Optimizing The Milling Efficiency Of Hammer Mill For Maize Processing Using Response Surface Methodology (RSM)

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***Abstract*— Response surface methodology (RSM) was used to study the interaction between the factors and the response (milling efficiency) of a hammer mill. Three varieties of maize (ART/98/SW06-OB-W, ART/98/SW1 and Suwan-1-SR-Y) were used for the experiment. The moisture content (ranging from 3% to 20%) and four speeds (1200 rpm, 1400 rpm, 1800 rpm, and 2200 rpm) were selected for the machine. From the result, values of R^2 obtained for each variety was 0.63, 0.37 and 0.25 respectively. However, the result shows that the models were significant for the three varieties. The response plots also show that optimal values for milling efficiency of 82.60%, 91.24% and 92.46% were obtain for ART/98/SW06-OB-W, ART/98/SW1-*Oloyin* and Suwan-1-SR-Y respectively at a speed of 1700 rpm and moisture content 11.5%.**

Keywords— Optimizing, Milling efficiency, Mill, Maize processing, RSM

I. INTRODUCTION

The maize kernel is composed of four primary structures from a processing perspective. They are endosperm, germ, pericarp, and tip cap, making up 83%, 11%, 5%, and 1% of the maize kernel, respectively (1). The endosperm is primarily starch surrounded by a protein matrix. The germ or embryo of the maize kernel is high in fat (33.3%) in addition to enzymes and nutrients for new maize plant growth and development. The germ also contains vitamins from B complex and antioxidants such as vitamin E. The two primary methods of processing maize are referred to as "dry" and "wet" milling, with wet milling by far the most widespread. Dry milling is the process in which maize is separated into flour, grits, animal feed, beer, breakfast cereal and other food ingredients, such as corn-meal. The remaining parts of the kernel are ground and sieved into various fractions. Different products like corn starch, corn flakes and corn flour can be produced from maize seed. Maize flour is derived from grounded and desiccated seed of the maize seeds. It is whitish in colour and it is the second most produced and consumed flour after wheat flour, competing with rice flour. In Nigeria dry corn millers process corn in one of three ways -a tempering degerming process, stoneground or non-degerming process, and alkaline-cooked process (2). According to (3), the amount of usable flour after raw materials are milled is known as the 'yield' and is calculated as follows:

$$Yield\ (\%) = \frac{weight\ of\ flour}{weight\ of\ raw\ material}\ x\ 100 \qquad (1)$$

(4) used response surface methodology (RSM) to determine the optimum processing conditions that yield maximum water loss and weight reduction and minimum solid gain and water activity during osmotic dehydration of potatoes. (5) employed response surface methodology for simultaneous analysis of the effects of enzymatic treatment conditions of incubation time, incubation temperature and enzyme concentration on physical characteristics such as turbidity, clarity, viscosity, and color. (6) employed response surface methodology (RSM) to optimize the drying conditions of horse mackerel dried in a heat pump dehumidifier (HPD). This research uses response surface methodology (RSM) to study the interaction between the factors (speed and moisture content) as they affect the milling efficiency of a hammer mill.

II. MATERIALS AND METHODS

A. *Varieties of Maize*

Maize varieties {ART/98/SW06-OB-W (V1), ART/98/SW1 (V2) and Suwan-1-SR-Y (V3)} fortified with protein obtained from the Institute of Agricultural Research and Training, Moor Plantation, Ibadan were used for the experimentation.

B. *Description of the hammer mill*

The hammer mill, Figure 1 (Plate 1) was made from a steel drum containing a horizontal rotating shaft on which hammers/beaters are mounted. The hammers are free to swing on the central rotor. The rotor is spun at a high speed inside the drum while material is sucked into the hammer mill. The material is impacted by the hammer bars and is thereby shredded and expelled through screens in the drum. The rotor was improvised with sets of fan blade that blow off the material through a screen into the cyclone after being crushed. The hammer mill was powered by an electrical motor.

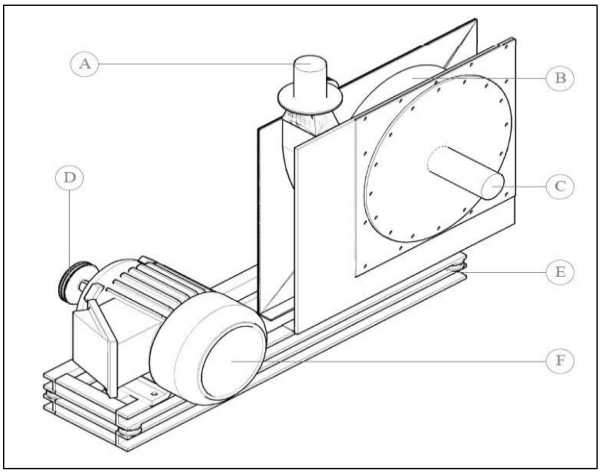

Figure 1: The hammer mill (A-Outlet to Cyclone A, B-Involute, C-Maize Inlet, D-Pulley, E-Base Support and F- Electric Motor).

