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EFFECT OF CORN *Zea mays L.* COB MOISTURE CONTENT ON THE PERFORMANCE OF A CORN-COB SHELLER MACHINE

The object of the research is machine shelling efficiency. This study focused on the assessment of a fabricated corn Sheller machine and resolution of optimal moisture content percentage dry basis (% MC_{db}) for shelling corn-cobs. Corn-cobs samples at 8, 13 and 18 % MC_{db} were sorted into 3.15, 2.15 and 1.15 kg feed-masses, respectively. Samples were selected in triplicates for shelling operations time 5, 6 and 7 seconds. Standard method was used to determine the effect of shelling operation on corn-cobs' quality variables. Response Surface Method was employed to optimize data with machine feed-mass and moisture content as independent variables, whilst responses being: shelled, un-shelled, damaged, un-damaged corn grains, as well as grain breakage ratio, machine shelling efficiency and shelling process time. The data gotten from the results were utilized to evaluate the corn-cob shelling machine and were analyzed using ANOVA at 95 % confidence interval. Corn-cobs 8 % MC_{db} shelled at 5 seconds and machine feed mass of 3.15 kg had the highest shelling efficiency of 97.78 %, followed by 13 % MC_{db}, feed mass of 2.15 kg, machine shelling efficiency 92.06 %; shelled in 6 seconds, lastly, 18 % MC_{db}, feed mass of 1.15 kg, shelling efficiency was 87.82 % shelled in 6 seconds. The resultant recorded response masses; shelled, un-shelled, damaged corn grain (kg) and grain breakage ratio recorded were at lower values. At lower machine shelling time, feed mass and moisture content percentage (% MC_{db}) of the corn cobs, higher shelled grains off the corn-cobs were recorded with reduced damaged grains, indicating higher shelling efficiency of the fabricated corn-cob Sheller machine.

Keywords: *Zea mays L., corn-cobs, moisture content, shelling machine, performance, machine shelling efficiency.*

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1. Introduction

Maize (*Zea mays L.*) sometimes called corn-both in North America and Australian English- is a type of cereal crop [1]. It is among the mostly grown seed crop worldwide. It was firstly cultivated by the native people of South Mexico decades ago [2–4]. «Maize or Corn» literally means that which sustains life [5]. In Africa and other developing countries of the world, maize or corn has become a staple food crop that is synonymous to the poorest of families. It is used in various forms to alleviate hunger in developing, these processed forms include: baby foods, pap or *ogi*, breakfast meals, bread, maize flour, corn meals, etc. Maize sustenance nature makes it important that preservation, storage and processing it to the op-timed conditions be analyzed. However, in Asia corn production is over 200 billion kg annually and expected that the total corn production in developing countries will eventually rise above production demand in or from industrialized countries [2].

Maize or corn is described as the most important cereal grain in the world after wheat and rice, supplying nutrients for both humans and animals alike [6] and regarded as a fundamental material needed in the production of protein, starch, oil, food sweeteners and alcoholic beverages and in recent times biofuel [5]. It is a green stem plant that grows efflorescence (tassels) which produces pollen grains a detached ovuliferous floweret referred to as ears which when pollinated yields seeds (grains) that are botanically referred to as fruitlets [7, 8]. It is a significant cereal crop belonging to the grass family (Gramineae) which produces edible seeds [9]. Planting and harvest of this unique crop (Corn) determines the cultivar sown; however, the crop generally matures within 7 to 8 weeks after physiologically flowering. At this period, the cob and grains hold 35–45 % moisture content with highest placidity of dry matter [10].

Corn of Maize is grown globally as a sustenance crop within sub-Saharan Africa (SSA) topping over 33 million (ha) of land annually; it covers almost 17 % of the approximated 200 million ha of land cultivated in SSA. However, it is processed into diverse production environments and eaten by individuals having different food palates and socio-economic requirement [11]. The six most important variety of corn include; dent, flint, pod, pop, flour, and sweet corns, however, the glucose-enrich type described as sweet corn is used mostly cultivated as human food crop (main grains), whilst, the green corn cultivars are utilized as feeds for animals, pressed into corn oil, fermented and distilled into alcoholic beverage as well as other corn-based foods for humans (including grinding into corn meals or Masa) and as a feedstock for chemical industries. Maize or corn is also used in making ethanol and ingredients biofuels [7]. Maize as a whole was distributed all over the globe after Europeans discovered America in the early 15th century, particularly to the clement region of the world [12, 13].

Maize or corn shelling involves separation or removal of maize seeds from the cobs by abrasive impression an operation carried out after the harvesting stage; the hard part of maize shelling operation depends largely upon the content of moisture in the cob; varieties of maize cultivated, and level of maturity of grain crop [14].

The higher the content of moisture in seeds or grains on the corn-cobs, the higher the breakage percentage which in turn lowers the total efficiency of the Corn shelling machine, as the higher moisture content of the corn seeds on the corn-cob affected the rotational speed of the threshing cylinder of the corn shelling machine [15].

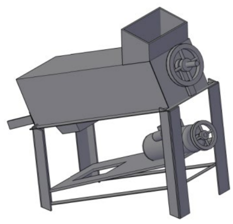
A study demonstrated by [16] stated moisture content of the maize significantly affect shelling efficacy of maize shelling devices and concluded that high moisture content of the maize grain cobs leads to decrease in shelling ability of maize Sheller used for the experiment.

