SIMULATION OF OPTIMUM CHIPPING EFFICIENCY OF A COCOYAM CHIPPER

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ABSTRACT

A chipping efficiency model was simulated at three factor interaction of process variables in order to select a combination of optimum crop and machine variables (cutting velocity, chipping slot size and feed rate) that will yield minimum chip loss for the cocoyam chipper. Visual basic computer simulation programme was used to identify the minimum chip loss for the various combinations of process variables and chipping efficiency. The results obtained from the simulation revealed that a minimum chip loss of 0.1667 kg was obtained for the cocoyam chipper at 4.91 m/s cutting velocity, 0.001 8 m^2 chipping slot size and 0.056 kg/s feed rate. The chipping efficiency obtained at this level was 85.2 %. These results gave room for good comparison with a minimum chip loss value of 0.1682 kg and 84.6 % chipping efficiency obtained from the actual measurement at same values of parameters for the cocoyam chipper.

Keywords: Chipper, Cocoyam, Efficiency, Model, Optimization.
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INTRODUCTION

The purpose of modeling a physical system is to have a better understanding of the fundamental mechanism of that system, and to be able to establish the optimum conditions for the construction and operation of the system [1]. Optimization of chipping efficiency model for the cocoyam chipper helps to select combination of optimum variables needed for the design, construction and operation of the machine. This could be achieved by the use of predicting equations to identify the independent variables (cutting velocity, chipping slot area and feed rate) in the order of their contributions to the total variations on the dependent variable such as chipping efficiency etc. Optimum conditions are those that produce the most favourable or most beneficial result from a system [2]. An algorithm or minimization technique using computer simulation programme can be developed to select combination of optimum variables. Optimization is aimed at maximizing or minimizing some functions relative to some set, often representing a range of choices available in a certain situation [3]. The function allows comparison of different choices for determining which might be "best". Optimization is applied to achieve minimal cost, maximal profit, best approximation, optimal design, optimal management or control. The schemes by which optimization techniques can be classified are: by number of independent variables, whether derivative or numerical methods could be employed and whether the problem is constrained or not. These and other considerations give rise to several different approaches to optimization [4]. Excellent presentation and discussions of widely used techniques have previously been presented by Biles and Swain [5] and many others. Ndirika *et al*. [6] developed a mathematical model for predicting threshing efficiency of stationary grain thresher. The model was validated with experimental results from stationary grain thresher. Ndirika [4] optimized the threshing efficiency model developed in order to obtain optimum values of the independent variables at minimum grain loss for millet and sorghum threshers. Ikejiofor [7] developed mathematical models for predicting the performance of cocoyam chipping processes. However, there is still need to optimize the models in order to obtain optimum values of the independent variables at minimum chip loss for the cocoyam chipper. Therefore, the specific objective of this study is to develop an algorithm or minimization technique using computer simulation programme at three factor interactions of the process variables to select the best combination of the independent variables (cutting velocity, chipping slot area and feed rate) that yield optimum chipping efficiency at minimum chip loss for the cocoyam chipper.

MATERIALS AND METHODS

Model description

The model under consideration for optimization is the model developed by Ikejiofor [7] for predicting chipping efficiency of a cocoyam chipper. The model was developed by dimensional analysis using the concept of Buckingham's Pi theorem. The chipping efficiency (η) can be predicted as given by the equation.

$$\eta = \frac{K_c\left[\frac{V_c \beta_d^{\,2} S_s^{\,2} F}{(1-M_c)^2 F_r^{\,2}}\right]t - K_d\left[\frac{(L_a \beta_d V_c)^2 S_s}{(1-M_c)^2}\right]t}{W_1} \quad (1)$$