C. *Experimentation*

The maize used for the experiment was roasted and passed into the hammer mill through the hopper. Mass of the material and the moisture content (ranging from 3% to 20%) was noted before passing it to the hammer mill. The hammers/beaters in the machine impacted force on the material thereby reducing its sizes and simultaneously, the hammer blade on the rotor blow off the milled material through a screen into the cyclone. Four speeds (1200 rpm, 1400 rpm, 1800 rpm, and 2200 rpm) were selected for the machine. The operation time was noted and the mass of the material retained by the hammer mill was recorded. Moisture content (MCdb) was determined using a microprocessor grain moisture meter. Milling efficiency η_m is calculated from the relationship given as:

$$\eta_m = \frac{moh}{mrh+moh} \quad (2)$$

where *moh* is equal to the mass of material obtained through the cyclone and *mrh* is equal to the

mass of material retained by the hammer mill. Response surfaces methodology (RSM) was used to examine the relationship between the factors and the evaluation parameter. This was aimed at optimizing the performance of the hammer mill. Design expert version 8.0.7.1 was used.

Plate 1: The hammer mill

III. RESULTS AND DISCUSSION

The effect of moisture content of maize and hammer speed on response (milling efficiency) were presented in Table 1. The model formed was 2FI (two factor interaction) for ART/98/SW06-OB-W and ART/98/SW1-*Oloyin* but, cubic for Suwan-1-SR-Y. The value of R^2 obtained for each variety was 0.63, 0.37 and 0.37 respectively. The response curves for the data are shown on Figures 2, 3 and 4. However, the result (Table 1) shows that the models were significant for the three varieties. There was a significant ($p \leq 0.05$) influence of the 2FI factor of hammer speed. It was observed from the statistical analysis that hammer speed had significant ($p \leq 0.05$) 2FI effect on the model (Table 2).

Table 1: Analysis of variance showed the effect of speed and moisture content as a 2FI term and linear term and interactions on the response for each variety.

Source	**Df**	**Sum of Squares**	**Mean Square**	**F Value**	**P- value**	
(a) ART/98/SW06-OB-W						
Model	3	4118.77	1372.92	25.59	< 0.0001	significant
A-MC	1	483.13	483.13	9.01	0.0046	
B-speed	1	2388.77	2388.77	44.53	< 0.0001	
AB	1	288.75	288.75	5.38	0.0254	
Residual	41	2199.31	53.64			
Cor Total	44	6318.08				
R^2	0.63	2FI				
(b) ART/98/SW1-*Oloyin*						
Model	3	668.15	222.72	9.68	< 0.0001	significant
A-MC	1	142.07	142.07	6.18	0.0171	
B-speed	1	297.44	297.44	12.93	0.0009	
AB	1	193.42	193.42	8.41	0.0060	
Residual	41	943.24	23.01			
Cor Total	44	1611.39				
R^2	0.37	2FI				
(c) Suwan-1-SR-Y						
Model	9	277.20	30.80	3.99	0.0014	significant
A-MC	1	6.66	6.66	0.86	0.3594	
B-speed	1	34.32	34.32	4.44	0.0422	
AB	1	10.74	10.74	1.39	0.2462	
A^2	1	2.56	2.56	0.33	0.5685	
B^2	1	12.05	12.05	1.56	0.2199	
A^2B	1	9.89	9.89	1.28	0.2655	
AB^2	1	3.40	3.40	0.44	0.5116	
A^3	1	1.88	1.88	0.24	0.6248	
B^3	1	32.31	32.31	4.18	0.0484	
Residual	35	270.27	7.72			
Cor Total	44	547.47				
R^2	0.37	Cubic				

p- Value < 0.05

Table 2: Regression models and coefficient of determination (R^2) of the effect of factors on the milling efficiency of the hammer mill

Variety	**Model Equation**	**Model**	R^2
ART/98/SW5-OB-W	M eff = 95.91437+1.87036*Mc* -2.44821E-003*S* -1.56830E-003*McS*	2FI	0.63
ART/98/SW1-*Oloyin*	M eff = 85.01575 +1.53430*Mc* +5.98689E-003*S* -1.10496E-003*McS*	2FI	0.37
Suwan-1-SR-Y	M eff = -5.18601 -8.10653*Mc* +0.26309*S* +5.06910E-003*McS* +0.29792Mc^2 -1.85968E-004 S^2 -1.04091E-004Mc^2S -6.46887E-007McS^2 -2.93937E-003Mc^3 +3.90672E-008S^3	Cubic	0.37