This study is aimed at studying the effect of moisture content percentage of corn-cobs on the performance of a corn shelling machine and the determination of optimal moisture content percentage dry basis (% MC_{db}) for shelling corn-cobs.

2. Materials and Method

A corn-cob shelling machine for shelling off grains off the maize cob was designed, constructed and installed at Crop Production Technology Department, Federal College of Forestry, Jericho, Ibadan located between (latitude 7°23′46″ N and longitude 35°14′7″ E) of the Equator in Ibadan, Oyo state Nigeria. The annual rainfall is recorded to be 1250 mm having two practical seasons; a wet season of about to 8 months lasting from April to November, in between is a short dry spell which usually starts mid-August. The mean maximum and minimum daily temperatures lie between 21.9 °C and 35.5 °C [17]. The machine characteristics to be evaluated will include the machine feed-mass, grain breakage ratio, machine shelling efficiency and shelling process time, while the corn-cobs' quality parameters to be evaluated will be moisture content in relation to the (shelled, un-shelled, damaged, un-damaged) corn grains. Summarily, the data obtained from the evaluation will be used to determine the optimal moisture content of corn percentage of corn cob that will enhance the performance of the corn shelling machine.

2.1. Corn shelling machine descriptions. The corn shelling machine consisted of five major parts: the inlet, the shelling chamber made up of the spikes placed around the shaft, the discharge outlet, the sieve and the driving unit as shown in (Fig. 1) [18]. The main process of shelling the grains off the corn-cob occurs mainly in the maize shelling drum. The engine transmits torque to the shelling shaft and the blower, this torque causes the shaft to rotate. The rotation of the shelling shaft helps the shelling head (with spike) to shell the maize against the surrounding (shelling drum). The continuous rotation of the shaft and the arrangement of the spikes and the drum help the shelpled cob move toward the cob collector while the drum assists in the shelled grains collection.


a


b


c

Fig. 1. The corn-cob sheller machine: *a* – isometric diagram; *b* – front view; *c* – side view

2.2. Machine feed rate. The corn shelling machine was fed at 1.15, 2.5 and 3.15 kg corn-cob per time respectively. Through put process was calculated using Equation (1) [19]. However, the feed masses of corn-cobs supplied to the Sheller for the shelling process were measured in kilograms:

$$FM = \frac{M_T}{t}, \quad (1)$$

where FM – feed mass; M_T – total mass of corn-cob (kg); t – time (s) taken to for the shelled corn grains to empty out of the shelling machine.

2.2.1. Determination of evaluation parameters. In this study, independent variables used to assess the performance of the corn shelling machine were feed mass FM (kg), moisture content percentage dry basis (% MC_{db}) of the corn-cobs and the time taken to shell the corn-cobs (though put time) (kg/h). The dependent variables included mass of un-shelled grains from corn-cobs M_1 (kg), mass of damaged grains after shelling operation M_2 (kg), mass of shelled grains M_3 (kg) and the machine shelling efficiency MSE (%).

2.2.2. Moisture content determination. In this study, collected samples with initial moisture content 23.8 % MC_{db} were oven dried to 8, 13 and 18 % MC_{db} in the laboratory using the ISTA oven dry standard method, respectively, resultant dried samples were labeled *A*, *B* and *C* respectively to ease identification. Conversely, the dried corn-cobs samples collected were utilized to perform the experiment of determining the optimum moisture content for shelling corn-cobs with minimum damage to the corn grains (maize) on the cobs.

2.2.3. Evaluation of corn shelling machine performance. A total of thirteen (13) samples of corn-cobs (maize ears) were collected with initial moisture content at harvested averaging 23.8 % MC_{db} which was determined in the laboratory using standard measures. Specimens were further oven dried to moisture contents of 8 %, 13 %, and 18 % dry basis in triplicates. Afterward, the shelling performance of the machine was subjected to evaluation by running the samples through the machine. The masses of the maize were measured and recorded before and after the shelling process. Data obtained from the machine performance test were used to determine the capacity, efficiency and grain damage of the machine using Equations (2)–(5) as used by [18–20]:

$$CM = \frac{(M_3)}{t(s)} \cdot 3600 \text{ kg/hr}, \quad (2)$$

$$MSE = \frac{(M_3)}{(M_3 + M_1)} \cdot 100, \quad (3)$$

$$GD(\%) = \frac{(M_2)}{(M_3 + M_1)} \cdot 100, \quad (4)$$

$$GBR = \frac{CD}{CD + CU} \cdot 100, \quad (5)$$

where CM – machine capacity; M_1 – mass unshelled maize grains on cob; M_2 – mass of damaged shelled grains; M_3 – mass of shelled maize grains; t – time taken to shell grains; MSE – machine shelling efficiency; GD – grain damage; GBR – Grains Breakage Ratio; CD – Cracked and Damaged grains; CU – Cracked and Undamaged grains.

2.3. Experimental design and optimization. Surface response methodology RSM was used to evaluate variables in this study in order to enhance the evaluation process of the fabricated corn-cobs shelling machine using Central Composite Rotatable Design (CCRD) [21]. Comparable to [22]'s study applying dimensional analysis premised on Buchingham's ϖ theorem as a veritable tool to establish a prediction equation of different systems. This will assist in reducing the cost of the experiment; considering the procedure allows the statistics model to generate fewer experimental runs. However, design of 2 to 27 factors is set at two levels in design of the experiments, for which it can be utilized to estimate the pivotal effects or responses and interface where fractional factorials can be adopted for screening multiple factors and obtaining the levels of significance.