Where,
K_c = capacity constant, K_d = damage constant,
F = chipping force (kgm/s^2), V_c = cutting velocity (m/s), L_a = tuber average length (m), S_s = chipping slot area (m^2), M_c = moisture content of crop (decimal), β_d = bulk density dry basis
(kg/m^3),
t=chipping time (sec.)
F_r = feed rate (kg/s), W_1 = initial weight of tubers (kg).
The capacity constant (K_c) in the equation was determined by linearizing π_1 and π_4 $\frac{T_c}{F_r}$ and $\frac{V_c\beta^2 S_s^{\,2} F}{F_r^{\,3}}$ from the developed model by the method of least squares using data from available literatures [8, 9, 10].
The damage constant (K_d) in the equation was also determined by linearizing π_1 and π_4 $\frac{D_c}{F_r}$ and $\frac{L_a \beta V_c S_s}{\sqrt{S_s} F_r}$ from the developed model by the method of least squares using data from available literatures [8, 10, 11, 12]. The slopes of the lines of best fit give the values of the capacity and damage constant K_c and K_d which were found to be 2.3298x10^{-7} and 9.328x10^{-5}as presented in Figures 1 and 2 respectively.

Formulation of optimization function

Any optimization formulation as stated by Ndirika [1] and Babashani [13] is characterized by:

i. An objective function stating the quantity to be minimized or maximized and its functional dependence from the design variables, and.
ii. The constraints on the design variables under which an optimum is to be searched.

This can be expressed mathematically as follows:

$$Y_o = g_o(X_1, X_2, \ldots\ldots, X_n) \quad (2)$$

Where,
Y_o = Objective function
g_o = Some relationship between Y_o and X_1
X_i = Design variables

For this study, the objective function considered is the minimization of chip loss which helps to determine the optimum levels of the chipping efficiency and the design variables under consideration that results to minimum chip loss. A measure of total chip loss (TCL) was obtained using the total chip loss model equation developed by Ikejiofor [7] as:

$$\text{TCL} = W_1 - K_c\left[\frac{V_c \beta_d^{\,2} S_s^{\,2} F}{(1-M_c)^2 F_r^{\,2}}\right]t \quad (3)$$

Where,
W_1 = initial weight of cocoyam corms used (kg), K_c = capacity constant (2.3298x10^{-7}), V_c = cutting velocity (m/s), β_d = bulk density dry basis (kg/m^3), S_s = chipping slot size (m^2), F = chipping force (kgm/s^2), F_r = feed rate (kg/s), M_c = moisture content (decimal) and t = chipping time (sec.).

The design variables used in the optimization are cutting velocity (V_c), chipping slot area (S_s) and the feed rate (F_r). The lower and upper limits of the design variables used are as follows: i) 3.93≤ V_c ≤4.91 (m/s), ii) 0.0014≤ S_s ≤0.0018 (m^2) and iii) 0.056≤ F_r ≤ 0.06 (kg/s). The optimum values were computed using visual basic computer simulation programme at three factor interactions of the process variables: 3x3x3 levels of variable combination (3 levels of cutting velocity, 3 levels of chipping slot size and 3 levels of feed rate). A maximum chip loss of 5% was used in the optimization process. The crop and operating conditions for the chipper are presented in Table 1.

Experiments

Minimum chip loss (MCL) and chipping efficiency obtained from simulation were compared with the experimental data from the developed cocoyam chipper using the optimum parameters. The chipping efficiency was measured by determining the quantity of normal cocoyam chips produced compared with the total quantity of cocoyam tubers fed into the machine, usually expressed in percentage. An electronic balance of the model EK 5055 and sensitivity 0.01g, whose values ranged between 0.01 g to 5000 g was used for weighing. Time was measured using a digital stop watch of the model KD 1069. Moisture contents of the sliced cocoyam corms were determined by oven drying the cocoyam samples at a temperature of 75ºC for 24 hours, using hot air oven with temperature range of 0 – 90ºC.

The moisture contents in wet basis for the various oven-dried samples were calculated using the formula provided by Kajuna *et al.* [14] as:

$$\text{Mc (wb) \%} = \frac{W_w - W_d}{W_w} \text{X}100 \qquad (4)$$

Where,

Mc (wb) % = Moisture content wet basis; W_w is the weight of the fresh sample (g); W_d is the weight of the dried sample (g).

