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Full Length Research Paper

Modelling some ergonomic parameters with machine parameter using hand powered maize sheller

Ilori T. A.[1]*, Raji A. O[2] and O. Kilanko[3]

[1]Department of Agriculture Engineering Programme, Federal College of Agriculture, Ibadan, Nigeria.
[2]Department of Agriculture and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.
[3]Department of Mechanical Engineering, School of Engineering and Technology, College of Science and Technology, Covenant University, Ota,Ogun State, Nigeria.

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The economic situation in most developing countries have left farmers and processors operating at the small scale, hence the use of automated and electric power driven equipment is limited to the few large scale processors. The effect of the ergonomic parameters namely; weight, age, height and arm length in relation to the resulting efficiencies; shelling efficiency, cleaning efficiency, mechanical damage and percentage sieve loss of a hand powered Maize Sheller incorporating a blower were studied using a non linear regression analysis. The study was with a view to developing a model for the performance of the hand powered maize sheller. The power transmission increases the speed of the blower for high cleaning efficiency. Preliminary studies were carried out to determine the ergonomic data of operator, and moisture content and grain/chaff. The results on studies with maize with 12% dry basis moisture content and grain/chaff ratio of 3.04:1 show that weight has the most significant effect (p<0.05). The mean of the shelling efficiency, cleaning efficiency, sieve loss and mechanical damage of the machine are 94.3, 96.4, 2.3 and 5.23% respectively and the coefficient of determination for the regression equations relating the ergonomic parameters to machine efficiency and parameters ranges from 0.29 to 0.86 with quadratic regression obtained. Equations were derived to relate the variables and an approximate solution was obtained from a particular example, which validates the theoretical prediction with known results.

Key words: Shelling, efficiency, hand powered, ergonomic, model.

INTRODUCTION

Maize (*Zea mays*) is one of the most common cereal crop grown in the world. It belongs to a grass family (Gramineae) and originated from Mexico and South America. The plant prefers light (sandy), medium (loamy), and heavy (clay) soils and requires well-drained soil. It cannot grow in the shade and also requires moist soils. The period between planting and harvesting for maize depend upon the variety, but in general the crop physiologically mature 7 to 8 weeks after flowering at that time the kernel contains 35 to 40% moisture and has the maximum content of dry matter (Danilo, 1991).

Shelling is the removal or separation of maize grain from the cob and it is an operation that follows the harvest. It can be carried out in the field or on the farm by hand or with the help of animals or machines. The grain is obtained by threshing, friction or by shaking the products. The difficulty of the process depends on the varieties grown, the moisture content and the degree of maturity of the crop (FAO, 2005). Maize shelling is difficult at a moisture level content above 25%, with this moisture content, grain stripping efficiency is very poor with high operational energy and causing mechanical damage to the seed. A more efficient shelling is achieved when the grain has been suitably dry to 13 to 14% moisture content (Danilo, 1991).

Maize is shelled traditionally by hands. This is done in

*Corresponding author. E-mail: iloritaa@yahoo.com.

such a way that maize is rubbed against another until the grains are removed from the cob. Likewise the grain can be detached from the cob with the use of pestle and mortal. But this traditional method of shelling is highly tedious, inefficient and time consuming with low productivity as worker can only shell a few kilogram's par hour (FAO, 2005). However, the modern way of shelling is by the use of mechanical means, which can be driven by prime mover or tractor. This prime mover can either be diesel/petrol engine or electric motor. The efficiency and throughput of this machine depending on the type of machine, the skill of workers and organization of the work, yield can vary from 100 to 5000 kg/h (FAO, 2005). The power requirement of such sheller is high and hence, the prime mover is very expensive. Akubuo (2002), observed that manual shelling of maize is time-consuming tedious operation and the few existing mechanized shellers on Nigerian farms are imported and out of reach of the rural peasant farmers that are characterized by small holding and low income.. However, due to the initial cost and high operating cost of this machine a manually driven maize sheller can as well be used to perform similar operation. The machine is hand powered and a blower is incorporated to separate chaff from the grains. The efficiency of this maize sheller depends on skill, age and some ergonomics parameter. The objective of this work is to develop a mathematical model of some ergonomics parameter with some machine parameters and to validate the model developed.

MATERIALS AND METHODS

A hand powered maize Sheller (designed and constructed at the Federal College of Agriculture, Ibadan for small scale processors) of about 125 kg/h capacity incorporating blower was used in this study. The crank to blower speed is 1:10. Operators of this machine were randomly selected. Their height, arm length and weight were obtained before operating the machine. Unshelled maize used in this study with moisture content of 12% dry basis, Diestro (1990) and grain/chaff ratio of 3.04:1.

