DEVELOPMENT OF MAIZE-BASED ANIMAL FEED PRODUCTION MACHINE

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ABSTRACT

The major steps in the processing of maize for industrial and human use involves various operations such as dehusking, shelling, cleaning, and grinding. These operations are mostly done manually or the use of a single machine for each operation. Hence, this study focused on design, fabrication, and evaluation of the performance of a maize processing machine that would integrate dehusking, shelling, cleaning, and grinding processes. The effect of machine speeds (600 to 1000 rpm), feed rates (40 to 50 kg/h), and concave clearances (40 to 50 mm) on dehusking-shelling efficiency, cleaning efficiency, and grinding efficiency were evaluated. The results showed that the maximum dehusking-shelling efficiency, cleaning efficiency, and grinding efficiencies of 68%, 98%, and 78%, respectively were achieved at a feed rate of 45 kg/h, concave clearance of 50 mm, and machine speed of 1000 rpm. The developed machine will help to reduce the labour-intensive tasks of manual maize processing and cost of procuring or maintaining different processing machines for dehusking, shelling, cleaning, grinding processes.

Keywords: Dehusking – Shelling Efficiency; Cleaning Efficiency; Grounding Efficiency; Animal Feeds; Ground Maize.

INTRODUCTION

Maize *(Zea Mays)* is an important cereal crop which belongs to the grass family (*Graruineae*) producing small edible seeds which was said to have originated from Mexico over the years (Iwena, 2002). Maize is the most important cereals crops after rice and wheat in the world providing nutrients for humans and animals, which serves as a basic raw material for the production of starch, oil, protein, alcoholic beverages and food sweeteners (Iwena, 2002). These aforementioned uses of maize make its processing and preservation very vital (Nkama, 1998). The major steps involved in the processing of maize are dehusking, shelling, cleaning and grinding which can be done manually (Ugwa and Omoruyi, 2016).

However, manual maize processing method is considered one of the most labour-intensive tasks in post-harvest of maize handling (Mogaji, 2016). Also, the traditional method of manually dehusking, shelling, and grinding maize grain on the floor introduces foreign materials such as sand, which reduces the crop's market value and lowers its quality for human consumption. Moreover, the manual processing of maize is not suitable for large-scale maize production, particularly for commercial farmers (Mohammed, 2009; lrtwange, 2009).

In recent time, various processing machines for maize have been developed to replace the traditional manual method. These maize processing machines include hand-held sheller, small hand sheller, the free-standing manually operated sheller, and electric motor-driven types (Chukwu, 1994; Ugwa and Omoruyi, 2016; Osueke, 2013; Adewale *et al*., 2020; Mohammed and Maksoud 2009).).

However, these maize processing machines are mostly limited to one process operation at a time, hence, this research focuses on multiple processing of maize in one machine powered by a tractor power-take-off shaft (P. T. O). To the authors' knowledge, no literature has reported the integration of dehusking, shelling, cleaning and size reduction of maize using power from a tractor P. T. O shaft. Therefore, the aim of this research is to develop and carryout performance evaluation of maize feed multiple processing machine that is capable of dehusking-shelling, cleaning and grinding maize seed.

MATERIALS AND METHODS

Materials Selection

The materials used for constructing the dehusking, shelling and grinding machine were chosen on the basis of their availability, suitability, economy, viability in service among other considerations (Gupta and Das, 1997; Sahaya and Singh, 1994; Mohsenin, 1980).

Design of Machine Components

The Size Reduction Chamber

The chamber was made of swinging hammers of dimension 0.15 m x 0.05 m x 0.05 m with a concave sieve at the bottom (Fig. 1). The concave sieve radius was designed using Equation 1 (Nalado, 2006; Mohammed, 2009)

$$r_c = r_d + h_c + c_c \qquad (1)$$

Where:

r_c = radius of concave sieve, (mm)
r_d = radius of shelling cylinder, (mm)
h_c =concave hole diameter, (mm)
c_c = radius of concave clearance, (m

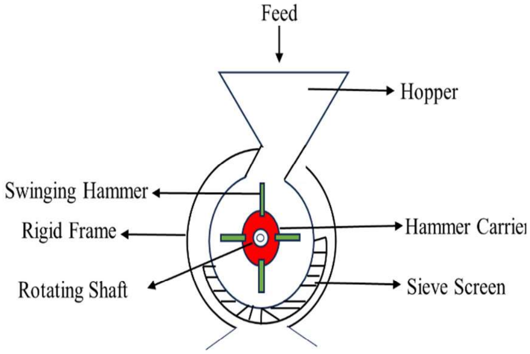


Fig. 1: Size reduction chamber

Determination of Angle of Wrap

Angle of wrap is the external angle that the point of contact of the belt on each of the pulleys makes with the center of the pulley. The angle of wrap for the driving and driven pulleys was determined using Equation 2 (Khurmi and Gupta, 2012).