The bulk density was determined as the ratio between the mass of the cocoyam corms in a graduated cylindrical container to its volume [15] as:

$$\text{Bulk density, } \beta_d = \frac{\text{Mass of cocoyam corms(kg)}}{\text{Volume (m}^3\text{)}} \qquad (5)$$

Total chip loss was evaluated as the amount of chips that could not be recovered from the machine after chipping. This was mathematically expressed by Ogundipe *et al*. [12] as:

$$TCL = W_1 - (W_2 + W_3) \qquad (6)$$

Where,

W_1 = input weight (kg), W_2 = output weight for normal chips (kg), W_3 = output weight of crushed tubers (kg), $W_2 + W_3$ = total mass of chips produced (kg).

RESULTS AND DISCUSSIONS

The results obtained as shown in Table 2 revealed that TCL reduces with increase in chipping slot size for both simulated and measured results. From the three levels of the chipping slot size considered in the study, the chip loss obtained at 0.0018m^2 slot size was the lowest and therefore more adequate. The optimum feed rate, cutting velocity and chipping slot size obtained from the Table 2 were 0.056 kg/s, 4.91 m/s and 0.0018 m^2, respectively.

The chipping efficiency of the cocoyam chipper obtained at the resulting values of optimum feed rate, cutting velocity and chipping slot size was 85.2%. The results obtained also revealed that the values of the total chip loss of 0.167 and 0.168 kg and chipping efficiencies of 85.18 and 84.60 % obtained for both simulated and measured data respectively were in close agreement as shown in Figures 3 and 4, respectively. The results from statistical studies as shown in Table 3 indicated that chipping slot size within the range of 0.0014 to 0.0018 m^2 had highly significant effect at 0.01 level of significance on the efficiency of the cocoyam chipper. The cutting velocity within the range of 3.6 to 4.91 m/s had significant effect only at 0.05 level of significance on the efficiency of the cocoyam chipper. This means that increase in cutting velocity of the cocoyam chipper from 3.6 to 4.91 m/s increases the efficiency of the cocoyam chipper but beyond that limit, the efficiency will start to drop. The result of the analysis also indicated that as the chipping slot size increases within the stipulated range, the efficiency of the cocoyam chipping machine also increases as shown in Figure 5.

CONCLUSION

From the study, visual basic computer simulation programme was used to identify the minimum chip loss for the various combinations of process variables and chipping efficiency. This revealed that chipping efficiency corresponding to optimum crop and machine variables (Cutting velocity, chipping slot size and feed rate) with minimum chip loss for the cocoyam chipper can be achieved by simulation. The optimum chipping efficiency of 85.18% was obtained with minimum chip loss of 0.167 kg at 0.0018 m^2 chipping slot size, 0.056 kg/s feed rate and 4.91 m/s cutting velocity.

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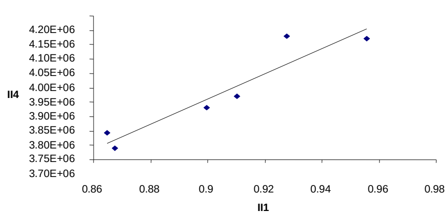

Figure 1: Determination of capacity constant, K_c

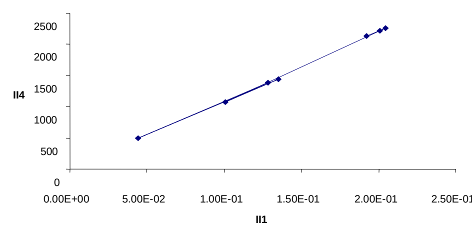

Figure 2: Determination of damage constant, K_d

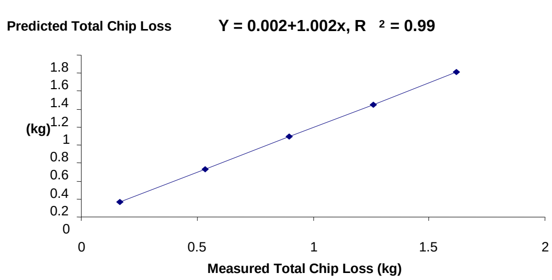

Figure 3: Predicted Vs measured total chip loss (kg)