Twenty-five operators were selected randomly and their ergonomic data (weight, height and arm length) at age ranges of 15 to 20, 21 to 25, 26 to 30, 31 to 35, and 36 to 40 years were recorded using measuring tape and digital weighing scale. This was replicated 3 times for each age range to study the relationship between age, weight, and height and arm length of the operators. Four kilogram's (4 kg) of unshelled maize were weighed and fed into the hopper and the machine was cranked continuously for 2 min. The shelled maize from grain outlet, those blown from the sieve and other outlet collected separately and each sample respective weight were taken. This operation was replicated five (5) times for different age ranges. The evaluation parameters were calculated (NIS, 1997) (Appendix I).

$$X = \frac{F_{r \times (G/C)}}{t} \quad (1)$$

Where, X is the total grain input (Kg), F_r is the feed rate (Kg/h), G/C, the grain to cob ratio, and t is the time (s).

$$\text{Quantity of Unshelled grain, P, (\%)} = \frac{100Y_1}{X} \quad (2)$$

$$\text{Mechanically damaged grain, q, (\%)} = \frac{100Y_2}{X} \quad (3)$$

$$\text{Quantity of blown grain, r, (\%)} = \frac{100Y_b}{X} \quad (4)$$

$$\text{Sieve loss, s,(\%)} = \frac{100Y_s}{X} \quad (5)$$

$$\text{Total grain loss} = P + q + r + s \quad (6)$$

$$\text{Shelling efficiency } S_h(\%) = \frac{100(X_1 + Y_2)}{X} \quad (7)$$

$$\text{Cleaning efficiency } C_L(\%) = \frac{100X_d}{X_d + Y_d} \quad (8)$$

Where:
X = Total grain input (Kg)
X_1= Clean grain (Kg)
X_2 = Materials other than grain (kg)
X_a = Weight of grain received at grain outlet (kg)
X_b = Weight of materials other than grain received at grain outlet (kg)
X_c = Weight of grain received at materials other than grain outlet (kg)
X_d = Weight of materials other than grain received at materials other grain outlet (kg)
Y_1 = Unshelled grain (Kg)
Y_2 = Cracked and broken grain (Kg) (NIS, 1997).

Output capacity is the mass of grain output corresponding to feed rate at which shelling efficiency is maximum and breakage is minimum at less than 7.0% (NIS, 1989).

In the experimental design, the factors considered for the ergonomic data include the age, height, arm length and weight while the shelling efficiency, the cleaning efficiency, mechanical damage and percentage sieve loss was considered for the machine parameter.

The independent variables which are the ergonomic data and the dependent variables which are the machine parameters were investigated using non linear regression analysis (quadratic equation) and this was used to obtain the initial estimates of the equations parameters, correlations of parameter estimates, analysis of variance and the coefficient of determination. The equation (quadratic equation) is expressed as:

$$J= a + bk_1 + ck_2 + dk_3 + ek_4 + fk_1^2 + gk_2^2 + hk_3^2 + ik_4^2 \quad (9)$$

Where: k_1 = age (year)
k_2 = height (m)
k_3 = weight (kg)
k_4 -=arm length (m)

a, b, c, d, e, f, g, h, i, represent estimated parameter coefficients

Table 1. Age relation with ergonomic parameters.

Age range (year)	Mid value (year)	Ergonomic parameter	Range	Mean	Standard deviation
		W	43.0 - 55.0	50.00	3.39
15 - 20	18	H	1.49 - 1.83	1.64	0.07
		AL	0.70 - 0.81	0.76	0.04
		W	51.0 - 84.0	58.60	12.00
21 - 25	23	H	1.57 - 1.91	1.72	0.08
		AL	0.74 - 0.84	0.80	0.04
		W	54.0 - 80.0	63.10	7.00
26 - 30	28	H	1.55 - 1.92	1.73	0.06
		AL	0.76 - 0.89	0.82	0.03
		W	49.0 - 85.0	68.00	6.28
31 - 35	33	H	1.57 - 1.92	1.73	0.08
		AL	0.70 -0.87	0.82	0.04
		W	53.0 - 86.0	73.60	8.79
36 - 40	38	H	1.60 - 1.92	1.74	0.06
		AL	0.79 - 0.87	0.83	0.02

W in kg, H in m, and AL in m.

from the data.

The Pearson correlation method was used for studying the relationship between the dependent and independent variables.

The model was developed by establishing mathematical equations to show the relationship between the ergonomic data (independent variable) and the machine parameter (dependent variable). These mathematical equations are the result of the non-linear regression analysis developed with software, statistical analysis for scientist (SAS).

The detailed results that were generated from the performance operation tests carried out on the hand processed maize sheller include:

a. Correlating the ergonomic data of the operator.
b. Correlating the ergonomic data with machine parameter.
c. Predicting machine parameters using ergonomic data.

