | | Adeq Precision | 4.8365 |

Where Std. Dev. is standard deviation, C.V. % is coefficient of variation, $R^2$ is coefficient of determination, Adjusted $R^2$ is adjusted coefficient of determination, Predicted $R^2$ is predicted coefficient of determination and Adeq Precision is adequate precision.

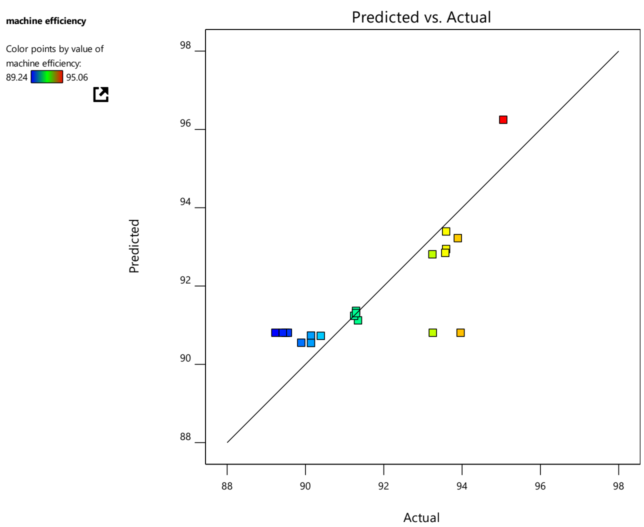


**Figure 6.** Predicted against actual values of machine efficiency of maize sheller.

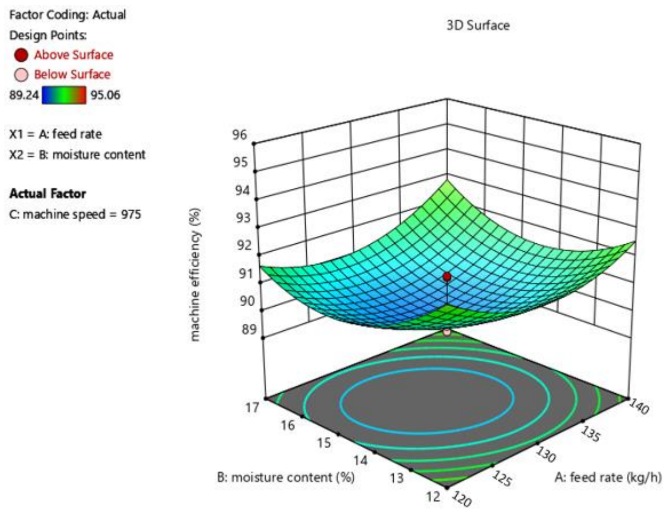


**Figure 7.** Feed rate and moisture content effects on machine efficiency.

Figure 7 shows the interaction of moisture level and feed rate on efficiency of the machine. The highest efficiency of 92.6% was observed at the peak interaction of feed rapture and moisture level and lowest value of 85%, as machine efficiency decreased with increased in feed rate and vice-versa, machine efficiency slightly improved and reduced with increased in moisture content. These results were in agreement with the findings of Roy *et al.* (2017). A reduction in moisture resulted into an increase in the machine efficiency of the improved maize sheller at the same shelling speed. This may be due to less time required to detach the maize grains from the cob as the moisture content reduced as explained by Chaudhary (2016). The machine efficiency was greatest at a moisture content of 12% and lowest at 17%.

**Optimize parameters**

The optimization of the interactions between factor terms and the evaluation of the machine is has presented in Figure 8 using surface response methodology. The results were found that at 129.6 kg $h^{-1}$ feed rate, moisture content 16.49% and machine speed of 1026.9 rpm the throughput capacity of 630.97 kg $h^{-1}$; shelling rate 485.34 kg $h^{-1}$ and machine efficiency 93.86 % of machine is maximum as shown in Figure 8. It was observed that the desirability at run 1 of 73 was the best compared to other runs.