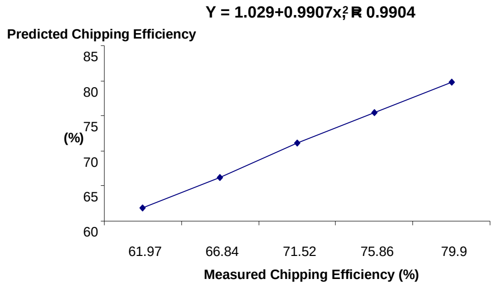

Figure 4: Predicted Vs measured chipping efficiency (%)

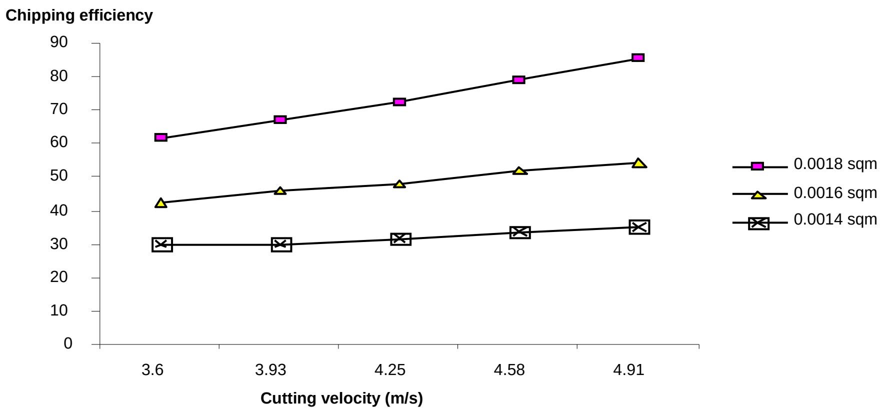

Figure 5: Curve of variation of machine chipping efficiency with cutting velocity at varying slot size

Table 1: Cocoyam (Colocasia esculenta / Xanthosoma sagittifolium) and operating conditions for the chipper

S/No	Parameters	Values / Levels 1	2	3
1	Cutting Speed N (rpm)	300	350	375
2	Cutting Velocity V_c (m/s)	3.93	4.58	4.91
3	Chipping force, F (Kgm/s^2)	137.44	193.68	249.92
4	Feed Rate, Fr (kg/s)	0.056	0.058	0.060
5	Chipping Slot Size, Ss (m^2)	0.0014	0.0016	0.0018
6	Moisture Content, M_c (%)	57.81	52.39	46.97
7	Bulk density, β_d dry basis (kg/m^3)	200.03	231.28	268.78
8	Tuber avg lenth L (cm)	10.06	10.02	9.97
9	Initial Weight of Tubers W_1 (kg)	5.6	5.8	6.0

Table 2: Optimum parameters and chipping efficiency corresponding to minimum chip losses for the chipper

S_s (m^2)	**V_c (m/s)**	**F_r (kg/s)**	**η (%)**		**TCL (kg)**	
			Simu.	**Meas.**	**Simu.**	**Meas.**
0.0014	4.91	0.056	45.29	46.05	2.313	2.304
0.0016	4.91	0.056	61.34	61.52	1.307	1.328
0.0018	4.91	0.056	85.18	84.60	0.167	0.168

Simu. = Simulated, Meas. = Measured

Table 3: Analysis of variance of machine chipping efficiency

Source of variation	**d.f**	**S.S**	**M.S**	**Fcal.**	**F-tabular**	
					5%	**1%**
Chipping slot size	2	4200.983	2100.492	149.672**	4.46	8.65
Cutting velocity	4	362.045	90.511	6.449*	3.84	7.01
Error	8	112.268	14.034			
Total	14	4675.296				

**** =** Highly significant (P = 0.01) *** =** Significant (P = 0.05