RESULTS AND DISCUSSION

Results of the experiment were collated, analyzed and presented in tables. The relationships of age on the ergonomic data of the operators were presented in Table 1. It was observed that the height (H), arm length (AL) and weight (W) of operators increase with increase in age. Table 2 shows Pearson correlation of the ergonomics parameters of operator. It was observed that age is more correlated with weight than arm length and height and significantly different at $p< 0.05$. The height of the operator have a very strong correlation (0.87) with arm length and significant at $p<0.05$, indicating that increase in height also result in the increase in arm length. Height of the operator has negative and weak correlation with age and weight. Age is significant with weight at $p<0.05$.

Table 3 shows correlation between ergonomic data and the machine parameter. It was observed that correlation between age and cleaning efficiency and efficiency of shelling are 0.691 and 0.656 respectively. There exit a weak correlation between age and mechanical damage and sieve loss and thus the same trend for weight. This is because mechanical damage and sieve loss are machine dependent rather than the operators.

As the age increases the average shelling efficiency increases (88.9 to 97.9%) and average cleaning efficiency also increases from 85.22 to 99.4% with high value at 38years (Table 4). There is no significant different between mean of shelling and cleaning efficiency at 23, 28, 33 and 38years. However, there is a strong indication that the youngest age group considered, 18, recorded the least efficiencies. This indicates that the manual shelling is better operated by age range 23 to 38 years. The highest shelling efficiency and cleaning efficiency were obtained at 38 years but highest mechanical damage and sieve loss is at 33 and 28 years respectively.

The arm length has a positive correlation of 0.439 and 0.470 with cleaning efficiency and the shelling efficiency respectively ($p<0.05$). The weight is of the same trend as the age. The result obtained for weight shows that it has a strong effect on the cleaning and shelling efficiency.

Table 2. Correlation of the ergonomic data of the operator.

Parameter	A	H	AL	W
Age (year)	1	-0.032	0.15	0.502*
Sig (2- tailed)	-	0.879	0.474	0.01
Height (m)	-0.032	1	0.870*	0.234
Sig. (2 - tailed)	0.879	-	0.000	0.261
Arm length (m)	0.510	0.870*	1	0.346
Sig. (2- tailed)	0.474	0.000	-	0.09
Weight (Kg)	0.502*	0.234	0.347	1
Sig (2- tailed)	0.10	0.261	0.09	-

*Correlation is significant at $p<0.05$ (2-tailed), N = 25.

Table 3. Correlation between ergonomic data and machine parameter.

Data	Mechanical damage	Shelling efficiency %	Cleaning efficiency (%)	% Sieve loss
A	0.122	0.65	0.691*	0.199
H	0.076	0.335	0.226	-0.236
AL	0.179	0.470*	0.439*	0.010
W	0.168	0.676*	0.653*	0.164

*Correlation is significant at $p<0.05$ (2-tailed)

The cleaning efficiency ranges from 82.1 to 91.3% which also indicates that the model is valid at 86%. Cleaning efficiency is in line with Saheed et al. (1995) stating that the cleaning efficiency has a maximum average value of 83.55 to 100%.

Predictive model developed

The performance evaluation carried out on the hand powered maize sheller using non linear regression analysis results in suitable models for the relationship between the dependent variable that is, the shelling efficiency (S_h), cleaning efficiency (C_L), mechanical damage (M_e) and percentage sieve Loss (P_s).

Shelling efficiency

The relationship are expressed as:

$$S_h = -44.644 + 0.687A + 531.884H - 1017.088AL + 2.084W - 0.008A^2 - 158.060H2 + 661.841AL^2 - 0.015W^2 (R^2 = 0.78) \quad (10)$$

Where S_h = Shelling efficiency (%)

Cleaning efficiency

The relationship is expressed as:

$$C_L = 461.624 + 2.980A - 294.580H - 546.235AL + 1.750W - 0.045A^2 + 79.181H^2 + 371.507AL^2 - 0.013W^2 (R^2 = 0.86) \quad (11)$$

Where C_L = Cleaning efficiency (%)

Mechanical damage

The relationship is expressed as:

$$M_e = -211.532 + 0.804A + 207.918H + 71.261AL + 0.103W - 0.014A^2 - 60.951H^2 - 45.760AL^2 - 0.001W^2 (R^2 = 0.29) \quad (12)$$

Where M_e = Mechanical damage (%)

Percentage sieve loss

The relationship is expressed as:

$$P_s = -110.788 + 0.666A - 6.223H + 266.607AL + 0.320W - 0.012A^2 + 0.824H^2 - 171.441AL^2 - 0.003W^2 (R^2 = 0.66) \quad (13)$$

Where P_s = Percentage sieve loss (%)

Table 4. The mean effect of age on parameter.