2.3.1. Experimental design and statistical analysis. A 2×3 Central Composite Design (CCD) rotatable surface response Design Expert 13.0.5.0x64 software was utilized to generate the design of experiment that will complement the shelling effectiveness of the shelling machine for grains (grains) from the cob [23, 24]. The experimental design generated 13 experimental runs using fed masses and moisture content of corn-cobs with the selection of two independent factorial interaction design (2*FI*) model. Variables were evaluated at low, central and high (–1, 0 and 1) levels as indicated in Table 1. The independent variables were different moisture contents of corn-cobs, machine fee masses coded variables, showing the coded and actual levels are as displayed in Table 2, whilst, the dependent responses indicated were the mass of the shelled, unshelled, damaged and undamaged maize grains (grains), as well as the grain breakage ratio of the grains and machine shelling efficiency and the time taken to shell the grains off the cobs as it runs though the machine (through put time).

The independent variables for the study will include the selected moisture content of 8, 13 and 28 % MC_{db} for each feed masses at 1.15, 2.5 and 3.15 kg at a constant shaft speed of 1440 rpm of the machine. On the other hand, the dependent variables used to evaluate the efficacy of the maize shelling machine were the shelled, un-shelled, damaged and undamaged maize grains measured in kilograms as well as the percentage grain breakage ratio of the grains and machine shelling efficiency and the shelling process time in seconds were utilized for performance assessment of the maize Sheller.

Table 1

Independent Variables, Coded and Actual levels of Design of Experiment

S/N	Independent variable	Symbol	Unit	Code	Level		
					–1	0	+1
1	Feed Rate	*A*	kg	X_1	1.15	2.15	3.15
2	Moisture Content	*B*	%	X_2	8	13	18

Table 2

ANOVA 2*FI* Model for the Machine Shelling Performance

Source	*Df*	M_1		M_2		M_3		*MSE*		*KBR*	
		F-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
Model	3	10.56	0.0026	0.9754	0.4462	88.46	<0.001	12.06	0.0017	0.4715	0.7096
A-Feed mass	1	5.15	0.0495	0.0381	0.8495	261.86	<0.001	4.38	0.06578	0.3164	0.5875
B-Moisture content	1	23.82	0.0009	2.86	0.1252	3.15	0.1096	0.1737	0.6866	0.5729	0.4684
AB	1	2.71	0.1342	0.0303	0.8656	0.3586	0.5641	–	–	0.5252	0.4871
Lack of Fit	5	1.18	0.4503	–	–	14.13	0.0119	0.7628	0.6206	0.8729	0.5682
Pure Error	4	–	–	–	–	–	–	–	–	–	–
Cor. Total	12	–	–	–	–	–	–	–	–	–	–

Table 1 shows each of the corn-cobs shelling procedure for the generated 13 runs coded at X_1, X_2 and X_3 values of the independent variables (–1, 0 and 1) used which represents the lowest, medium and highest levels of interaction and 6 dependent response factors, respectively, for the performance evaluation of the corn-cob shelling machine.

2.3.2. Data analysis. The central composite design (CCD) rotatable randomized was utilized to generate 13 experimental processes for the investigation. Surface Response Method (RSM) was applied to enhance the performance of the shelling machine, and validated it using desirability plots that will improve the shelling efficiency of the corn-cob Sheller. A sequential sum of squares for two variable factorial interactions (*2FI*) regression model design (*AB* and *BC*) for the interactions of the independent variables and dependent responses were used which can be presented in the general form as shown in Equation (3) [25, 26]. The data obtained from the experiment were developed with the aid of Response Surface Methodology (RSM) contour plotting to indicate levels of interactions in 3-dimessinal perspective. The results of the performance of the study were then subjected to Analysis of Variance (ANOVA). Furthermore, statistical significance was verified with the *F*-test and adequate precision ratio while means were separated at $p \leq 0.05$ level of significance to verify the adequacy of the fitted model. Reliability of regression model was confirmed with the confidence of correlation (R), coefficient of determination (Aadj-R^2) and lack of fit test. However, Desirable plots were employed to validate the optimal run of response surface methodology (RSM) expressed in Equation (6) [25, 26].

$$Y = \beta_o + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta_{ij} X_i X_j, \quad (6)$$

where Y – predicted response; β_o – constant coefficient; $\sum_{i=1}^{2}\beta_i$ – summation of coefficient of linear terms; $\sum_{i=1}^{2}\beta_{ii}$ – summation of quadratic terms; $\sum_{i=1}^{2}\sum_{j=i+1}^{2}\beta_{ij}$ – summation of interaction coefficient terms; X_i and X_j – coded variables; β_i and β_{ij} – first-order and interactive coefficients, respectively; i and j – index numbers of factors.