$$\alpha_1 = 180 + 2\sin^{-1}\left(\frac{R+r}{2C}\frac{\pi}{180}\right) \qquad (2)$$

$$\alpha_2 = 180 - 2\sin^{-1}\left(\frac{R-r}{2C}\right)\frac{\pi}{180} \qquad (3)$$

Where:

α_1 = the angle of wrap for driving pulley, (rads)
α_2 = the angle of wrap for driven pulley, (rads)
C = center to center distance between driving pulley and driven pulley and Center distance between R and r pulleys (mm)

Determination of the Approximate Length of the V-Belt

The approximate length of is the distance between the electric motor pulley and the drum's pulley. This was calculated using Equation 4 (Khurmi and Gupta, 2012).

$$L = 2C + \frac{1.57(D_1+D_2)}{2}\frac{(D_1+D_2)^2}{4c} \qquad (4)$$

Where:

L = the length of the belt (mm)
C = center distance of the belt and D_1 and D_2 are diameters of electric motor and drum pulleys, (mm)

Determination of Belt Tension

The belt tension is the pulling force that arises as a result of the movement of the belt over the pulleys. The tension on the slack and tight side of the belt was determined using Equation 5 (Kurmi and Gupta, 2012).

$$P = vW \qquad (5)$$

Where:

P = power of the electric motor, (watts)
v = speed of the electric motor (rpm)

W = tensions on the slack and tight sides (N)

$$W = \frac{T_t}{T_s} e^{\mu\theta cosec(\beta)} \qquad (6)$$

T_t= Tension on the tight side of belts (N)

T_s = Tension on the slack side of belts (N)
θ = Angle of lap (^{O})
β = One half angle of the pulley groove (^{O})
μ = coefficient of friction between the belt (rubber) and pulley (steel)

Design of Grinding Shaft

The cylindrical shaft is the solid rod for transmitting motion and supporting a set of loads. In the de-husking-shelling process, the shaft carries the load of a cylindrical drum with a raspbar, bearings, pulley and V-belt. All of these forces exert their influence on the shaft. The design of the shaft takes into account fluctuating torque, bending moment, and shearing force. The diameter of the shaft was determine using Equation 7 (Khurmi and Gupta, 2012).

$$d^3 = \frac{1}{\tau_{sy}}[(K_b M_b)^2 + (K_t M_t)^2 \qquad (7)$$

Where:

d is the diameter of the shaft in (mm)
K_b is the combined shock and fatigue factor for bending moment = 1.5 (Hall and Holowenko, 1982)
K_t is the combined shock and fatigue factor torsional moment = 1.0 (Hall and Holowenko,1982)
M_b is the resultant bending moment (Nm) = 1.5 (Khurmi and Gupta, 2012).
M_t is the resultant torsional moment (Nm).
τ_{sy} represent the allowable shear stress (MN/m^2), π = 3.142.

Determination of Torsional and Bending Moments

Torsional moment is a moment of a pair of equal and opposite couples which tends to twist a body. The torsional moment (M_t) was calculated (Rajput, 2013) with the expression given in Equations 8 and 9.

$$M_t = \frac{9550P}{N} \qquad (8)$$

Where:
P = Power of an electric motor (watt)
N =Speed of rotation of selected electric motor pulley in (rev/sec)

$$M_b = \frac{\sqrt{T_e^2 + (TK_t)^2}}{K_m} \qquad (9)$$

Where:
T_e= Equivalent twisting moment (Nm)
K_m = Shock factor = 2.0
K_t = Fatigue factor = 1.5
M_b = Maximum bending moment in (Nm)

Design of the Frame

Equation 10 holds for calculating the axial and lateral loads acting on the frame, which supports the total weight of the machine components (Gupta and Das, 1997).

$$\frac{F_c}{P_c} = \frac{F_{bc}}{P_{bc}} < 1 \qquad (10)$$

Where:
F_c = actual direct axial stress
F_{bc} = actual direct bending stres
F_{bc} = allowable axial stres
$F_c = \frac{\mathrm{F}}{\mathrm{A}}$
F = Axial load
A = Cross sectorial area of sectios
$F_{bc} = \frac{\mathrm{M}}{\mathrm{Z}}$, (Nm)

M = Moment
Z = Sectional Modulus (mm)

