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Research Article
Total Efficiency of Moringa Seed Shelling Machine as Affected by Some Process Parameters: Optimization Approach

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Abstract
Background and Objective: *Moringa oleifera* is a non-timber forest plant which produces oil bearing seeds. This study presents application of response surface methodology in optimizing the total efficiency of moringa seed shelling machine. **Materials and Methods:** The total efficiency of the moringa seed shelling machine was optimized applying response surface methodology. The independent variables were seed condition (moisture content), operation parameters (cylinder-concave clearance, cylinder speed and feed rate) and design parameter (cylinder bar inclination) while the dependent variable was total efficiency which is the overall efficiency of the machine. Central Composite Rotatable Design (CCRD) of second order polynomial model was applied in the experimental design having five factors at five levels. **Results:** Optimum values obtained for moisture content, cylinder concave clearance, cylinder speed, feed rate and cylinder bar inclination were 11.8%, 7.83 mm, 290.41 rpm, 30 kg h^{-1} and 40.0°, respectively. The total efficiency was found to have an optimum value of 75.3% with desirability value of 0.76 which indicated the nearness of the response to the predicted values and adequacy of models established in describing the observed values. **Conclusion:** The optimization of moringa seed shelling machine showed the optimal processing conditions for moringa kernel recovery.

Key words: Machine efficiency, independent variables and optimization

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Moringa oleifera is a fast growing shrub which originated from Agra and Oudh in north western region of India. It is a non-toxic natural organic polymer [1-3]. There are 14 species of moringa trees in the family of moringaceae. *Moringa oleifera* is the most popular species of all the species of moringa plant. The plant produces fruit having the shape of a drumstick which contains the seeds. Moringa seed is triangular in shape with papery wings along its ridges. Moringa kernel has white to creamy colour and nearly spherical in shape[4-6]. Process optimization is a method of combining two or more variables in production line to obtain the best desired outcome. Many researchers have worked on modeling and optimization of unit operations in food and industrial crops.

Optimization of unit operations in crop processing is usually achieved through the use of statistical tool such as Response Surface Methodology (RSM). Response surface methodology is a collection of mathematical and statistical techniques that are useful for modeling and analysis in applications where a response of interest is influenced by several variables and the objective is to optimize this response[7]. Processing machines for moringa fruit include decorticators for removal of pods, shelling machine for shell removal as well as oil expeller for mechanical extraction of oil. There have been researches on development and improvement of processing machines for moringa produce. Development of processing machines for moringa seed is necessary in deriving values from the seed. Processing of agricultural materials such as moringa seed is aimed at presenting moringa seeds and kernels in an acceptable state for use. Conversely, moringa seed processing is costly[8] when done manually, this should be relatively low in comparison to the asking price of the product. Moringa plant is a highly versatile plant which is of great economic importance. Processing machines with high performance cannot be dispensed with if processed moringa seed is to command an acceptable price in the market. Contemporarily, manual shelling of moringa seed goes at the rate of N679.50 per kilogram ($1.51 per kg). This is quite high. This could be made up for, if by-products or other components of moringa seed could be removed efficiently and converted into useful products for other use. These include extender in animal feed and fillers in briquette and bio-composite boards. Price[6] reported a moringa seed shelling machine using disc mechanism for shelling with a blower being incorporated into it.

Moreover, shelling machines have been developed for many agricultural products, these include melon[9-15], dika nut[16], shea nut[17], cotton seed[18], cashew nut[19,20], castor seed[21,22], mango seed[23], jatropha seed[24-28], maize[29,30]. Shelling is a very important primary unit operation in agricultural processing as it prepares crops for further operations such as cooking, steaming, size reduction, roasting, oil extraction and so on. It also adds value to agricultural materials by improving their quality[31]. Most oil bearing seeds are usually shelled before oil extraction in order to enhance oil extraction from the crop as well as reducing specific mechanical energy in an extractor. It has also been reported that removal of hulls or shells of some seed tends to reduce the wax content of oil during oil extraction thus lowering the turbidity of such oil[32]. Moreover, shelling also enhances reduction in further refinement of oil after extraction and thus making it to be available for immediate use. These research findings suggested necessity for the development of moringa seed shelling machine. Having established that moringa kernel and shell are potential industrial and pharmaceutical feedstock, this necessitates the optimization of moringa seed shelling machine. Therefore, this study presents application of response surface methodology in optimizing the machine efficiency of moringa seed shelling machine as related to seed condition (moisture content), operating conditions (viz. cylinder-concave clearance, feed rate and cylinder speed) and design parameter (cylinder bar inclination).