2.3.3. Experimental procedure. The dried-on farm samples of corn-cobs with initial 23.8 % MC_{db} were further oven dried in the laboratory until the stipulated moisture content for the purpose of this study to 8, 13 and 18 % MC_{db} using oven dry International Seed Testing Association method for determining the moisture content for seeds, respectively. The samples were selected in triplicates for the shelling operations with the machine maize shelling machine shaft speed power by a 1 hp motor operating at 1440 rpm. The mass of the corn-cobs were determined using electronic digital sensitive scale, model: Camry EK 5055 with a standard error of 0.001 mm in measured in triplicates before drying and after drying to determine final moisture content. The dried samples were shelled using the designed and developed maize shelling machine.

The maize Sheller machine utilized for this experiment consists of shelling chamber equipped the spiked shelling shaft made of mild steel. The maize shelling machine performance characteristics (dependent factors) were measured in thirteen (13) experimental processes involving; masses of shelled and unshelled, damaged maize grains measured in kilograms and machine shelling efficiency and grain breakage ratio percentages. Surface response methodology was employed to optimize the experimental data with moisture content of the moisture content, mass of the corn-cobs and the time taken by the machine to shell as the independent variables. The maize shelling machine was fed at a rate mass of corn-cob; 3.15, 2.15 and 1.15 kg respectively per time (*s*). Through put time was used to determine the time it took each fed mass of corn-cob to go through the machine for the shelling process.

3. Results and Discussion

The effect of variation in the machine shelling efficacy of the evaluated fabricated machine resulted from the varied fed masses, moisture content percentage (% MC_{db}) of the corn-cobs and the time taken for the shelling operation and a second order poly-nominal equation were fitted with data from the experiment.

3.1. Performance evaluation results. The performance evaluation results of thirteen (13) experimental processes (runs) of the maize shelling machine was based on the interaction between two independent variables, feed mass of corn-cobs, moisture content percentage dry basis (% MC_{db}) of corn-cobs at three levels whilst, corresponding dependent responses included: mass of un-shelled maize grains removed from the corn-cobs and weighed, mass damaged maize grains, mass of shelled grains, respectively, as well as the shelling efficiency percentage and grain breakage ratio shown in Table 3. It also reveals that the corn-cobs, at a constant moisture content percentage dry base of 8 % (% MC_{db}) had the highest shelling efficiency of 97.77 % achieved with the feed rates of the corn-cobs 3.15 kg, yielding a damaged grains 0.05 kg and 49.92 % grains breakage ratio by the maize shelling machine. This was closely followed by 13.8 % MC_{db}, 2.15 kg feed rate, achieving 91.16 % shelling efficiency, damaged 0.09 % and grains breakage ratio of 48.92 %, while 18 % MC_{db}, 1.15 kg feed rate yielded a machine shelling efficiency of 86.96 % damaged grains of 0.15 kg and grains breakage ratio of 34.58 %. Similar to the results of [27] study which indicated that increasing the moisture content increased both the grain breakage and unshelled grain, but decreased shelling capacity and shelling efficiency, respectively, of the Sheller. The shelling force required to detach maize grains from the unshelled cob also depended on the grain moisture content and cob size which is in close accordance with the study of [16]. It was observed that moisture content and cob size significantly affected shelling efficiency and capacity of the Sheller, as well as the grain breakage ratio and unshelled grain off the cobs during the shelling process.

In addition, the statistical analysis obtained from the results revealed that the mass of samples tested across the moisture contents % MC_{db} for: un-shelled grains and shelled grains were significantly different; meanwhile, these differences were not significant with respect to damaged grains and shelling time. Therefore, the results obtained from this study indicated that, at moisture content percentage of corn-cobs above 8 % MC_{db} at all feed masses of 1.15, 2.15 and 3.15 kg of the corn-cobs introduced into the shelling machine may not necessarily add to the machine optimum shelling efficiency, or minimize the rate of damaged grains and breakage grains, unlike the work of [28] on a local corn Sheller recorded results of machine shelling efficiency, grains damage, broken corn, being, 88.71; 1.53; 3.27 %, respectively.

Table 3

Fabricated maize shelling machine performance

FM (kg)	*MC* (%)	M_1 (kg)	M_2 (kg)	M_3 (kg)	*MSE* (%)	*KBK* (%)	Time (s)
3.15	8	0.07	0.05	3.08	97.77	49.92	5
2.15	8	0.1	0.04	2.05	95.35	49.41	5
1.15	8	0.06	0.03	1.09	94.78	48.48	5
3.15	13	0.22	0.07	2.93	93.03	48.62	5
2.15	13	0.19	0.09	1.96	91.16	48.92	5
1.15	13	0.12	0.08	1.03	89.57	49.78	5
3.15	18	0.37	0.05	2.78	88.25	46.69	5
2.15	18	0.26	0.13	1.89	87.91	33.44	5
1.15	18	0.15	0.11	1.00	86.96	34.58	5
3.15	8	0.18	0.06	2.97	94.29	33.19	6
2.15	8	0.14	0.04	2.01	93.49	33.13	6
1.15	8	0.13	0.02	1.02	88.69	32.09	6
3.15	13	0.25	0.05	2.9	92.06	32.63	6
2.15	13	0.28	0.09	1.87	86.97	32.34	6
1.15	13	0.17	0.17	0.98	85.23	35.93	6
3.15	18	0.42	0.09	2.73	86.66	32.26	6
2.15	18	0.34	0.13	1.81	84.186	33.39	6
1.15	18	0.19	0.04	0.96	83.47	32.57	6

Notes: M_1 – mass of unshelled maize grains removed from cob (kg); M_2 – mass of damaged maize grains (kg); M_3 – mass of shelled maize grains (kg); *MSE* – machine shelling efficiency (%); *GBR* – Grains Breakage Ratio (%)

It was observed that at a constant feed weight and an increase in moisture content of the corn cobs, there was a decrease in the shelling efficiency of the machine. This resulted from the fact that at higher moisture content grains cobs are soft (unyielding), therefore difficult to shell. This result is in agreement with the findings of [29] that observed that decrease in grain (cob) moisture content lead to increase in machine productivity. This occurred because of the low pressure exerted on the grain in the shelling (threshing) chamber brought about increase in machine productivity with the decrease in grain moisture content. These results are consistent with the results of [16] that stated that high moisture content of the maize grain cobs leads to decrease in shelling ability of maize.