Determination of the Cylinder Speed

The cylinder speed was determined using Equation 11, assuming there is no slip between the belt and the pulley. However, if slip or creep conditions occur, the resulting speed (1000 rpm) is reduced by 4% (Nasir, 2005).

$$N_2 D_2 = N_1 D_1 \qquad (11)$$

Where:
D_1 = Diameter of pulley on the electric motor (mm)
D_2 = Diameter of pulley on grinding shaft (mm)
N_1 = Speed of the electric motor (rpm)
N_2 = Speed of the machine (rpm)

Determination of the Dehusking-Shelling unit

Equation 12 determines the volume of the Dehusking-Shelling unit, which comprises the cylinder, cylinder end plates and raspbar components.

$$V = 2\pi r l t \qquad (12)$$

Where:
Radius of Dehusking-Shelling unit shaft (d)
Length of shelling unit shaft (l)
Thickness of shaft (t)
Density of steel is = 7800 kg/m^3. (Khurmi and Gupta, 2012).

Cylinder End Plate

Two end plates were utilized. They are constructed from mild steel sheet material, conforming to the specified specifications: Diameter of end plate = 300 mm, Thickness of end plate (t) and volume of cylinder (V_c).

$$(V_c) = \pi r^2 t \qquad (13)$$

To facilitate the rotation of the shaft during operation, a 30 mm diameter hole was drilled at the center of each plate. In order to calculate the volume of each plate, Equation 14 was used (Mohammed, 2009).

Volume of hole (V_h):
$V_h = \pi r^2 t$ (14)

Hence, volume of each cylinder end plate = volume of plate – volume of hole

Mass of cylinder plate (M_{cp}) is determine using Eqn (15).

$$M_{cp} = 2(volume \times density) \qquad (15)$$

Determination of Dehusking – Shelling Cylinder Casing diameter (D_{ds})

Equation 16 was employed to ascertain the diameter of the Dehusking - Shelling cylinder casing (Khurmi and Gupta, 2012).

$$\gamma = \gamma_0(1 + k\theta) \quad (16)$$

Where:
γ_0 = initial radius of casing (mm)
k = constant = 0.002 to 0.0023
θ= 20^o (Assume a displacement from the initial position)
γ_0 = 350 (Assume or displacement from the initial position)

Determination of Theoretical Capacity of the Machine

The theoretical capacity of the machine was determined using Equation 17 (Ahaneku *et al*., 2001)

$$Q_{th} = 60\pi N D_r D_p L\rho \quad (17)$$

Where:
Q_{th}= theoretical capacity (kg/h)
N= Revolution per minute of rolls (rpm)
D_r = Diameter of rolls (m)
D_p = Desired diameter of product (m)
ρ= Density of product (kg/h)
L= Length of rolls (m)

Equation 18 provides the machine's actual capacity Q_{act}, which was determined by multiplying Equation 17 by the Efficiency.

$$Q_{act} = \eta \times Q_{th} \quad (18)$$

Determination of Air discharged by the Blower

The airflow Q_A through a blower can be determined using Equation 19 (Hem, 1981) and Mohammed (2009).

$$Q_A = V \times D \times W \quad (19)$$

Where:

V = velocity of air required for cleaning, (ms^{-1})
D = depth of air stream (m)
W = width over which air is required (m)

Consequently, the theoretical air discharge (Q_t) was determined using Equation 20 (Mohammed, 2009; Hem, 1981).

$$Q_t = \frac{Q_A}{0.3} \quad (20)$$

Design of Cleaning Chamber Shaft

The Cleaning chamber is equipped with a pulley supported by two bearings. The power and blower speed values were determined as 0.03 kW and 460 rpm, respectively. The blower speed was determined using Equation 21 (Rajput, 2013). The shaft diameter of the cleaning chamber was computed using Equation 21.

$$N_{bs} = \frac{N_2 S_P \ X \ D_P^S}{Dpb} \quad (21)$$

Where:

$N_2 S_P$ = speed of pulley on splines (Nm)
D_P^S= Diameter of pulley on splines (mm)
Dpb= Diameter of pulley on blower (mm)

Determination of the P.T.O Shaft Torque Transmitted

A telescopic shaft with its two universal joints is called power take off drive (Kepner *et al*., 1982). It can transmit power from the tractor P. T. O. to the implement. It is a standard component of the machine which was selected based on the torque to be transmitted. This torque was computed using Equation 22.

$$Toque\ (P.T.O) = \frac{P \times 9550}{N} \quad (22)$$

Where:

P = Power developed by the tractor (kW)
N = Speed of P. T. O shaft (rpm)

The telescopic shaft is subjected to torsional stress only and the diameter of the shaft was calculated by employing Equation 23.

$$\delta_{as} = \frac{16 M_t}{\pi d^2} \quad (23)$$

Where:

δ_{as} = Allowable stress (MN/m^2)
M_t = Moment torque (Nm)
d = Shaft diameter (mm)

Determination of Volume of Grinding Chamber

The grinding (size reduction) chamber comprises a cylindrical shaft made of mild steel materials, with a diameter of 430 mm, width of 2.5 mm, and height of 100 mm. The volume of the grinding chamber was calculated using Equation 24.