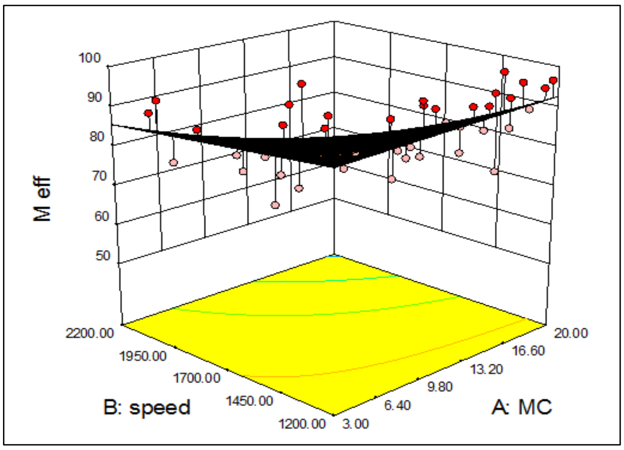

Figure 2: Response surface plot of the effect of speed (rpm) and moisture content (%) on the milling efficiency (%) of hammer mill for ART/98/SW06-OB-W

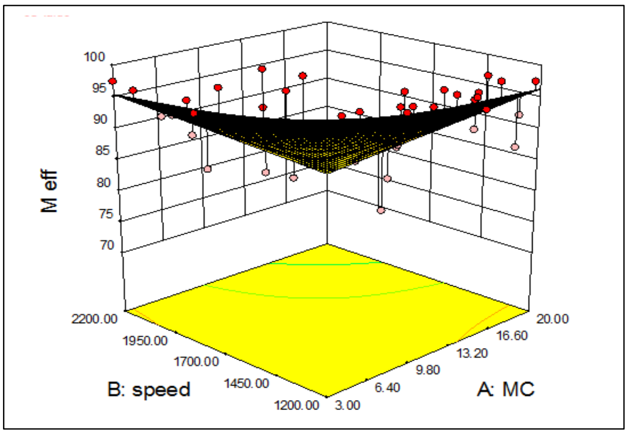

Figure 3: Response surface plot of the effect of speed (rpm) and moisture content (%) on the milling efficiency (%) of hammer mill for ART/98/SW1

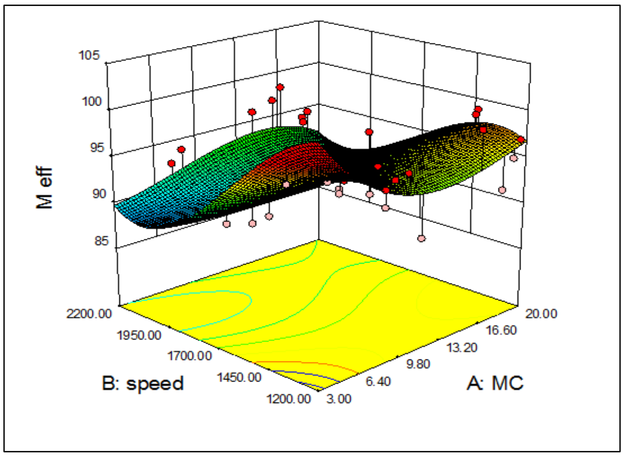

Figure 4: Response surface plot of the effect of speed (rpm) and moisture content (%) on the milling efficiency (%) of hammer mill for Suwan-1-SR-Y

The model could explain about 63% and 37% for ART/98/SW5-OB-W and ART/98/SW1 respectively of the variations in the milling efficiency level. Thus about 37% and 63% for ART/98/SW5-OB-W and ART/98/SW1 respectively of the variation was due to other factors not included in the model. As shown in the response plots (Figure 2 and 3), both speed and moisture content had significant effects on the milling efficiency of both ART/98/SW5-OB-W and ART/98/SW1 varieties of maize. The estimated response surfaces (Figure 2 and 3) confirm that the speed of the hammers and moisture content of maize have a neutral effect on the milling efficiency of the hammer mill. The effect of maize grains moisture is always 2FI in the studied range of hammer speed. There was a significant ($p \leq 0.05$) influence of the cubic factors of hammer speed and moisture content of maize on the milling efficiency (Table 2). It was observed from the statistical analysis that both hammer speed and moisture content of maize had significant ($p \leq 0.05$) cubic effect on the model. The model could explain about 37% of the variations in milling efficiency. As shown in the response plot (Figure 4), both hammer speed and moisture content of maize had significant effects on the milling efficiency of the Suwan-1-SR-Y maize. The response plots (Figure 2 - 4) show that optimal pridicted values for milling efficiency of 82.60%, 91.24% and 92.46% were obtain for ART/98/SW06-OB-W, ART/98/SW1 and Suwan-1-SR-Y varieties respectively at a hammer speed of 1700 rpm and maize moisture content of 11.5% (standard errors 7.43, 4.86 and 3.02 at $p < 0.05$).

IV. CONCLUTION

In all the varieties milling efficiency increases with decrease in speed and moisture content. At a speed of 1700 rpm and moisture content 11.5% a high optimal values for milling efficiency of 82.60%, 91.24% and 92.46% were obtained for ART/98/SW06-OB-W, ART/98/SW1-*Oloyin* and Suwan-1-SR-Y varieties respectively.

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