MATERIALS AND METHODS

Sample preparation: The moringa seed used in this study was purchased in Ibadan from Association of Moringa Farmers (AMF). The seeds were cleaned to remove all the undesirable materials such as stone, pods, leaves and so on. The initial moisture content of moringa seed was found to be 10.75% (w.b.) using[33] standard for oil bearing seeds. Samples of the moringa seed were moistened using calculated quantity of water to condition them to the desired moisture content using Eq. 1. The seeds were sealed in some polythene bags and left for 3 h so as to enhance moisture stability and uniform distribution of moisture within the seeds[34,35]:

$$Q = A \frac{b - a}{100 - b} \tag{1}$$

where, Q is quantity of water added to the moringa seed in g, A is mass of moringa seed in g, a is initial moisture content of moringa seed in % and b is final moisture content of moringa seed in %.

Optimization using response surface methodology: The process optimization of the machine efficiency was carried

Table 1: Experimental design for moringa seed shelling

	Levels				
Factors	1	2	3	4	5
Moisture content (%)	10.75	11.75	12.75	13.75	14.75
Clearance (mm)	5.00	6.00	7.00	8.00	9.00
Cylinder speed (rpm)	200.00	240.00	280.00	320.00	360.00
Feed rate (kg h^{-1})	12.00	18.00	24.00	30.00	36.00
Cylinder bar inclination (°)	30.00	40.00	50.00	60.00	70.00

Fig. 1: Moringa seeds shelling machine

out using a moringa seed shelling machine shown in Fig. 1. Response Surface Methodology (RSM) was adopted for the optimization process. The experimental plan was generated using a statistical package such as Design-expert 10 by applying central composite rotatable design with three replications for each run. The machine efficiency i.e., the overall efficiency of the moringa seed shelling machine and the independent parameters were analyzed using two factor interaction and quadratic models. The analysis of variance was carried out to determine the adequacy of the models developed. One hundred grams of moringa seeds was used for each test[36,37]. Table 1 shows the experimental design for the shelling process. Five parameters were considered and these included moisture content, cylinder-concave clearance, cylinder speed, feed rate and cylinder bar inclination. According to literature, all these independent factors have been found to relatively contribute to seed shelling process[38-41]. The dependent factor considered was machine efficiency which is the overall efficiency of the moringa seed shelling machine. The experimental design adopted was five factors, five levels Central Composite Rotatable Design (CCRD) as shown in Table 1.

Central composite rotatable design comprises three major design points which include axial, central and factorial points. Half fraction CCRD was adopted for the experimental design[7]. The total number of experimental runs is given as where 'k' is the number of independent parameters and 'c' is the centre point. The experimental design plan comprises of 16 factorial points, 10 axial points and 6 replications at the centre point. In the optimization process, 32 runs were generated in all as shown in Table 2. Some samples of moringa seed were adjusted to moisture levels of 10.75, 11.75, 12.75, 13.75 and 14.75%. The test was also carried out at five cylinder-bar inclination levels (30, 40, 50, 60 and 70°). Each cylinder bar inclination level was replicated concurrently with other factors three times for each run.

Determination of machine efficiency: The performance evaluation of the moringa seed shelling machine was carried out by calculating its machine efficiency. The independent variables include seed condition (viz. moisture content), operation parameters (viz. cylinder-concave clearance, cylinder speed and feed rate) and design parameter (viz. cylinder bar inclination). Machine efficiency is the overall efficiency of the moringa seed shelling machine, it depicts the effectiveness of the machine in recovering moringa whole kernel with little or no damage. The machine efficiency was calculated using the equations used by Fadele and Aremu[42], Atiku *et al.*[43] and Pradhan *et al.*[38] as shown in Eq. 2 and 3:

$$SE = \left[1 - \frac{M_1 + M_2}{M_o}\right] \times 100 \quad (2)$$

$$ME = SE \times \frac{M_1}{M_1 + M_2} \quad (3)$$

Table 2: Plans of experimental design for moringa seed shelling

Runs	FR (kg h^{-1})	CS (rpm)	MC (%)	CBI(°)	C (mm)	ME (%)
1	18	240	11.75	60	6	61.69
2	24	280	12.75	40	5	59.63
3	24	360	12.75	50	7	54.75
4	30	240	11.75	50	8	69.80
5	24	280	12.75	50	7	67.54
6	24	280	12.75	40	7	61.24
7	24	280	12.75	40	7	69.74
8	24	280	12.75	50	7	70.08
9	24	200	12.75	40	7	80.40
10	24	280	14.75	30	7	53.20
11	18	240	13.75	50	6	70.91
12	24	280	12.75	50	7	71.38
13	18	320	11.75	60	6	45.83
14	30	320	11.75	50	6	54.62
15	30	240	11.75	40	6	68.67
16	18	240	13.75	50	8	76.62
17	30	320	13.75	40	6	58.95
18	30	320	11.75	60	8	59.11
19	24	280	10.75	50	7	61.71
20	18	320	11.75	60	8	59.07
21	12	280	12.75	60	7	60.28
22	18	320	13.75	50	8	63.14
23	18	320	13.75	50	6	56.82
24	24	280	12.75	60	7	60.63
25	24	280	12.75	40	9	74.71
26	30	240	13.75	50	8	80.36
27	18	240	11.75	70	8	65.72
28	36	280	12.75	50	7	72.80
29	30	320	13.75	60	8	51.46
30	24	280	12.75	40	7	73.02
31	24	280	12.75	60	7	66.68
32	30	240	13.75	50	6	69.74

FR: feed rate, CS: Cylinder speed, MC: Moisture content, CBI: Cylinder bar inclination, C: Clearance, WKR: Whole kernel recovered, BKR: Broken kernel recovered, SE: Separation efficiency, USR: Unshelled seed recovered, ME: Machine efficiency, TKR: Total kernel recovered, C: Capacity

Where:

SE = Shelling efficiency
ME = Machine efficiency
M_1 = Mass of unshelled seed
M_2 = Mass of partially shelled seed
M_0 = Mass of seed introduced into the machine

RESULTS AND DISCUSSION

Effects of seed, operation and design parameters on machine efficiency: The surface diagram in Fig. 2 showed the relationship between machine efficiency and the independent parameters (clearance and cylinder speed) at $p<0.05$ significance level. Machine efficiency increased with increase in the clearance while it decreased with increase in cylinder speed. This is similar to the study of Sobowale *et al.*[15] reported for melon seed shelling. The increase of the machine efficiency with increase in clearance could be due to less damage to the moringa kernel as a result of increase space between the

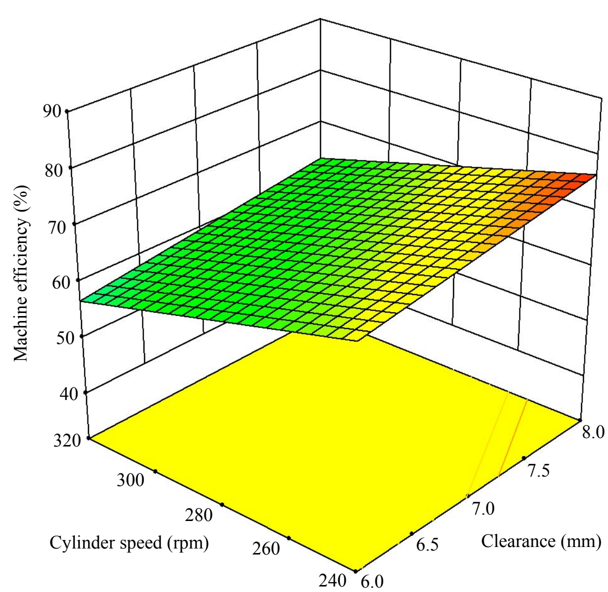

Fig. 2: Machine efficiency against cylinder speed and clearance

Table 3: ANOVA for regression model for machine efficiency

Sources	Sum of squares	DF	Mean square	F-value	Significance level
Model	1477.79	5	295.56	10.59	<0.0001
Moisture content	4.40	1	4.40	0.16	0.6947
Clearance	230.94	1	230.94	8.28	0.0079
Cylinder speed	1053.43	1	1053.43	37.76	<0.0001
Feed rate	25.37	1	25.37	0.91	0.3491
Cylinder bar inclination	49.19	1	49.19	1.76	0.1958
Residual	725.33	26	27.90		
Lack of fit	625.48	21	29.78	1.49	0.3498
Pure error	99.86	5	19.97		
Correlation total	2203.12	31			

cylinder and screen thereby reducing the impact of the bars on the seed while machine efficiency decreased with cylinder speed as a result more damage to the moringa kernel as the cylinder speed increased. However, machine efficiency was not significantly affected by moisture content, feed rate and cylinder bar inclination.