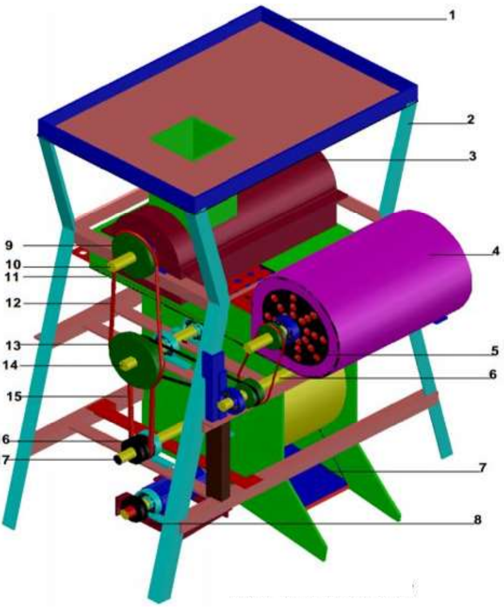
$$V_T = \pi r^2 \times L \quad (24)$$

Where:

V_T= Total volume of cylinder (cm^3)
r = Effective radius of cylinder (cm)
L = length of the cylinder (cm)

Description and Fabrication Process of the Animal-based Feeds Production Machine

Figs. 3 and 4 show the isometric view and production process of the machine. The machine consists of hopper through which the husked maize kernel are feed into the machine. The hopper measuring size is 920x510mm and trapezoidal in shape. The machine is supported on an angle frame with a height of 1660 mm and base of 1000 mm. The dehusking-shelling chamber where dehusking and the shelling processes take place is bolted beneath the hopper. This chamber consists of rotating shaft with rapsbar welded throughout its body at an angle of 80°. Beneath the dehusking-shelling chamber is a reciprocating sieve arrangement which separate the chaff from the seed with the help of the blower. Below the reciprocating sieve arrangement there is a grinding chamber which received the cleaned seed and grind it. The grinding chamber consist of sieves which help in obtaining the required sizes of the product with an aid of a swinging hammers.At the bottom of this chamber there is an outlet where the whole ground product comes out and is collected by tray or sack.



	LEGEND	QTY
1	Hopper	2
2	Frame	1
3	Dehusking-Shelling Housing	1
4	Blower Housing	1
5	V-Belt From Shaft Pulley- Blower Pulley	1
6	Blower-Shaft	1
7	Grinded Product Outlet	1
8	Electric Motor Pulley	1
9	Pulley On Cylinder Shaft	1
10	Shaft Of Dehusking – Shelling Unit	1
11	Chaft Outlet	1
12	V-Belt From Double Groove Pulley	1
13	Grinding Pulley	1
14	P.T.O Shaft For Tractor Connection	1
15	V-Belt From Electric Motor To Grinding Shaft	1
16	Pulley On Grinding Shaft	1
17	Shaft Of Grouding Unit	1

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SUPERVISOR: ENGR., PROF. S.M DAUDA	UNITS: ENGINEERING	Department: Agricultural And Bioresourses Engineering
SCALE 1 : 100	SHEET 9 OF 9	Isometric Drawing