3.2. Shelling efficiency of the fabricated maize shelling machine. The actual maximum shelling efficiency of 97.78 % occurred at corresponding independent variables moisture content 8 % and feed mass of 3.15 kg, damaged grains 0.05 kg and unshelled grains off the corn-cob 0.07 kg are as presented in Table 3, respectively. These results are unlike the results of [15, 16] that showed lowered shelling efficiency, grain damage percentage, breakage of grain, respectively, due to increase in moisture content of grains. Whilst ANOVA result indicated in Table 2 revealed *2FI* regression model equation and terms were significantly different at $p \leq 0.05$. Consequently, moisture content effectuated to a greater extent to the degree of significance among the factors with respect to the machine shelling efficacy. *AB* is interaction between feed masses and moisture content terms as expressed in Table 2 [27] that correlated two sets of moisture content (between 16–20 % and 12–16 %) and three statuses of cob sizes (less than 30 mm, 30–40 mm, and greater than 40 mm in diameters). The results of this study presented a shelling force required for detaching maize grains from the cobs depends largely on the amount of moisture present in the grains and the cob size. These results are in close agreement with the findings of [29, 30], where it was found that lower moisture content yielded higher machine capacity and shelling efficiency with minimum percent grain breakage ratio. In these studies, both cob size and moisture content significantly effectuated shelling capacity shelling efficacy of the machine, as well as un-shelled grains remaining on the corn-cobs and the grain breakage.

Increase in the amount of moisture contained in the corn-cobs and grains elevated both the grain breakage ratio and un-shelled grain still on the cobs, but, brought a decreased in machine shelling capacity and efficiency, respectively. This is also comparable to the work of [28] that studied adjusted threshing clearance cylinders of the maize shelling machine and three maize grain moisture content levels. It was observed there that lower ranged moisture content turned out to be significantly higher in machine efficiency, capacity and shelled grains, but lower grain breakage ratio and un-shelled grain (still on the cobs) compare to other higher moisture content ranges in the experimental parameters observed. The results obtained is also in agreement with [18] performance evaluation of a maize Sheller which illustrated that the mass of wholly shelled maize grains (190±160 kg) was greater than the damaged grains (6.3±4 kg) at the machine shelling capacity and efficiency at 10, 15, and 20 % MC_{db} are 315, 298 and 264 kg/h and 99.02, 94.50 and 88.20 %, consecutively. The grain breakage percentages were calculated to be 1.77, 3.64, and 5.02 % for 10, 15, and 20 % MC_{db}.

Additionally, the results from this work are akin to the postulates of [31] findings of efficiency, shelling performance indexes, total grain losses, and throughput capacity of 95.48 %, 91.55 %, 2.96 %, and 623.99 kg/h, accordingly, at 13 % MC_{db} and 886 rpm shelling speed for a developed maize shelling machine.

The experimental response (machine shelling efficiency) as a function of the shelling process with conditions such as Feed Mass (*A*) and Moisture Content of corn-cob (*B*) are as presented in Table 2 and expressed in Fig. 2. The value of shelling efficiency percentage from the evaluation data was within the range of 83.48–97.78 %. ANOVA results using the *2FI* model and Regression analysis are as presented in Tables 2, 4, respectively. Alongside, the *F*-values model response was 7.78 and *p*-value 0.00891 indicating that the simulation used for the experiment is significant at $p \leq 0.05$. Table 4 shows the regression coefficients for responses of the corn-cobs fit statistics.