Age (year)	Weight (kg)	Height (m)	Arm length (m)	Shelling efficiency %	Cleaning efficiency %	Mechanical damage %	% Sieve loss
18	50[b]	168.8[c]	76.2[b]	88.9[b]	85.22[b]	5.73[a]	1.76[a]
23	63.4[a]	181[a]	85.2[a]	96.88[a]	99.2[a]	6.32[a]	2.14[a]
28	64.8[a]	171.4[b]	81[a]	96.34[a]	99.0[a]	6.5[a]	2.91[a]
33	62.8[a]	177[b]	83[a]	96.26[a]	99.4[a]	7.08[a]	2.71[a]
38	64.8[a]	170[b]	79.8[a]	97.9[a]	99.4[a]	5.8[a]	2.01[a]

Mean with the same letter in the same column area not significant at $p<0.05$

The result of the non-linear regression on studying the relationship between dependent and independent variables show a strong R^2 for the machine parameters except for the mechanical damage. It is observed that all the independent variables (Age, height, arm length and weight) were the major cause of variation in the dependent variables. From the result the independent variables contributing to variation in shelling efficiency include the age, weight and arm length of the operator.

However, the result is in accordance with Adejumo (2006) model for okra thresher with R^2 of 0.77, El Behery et al. (1997) model for portable Egyptian thresher with R^2 of 0.97, suggested that there are many factors affecting threshing which must be properly investigated and combined for effective threshing of any Agricultural produce. The variables contributing to the shelling efficiency is also found contributing to the variation in the cleaning efficiency, all significant at 5% level, the R^2 is 0.86.

Validating the model

The result of the machine performance data shows that for age 18 years, the shelling efficiency ranges from 83.3 to 92.5% which make the model for shelling efficiency valid and in accordance with Majumdar (1985) for a multi-crop thresher with threshing efficiency of 99% for maize, Adejumo (2006) for performance evaluation of hand-operated maize sheller with 95.35% shelling efficiency and Ahaneku et al. (2001) for multi-crop thresher with shelling efficiency of 87% for cowpea and 95% for sorghum.

The cleaning efficiency ranges from 82.1 to 91.3% which also indicates that the model is valid at 86%. Cleaning efficiency is in line with Saheed et al. (1995) stating that the cleaning efficiency has a maximum average value of 83.55 to 100%. The data obtained also indicates that the mechanical damage at age 18 ranges between 4.10 to 6.60% which means that the mechanical damage at 5.6% is also valid and also the percentage sieve loss ranges between ± 0.91% which is in accordance with Majumdar (1985) who developed a multi-crop thresher with total grain loss of 2.3% for maize.

Conclusions

From the results obtained in this study, the following conclusions were drawn; the shelling efficiency increase with increases in weight of the operator and significantly with age and arm length. The weight of the operator has a great influence when driving the machine. The mechanical damage observed from the performance evaluation has very low correlation with the ergonomic parameters. While an increase in cleaning efficiency increase the sieve loss as the blower tends to blow away the chaff, some grain are equally blown. The predicted threshing equation showed that all the variation in ergonomic data contributed to the total variation in the machine performance parameter (R^2 = 0.29 to 0.86). The mean shelling efficiency of age range of 18 to 20, 21 to 25, 26 to 30, 31 to 35, 36 to 40 are 88.9, 96.9, 96.3, 96.3 and 97.9% respectively while the cleaning efficiency is 85.2, 99.2, 99, 99.4 and 99.4% respectively.

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APPENDIX I

The shelling efficiency from Equation 1

S_h = - 44.644 + 0.687 (18) + 531.884 (1.78) - 1017.088 (0.84) + 2.084 (52) - 0.008(18^2) - 158.060 (1.78^2) + 661.841 (0.84^2) - 0.015 (52^2) (R^2 = 0.78)

S_h = 91.5%.

Cleaning efficiency from Equation 2

C_L = 461.624 + 2.980 (18) - 294.580 (1.78) - 546.235 (0.84) + 1.750 (52) - 0.045 (18^2) + 79.181 (1.78^2) + 371.507 (0.84^2) - 0.013 (52^2) (R^2 = 0.86)

C_L = 86%.

Mechanical damage from Equation 3

M_e = - 211.532 + 0.804 (18) + 207.918 (1.78) + 71.261 (0.84) + 0.103 (52) - 0.014 (18^2) - 60.951(1.78^2) - 45.760 (0.84^2) - 0.00(52^2) (R^2 = 0.29)

M_e = 5.6%.

Percentage sieve loss from Equation 4

P_s = - 110.788 + 0.666 (18) - 6.223 (1.78) + 266.607 (0.84) + 0.320 (52) - 0.012 (18^2) + 0.824 (1.78^2) - 171.441 (0.84^2) - 0.003 (52^2) (R^2 = 0.66)

P_s = 0.35%.