Modeling and optimization of machine efficiency: The optimization of the moringa seed shelling process showed the optimum values of 11.79%, 7.98 mm, 249.21 rpm, 30.0 kg h^{-1} and 40.0° for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination, respectively while the response factor has an optimum value of 75.3% for the machine efficiency with desirability of 0.76. Sobowale *et al.*[15], Oriaku *et al.*[13] and Adekunle *et al.*[29] reported a maximum efficiencies of 76.3, 70 and 68%, respectively for melon seed shelling machine. Balami *et al.*[21] and Pius *et al.*[22] obtained 79.3 and 96.3% efficiencies, respectively for castor seed shelling machine, Jekayinfa and Durowoju[23] reported 91.5% shelling efficiency for mango seed shelling machine, Aremu *et al.*[26] obtained 74% shelling efficiency while Romuli *et al.*[27,28] also reported 84.6 and 98.8% efficiencies, respectively for jatropha seed shelling machine. Sharma *et al.*[34] also reported an efficiency of 74.6% for tung fruit decorticator. Gupta and Das[44] and De Figueiredo *et al.*[45] optimized the dehulling process of sunflower seed and obtained optimum machine efficiency values between 69 and 77%, respectively. The optimum value for machine efficiency of the moringa seed shelling machine agrees with the values obtained by other researchers. The results for the analysis of variance of regression model relating the machine efficiency to the independent variables are presented in Table 3. The information obtained for the ANOVA test showed the statistical significance of the regression model in Eq. 4 at 95% confidence level ($p<0.05$). The model F-value of 10.59 implies that the regression model obtained was significant. There is only a 0.01% chance that an F-value this large could occur due to noise, this means that at least one of the independent variables contributed to response observed in machine efficiency.

The F-values and corresponding p-values obtained for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination were 0.16, 8.28, 37.76, 0.91 and 1.76, 0.69, 0.0079, 0.0001, 0.35 and 0.1958, respectively. These values suggested that there are 69.0, 0.79, 0.01, 35.0 and 19.580% chances that the F-values for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination could occur due to noise. This implied that machine efficiency was significantly influenced only by clearance and cylinder speed. The model developed was significant as depicted by the F-value, this implies that at least one of the independent variables contributed to responses observed in machine efficiency. The machine efficiency was significantly influenced by clearance and cylinder speed as shown in Table 3. This showed that the effect of variation of the independent parameters on the machine efficiency was not by chances. The lack of fit was also found to be insignificant. It was established that there is only a 34.98% chance that insignificance of the lack of fit could occur due to noise.

The coefficient of determination (R^2 value) obtained was found to be 0.67 as indicated in Eq. 4. This shows that the variation in the independent variables accounts for 67% of the total variability in the machine efficiency of the moringa seed shelling machine. The predicted R^2 and adjusted R^2 values were found to be 0.45 and 0.61, respectively. The predicted R^2 is in reasonable agreement with the adjusted R^2 i.e., difference between the two is less than 0.2. The regression model was reduced with respect to the significance level of the independent parameters for model improvement as expressed in Eq. 4. The adequate precision (signal to noise ratio) of 12.45 was obtained, which is greater than 4, this shows that the model has a signal which is strong enough for optimization and can be used to navigate the design space:

$$ME = 87.359+3.195C-0.167CS \qquad (4)$$

(R^2 = 0.67, Adj. R^2 = 0.61, Pred. R^2 = 0.45, Adeq. Precision = 12.45).

Where:

ME = Machine efficiency
C = Clearance
CS = Cylinder speed
R^2 = Coefficient of determination

CONCLUSION

The optimization of the shelling process of moringa seed was carried out using a moringa seed shelling machine and the following findings were discovered about *Moringa oleifera* seed shelling process:

- The machine efficiency was significantly affected by variation in cylinder-concave clearance and cylinder speed at $p<0.05$
- The optimum values for the independent parameters were 11.84%, 7.98 mm, 249.55 rpm, 30 kg h^{-1} and 40.0° for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination while the response factor has an optimum value of 75.3% for machine efficiency
- The desirability values established for the optimization process for moringa seed shelling indicated the nearness of the response values to the predicted values and adequacy of models developed in describing the obtained data. The optimizations of moringa seed shelling process showed the best combination for the process parameters and their effects on machine efficiency of the moringa seed shelling machine

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