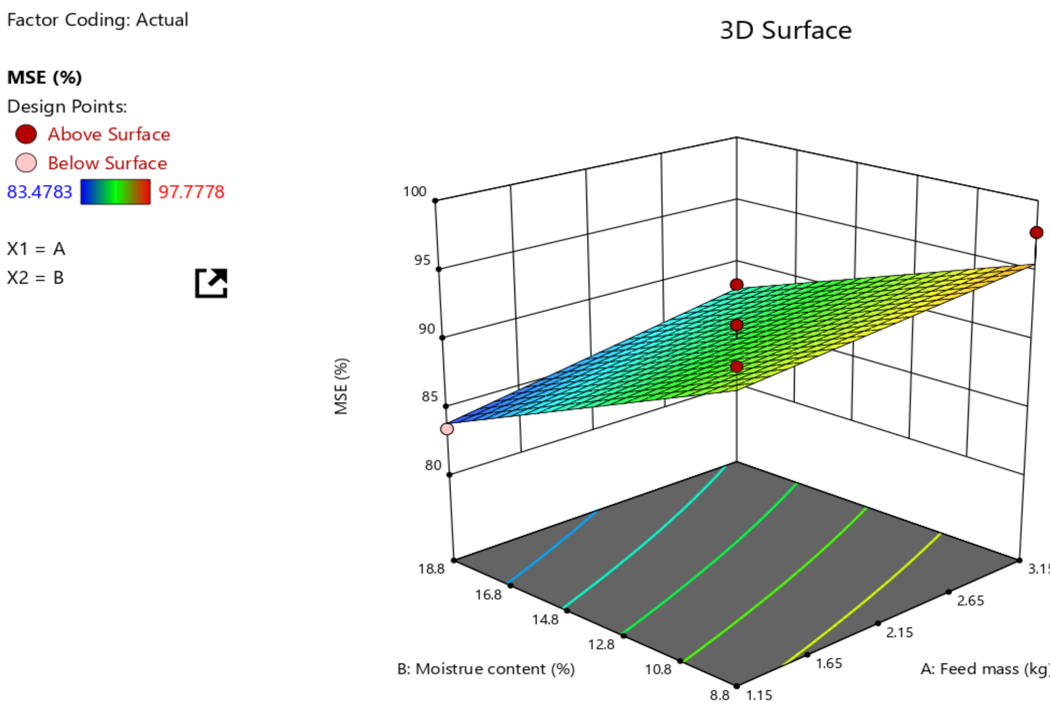


Fig. 2. Surface response 3D plot effect of moisture contents and feed masses on machine shelling efficiency

Table 4

Regression coefficients for responses of the corn-cobs fit statistics

Std. Dev.	M_1	M_2	M_3	*MSE*	*KBR*
	0.0516	0.0287	0.1420	2.14	8.76
Mean	0.2031	0.0723	1.95	90.15	42.62
C.V. (%)	25.43	39.71	7.29	2.37	20.55
R^2	0.7787	0.2454	0.9672	0.8008	0.1358
Adjusted R^2	0.7050	–0.0062	0.9563	0.7344	–0.1522
Predicted R^2	0.4660	–2.0603	0.8786	0.5525	–0.7135
Adequate Precision	10.4391	3.0476	29.1726	10.3641	2.2713

Notes: *Std. Dev.* – Standard Deviation; *C.V.* – Coefficient of Variance

However, the Models *F*-value of 12.06 suggest the design used for assessing the performance of the maize shelling machine is significant, although there is a 0.17 % possibility that an *F*-value as high as this may have occurred due to noise that is other variables not considered in this study. However, statistical *p*-values <0.0500 indicate design parameters used for the study are significant which means that *B* terms are significant design representation. It is notable to indicate that values >0.1000 shows that the model parameters are not significant terms. If insignificant model terms surfaced (that is those not counted or required to support hierarchy), simulation reduction may be required. The Lack of Fit *F*-value of 0.76 in the statistical of the data gotten for the study implies that the Lack of Fit is not significantly relative to pure error. There exists a 62.06 % possibility that a Lack of Fit having an *F*-value that is this high could happened as a result of noise. A not-significant lack of fit is a good indication that the model adopted for the study is a fit model which is desirable.

The Predicted R^2 value of 0.5525 obtained from the performance evaluation data of the maize shelling machine reasonably agrees with the Adjusted R^2 of 0.7344 calculated to be less than 0.2 which indicated that the designed model utilized for predicting shelling efficiency level of the machine is fit and reliable. In design of experiment, Adequate Precision is used to measure the level of noise ratio to the variables used. An indicator ratio above 4 is desirable. A ratio of 10.3641 gotten from this study implies an adequate signal. Consequently, it is safe to say that the model adopted to navigate the design space of the experiment. However, adequacy of the simulation of the study was further analyzed by the coefficient of determination (R^2) and was set up as 0.8008 (Table 4) values of coefficient of determination obtained correspond with the response variables which indicated that the developed model for the maize shelling efficiency correlates to the predicted values which therefore adequately justified the highest shelling efficiency of 97.77 % among the total variation obtained from the study. The regression equation which describes the effects of other variables on shelling efficiency in observing the actual values of the variables calculated in Equation (7), which further shows the level desirability (97.77 %) of the regression for the machine shelling efficiency:

$$MSE=+90.15+1.158A-4.025B+0.4451AB, \quad (7)$$

where *MSE* – Machine Shelling Efficiency; *A* – Feed Mass and *B* – Moisture Content of corn-cobs are linear terms (first-order); 97.77 % – intercept coefficient (offset); *AB* indicate interaction terms.

Fig. 2 of Response surface plots of 3D shows the predicted optimum shelling efficiency to be 97.77 % which occurred at the moisture content 8 % of the corn-cobs and machine feed mass of 5 kg. However, comparing the values of the predicted machine shelling percentage with that of the actual experimental values, it is well established that the optimum machine shelling efficiency of 97.77 % occurred at the machine shelling process of 8 % MC_{db}, machine feed mass 5 kg, followed by the result at constant moisture content 13.8 % MC_{db}, where the machine recorded a maximum shelling efficiency of 94.29 % at a feed mass of 3.15 kg damaged grains 0.05 kg and un-shelled mass of 0.25 kg of Lastly followed by 92.06 % machine shelling efficiency at a feed rate of 2.15 kg and the least machine shelling efficiency of 86.97 % was recorded at the feed rate of 1.15 kg, shelling time remains between 5 and 6 seconds.