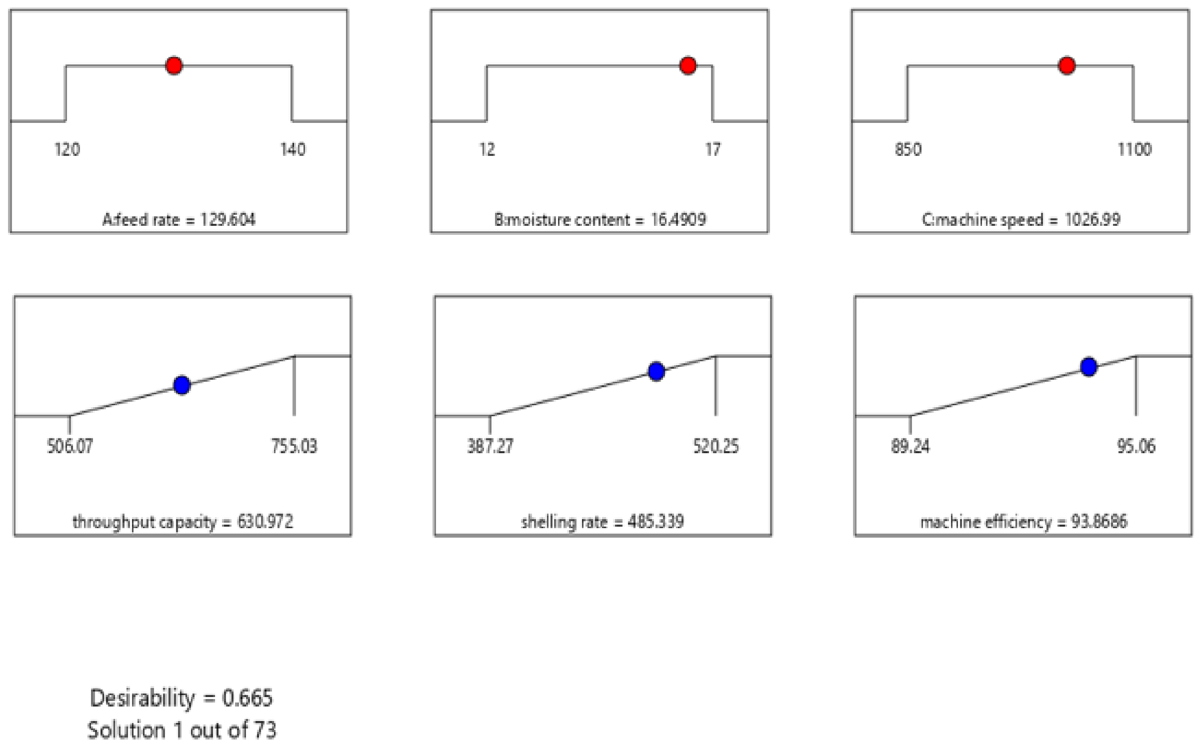


**Figure 8.** Optimize parameters of machine.

## CONCLUSION

A motorized maize sheller machine has been designed and fabricated with the use of locally available materials. The machine was tested at three levels of moisture content (12, 15 and 17%), three levels of feed rate (120, 130 and 140 kg $h^{-1}$) and three levels of machine speed (850, 950 and 1100 rpm) had different machine efficiency (%), throughput capacity (kg $h^{-1}$) and shelling rate (kg $h^{-1}$). The throughput capacity of machine varied from 480 kg/h to 755.03 kg $h^{-1}$ at different moisture content and different speed of operation. Regression analysis showed a quadratic relationship for throughput capacity, shelling rate and machine efficiency having coefficient of determination $R^2$ of 0.6513, 0.7759 and 0.5905 respectively. The moisture content had no effect on the throughput capacity of motorized maize shelling machine. The shelling rate decreased with increase in moisture content and decreased with increase in moisture content. The machine speed had great effect on the shelling rate. With the increased in speed of operation, the machine efficiency increased. It showed an increasing trend with the increased in speed of operation. The overall machine efficiency of machine had approximately 95.06%. The optimized results show shelling rate and throughput capacity was determined; with throughput capacity of 630.97 kg $h^{-1}$; shelling rate 485.34 kg $h^{-1}$ and machine efficiency 93.86% of machine is maximum for 129.6 kg $h^{-1}$ feed rate and moisture content 16.49% and machine speed of 1026.9 rpm.

## DECLARATION OF COMPETING INTEREST

The authors of this manuscript declare that there is no conflict of interest.

## CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

**Adewale Moses Sedara:** Methodology, conceptualization,, validation, writing - original draft, review and editing.

**Emmanuel Olutope Odediran:** Investigation, formal analysis, data curation, visualization.

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