3.3. Grains breakage ratio percentage of corn-cobs. The optimum grains breakage ratio (*GBR*) % of 49.92026, 2.63274 and 86.95652 % occurred at the experimental shelling of the corn-cobs with corresponding independent variables of 8, 13 and 18 % MC_{db}, feed mass 3.15, 2.15 and 1.15 kg and shelling time occurred between 5 and 6 seconds, respectively, as shown in Table 3 and indicated in (Fig. 3). This result is similar to the observation of the study of [31] on breakage susceptibility and hardness of three yellow dent corn hybrids where kernels were separated by size and shape categories with equilibrated moisture content of the corn cobs.

A Model *F*-value of 0.68 signals the model of the design of experiment DOE is not significantly related to the factors not considered (noise). Nevertheless, a 70.96 % possibility exist that an *F*-value as high as this could have occurred due to other variables (noise) not used to evaluate in the performance of the corn Sheller ANOVA response (2*FI* model) grain breakage ratio (*GBR*) during processing. However, $P<0.05$ indicates model terms are significantly related. In this study, there is no significant model term, model in the ANOVA response 2*FI* model of grain breakage ratio (*GBR*) of the corn-cob shelling machine is due to noise. The Lack of Fit's *F*-value of 0.87 translated to mean that the Lack of Fit is not significantly related to pure error, but a 56.82 % possibility of a Lack of Fit *F*-value as high as this may have occurred resulting from noise. Non-significant lack of fit value is a desirable result.

In addition, adequacy of model used was further analyzed applying coefficient of determination (R^2) and result gotten was 0.21378 (Table 4) fit Statistics regression analysis. Adequate precision measures the signal to noise ratio, however a ratio greater than 4 is desirable, and the fit statistics ratio of –1.3612 results indicated an adequate signal which implied that the model used in analyzing the grains breakage ratio percentage can be used to navigate the design space of the study as shown in Table 4 calculated using Equation (5).

$$GBR=+42.62+1.74A-2.34B+3.17AB. \quad (5)$$

However, the equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as –1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. Fig. 3 shows Surface Response 3D plot effect of moisture contents and feed masses of grain on grain breakage ratio.

3.4. Optimization of variables using desirability model. This desirability solution of the optimum interactive step indicated optimum drying variables and responses to be 3.15 kg, 2.15 and 1.15 kg; shelling time 5, 6 and 7 seconds; 97.78 %, 92.06 % and 89.77 % shelling efficiency for the corn-cob samples for feed rate, moisture content and shaft speed with responses; un-shelled, damage and shelled grains along with the machine shelling efficiency and grains breakage ratio, respectively. However (Fig. 4) of desirability plots indicated optimum responses as shelled mass of grains (3.08 kg), unshelled mass (0.07 kg), damage mass (0.05 kg), grains breakage ratio (1.59 %) and machine shelled efficiency (93.34 %).

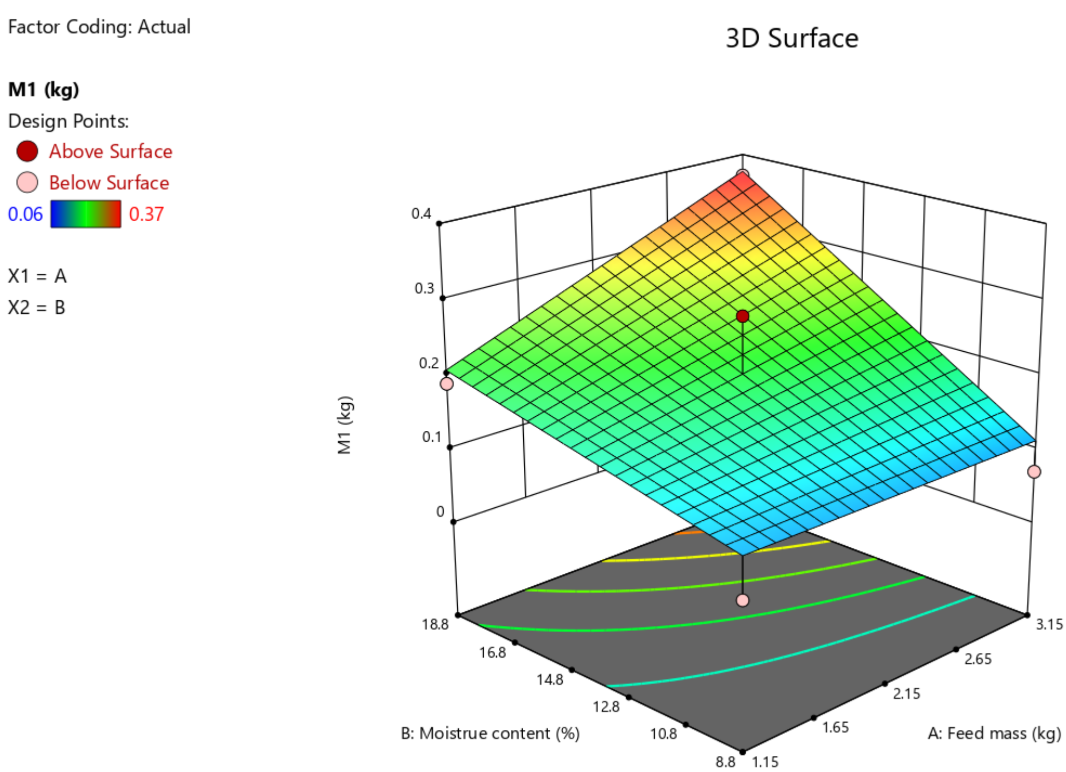


Fig. 3. Surface Response 3D plot effect of moisture contents and feed masses on grain breakage ratio

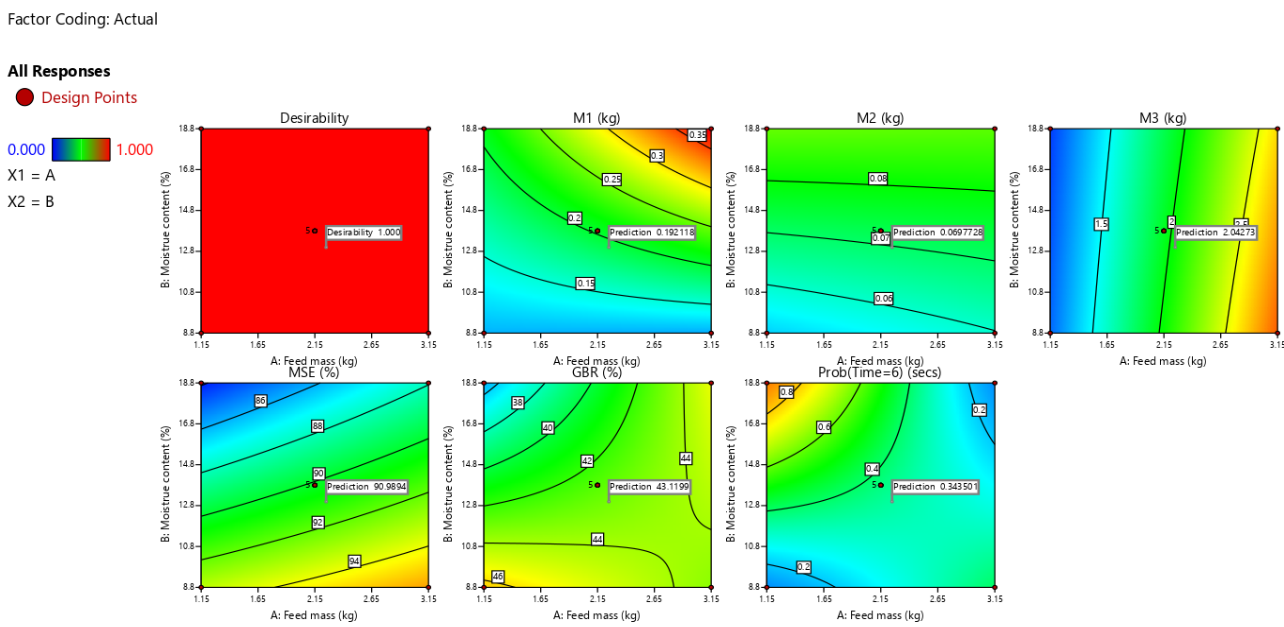


Fig. 4. Desirability plot at optimum independent variables showing optimum M_1, M_2, M_3, *MSE* and *GBR* of 0.07 kg, 0.05 kg, 3.08 kg, 97.77 %, and 49.92 %, respectively, at desirability of 1: M_1 – mass of unshelled maize grains removed from cob (kg); M_2 – mass of damaged maize grains (kg); M_3 – mass of shelled maize grains (kg); *MSE* – machine shelling efficiency (%) and *GBR* – grain breakage ratio (%)

These desirable variable values correspond to desirability solution values and closer to the actual variables deduced from the experimental Table 3. Hence, RSM plots predicted values and desirability solution values validated experimental operations of independent factors: moisture content percentage (% MC_{db}) corn-cobs, machine feed mass and shelling 8 %, 3.15 kg; 13.8 %, 2.15 kg, to be the optimum shelling operation for corn-cobs samples, respectively, possessing optimum responses of shelled mass, un-shelled mass, damage mass, grains breakage ratio and machine shelling efficiency, respectively. However, these results were obtained between the machine shelling process time of 5 and 6 seconds.

4. Conclusions

Based on the findings from this study, it can be concluded that moisture content percentage dry basis of the corn grain cobs samples as a factor of evaluation, influenced the shelling efficiency and performance of the maize shelling machine. 2*FI* regression model was used to predict the shelling efficiency. The optimum machine shelling efficiency of 97.77 % occurred at the machine shelling process of lowest moisture of corn-cobs at 8 % MC_{db} and machine feed mass 3.15 kg, yielding damaged grains 0.05 kg and 49.92 % grains breakage ratio by the maize shelling machine all in 5 seconds. At lower machine shelling time, feed mass, and moisture content percentage (8 % MC_{db}) of the corn cobs, higher shelled grains off the corn-cobs were recorded with reduced damaged grains, indicating higher shelling efficiency of the fabricated corn-cob Sheller machine. The machine is able to remove the drudgery parts of operation involving manual shelling within a short period of time.

It is thus recommended to further study the following: development of portable corn shelling machine fed at single corn cob per time and effects of lower 8 % MC_{db} moisture content of corn on the efficiency of corn shelling machine.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The data used for the study were generated from the study and are available from the authors upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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