Fig. 3: Isometric view of the Maize Animal Feed Processing Machine

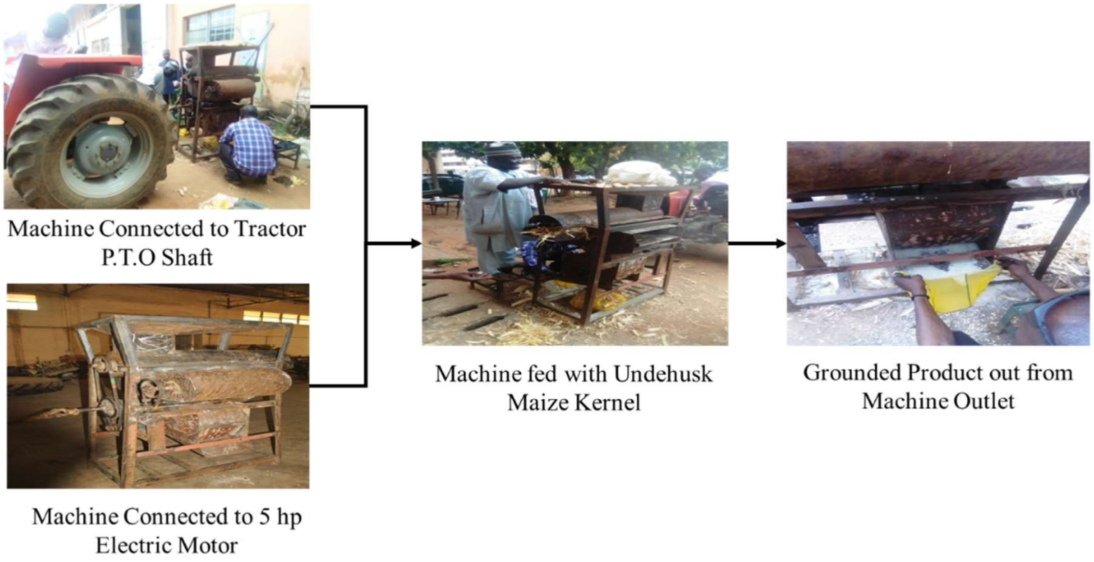

Fig. 4: Present the Flow Diagram of Maize Feed Animal Machine Operation

Principle of Operation and Performance Evaluation of the Maize Processing Machine

Principle of Operation of the Machine

The maize-based animal feeds machine is powered with 5 hp electric motor and also P.T.O shaft of a tractor 767 Mersey Ferguson. Undehusked maize is fed into the dehusked-shelling chamber through the hopper, where it undergoes dehusking and shelling due to the impact force of 3 N by an abrasive action between the raspbar on the rotating cylinder and the concave clearance which result in separation of the husk and seeds from the cob. Air is blown from a fan to remove the chaff, and the seeds drops into the grinding chamber where it is ground and the resulting product is discharged through a sieve arrangement.

Performance Evaluation of the Maize Processing Machine

In carrying out the performance evaluation of the machine, three (3) independent variables (machine speed, feed rate and concave clearance) that influence the performance were examined. To avoid laying-off (unnecessary repetition of experiments), a face composite design (FCRD) was employed. The range of parameters that were examined are shown in Table 1. Machine speed was assessed in a range from 600 to 1000 rpm, the feed rate varied from 40 to 50 kg/h and the concave clearance varied from 40 to 50 mm. Three levels each of the variables were investigated at low (−1), medium (0) and high (+1) levels. Each of these processes were repeated three time

Table 1: Independent Variables and levels

Factor	Unit	Code Factor Level		
		(-1)	(0)	(+)
Machine Speed	rpm	600	800	1000
Feed rate	kg/h	40	45	50
Concave Clearance	mm	40	45	50

Dehusking-Shelling Efficiency

Equation 25 provides the expression for dehusking-shelling efficiency which is the ratio of the dehusking-shelling output, multiplied by one hundred percent, to the inputted feed rate.

$$\text{Dehusking} - \text{Shelling Efficiency}(\%) = \frac{\text{Dehusked - shelled output}}{\text{Quantity fed to the machine}} \quad (25)$$

Cleaning Efficiency

Equation 26 provides the expression cleaning efficiency and is the ratio of the difference between the fed rate and the weight of chaff to the feed rate, multiplied by one hundred percent.

$$\text{Cleaning Efficiency}(\%) = \frac{\text{Fedrate} - \text{Weight of Chaff}}{\text{Quantity fed to the machine}} \quad (26)$$

Grinding Efficiency

This is the ratio of grounded materials to the Dehusking-shelling output multiplied by hundred percent and as expressed in Equation 27 (Balami *et al.*, 2012).

$$\text{Grinding Efficiency}(\%) = \frac{\text{weight of ground materials}}{\text{dehusking} - \text{shelling output}} \quad (27)$$

RESULTS AND DISCUSSION

Effect of Machine Speed of 600 rpm, Feed Rate and Concave Clearance on Machine Efficiency

The evaluation results on the effects of feed rate and concave clearance on dehusking-shelling, cleaning, and grinding efficiency at a constant machine speed of 600 rpm are presented in Table 2. The mean values of the dehusking-shelling, cleaning, and grinding efficiency ranged from 60% to 63%, 96% to 98%, and 45% to 74%, respectively, for feed rates and concave clearances ranging from 40 kg to 50 kg and 40 mm to 50 mm. The highest mean efficiency values of 63% for dehusking-shelling, 98% for cleaning, and 74% for grinding were obtained with a feed rate of 45 kg and a concave clearance of 50 mm. The lowest mean efficiency values of

60% for dehusking-shelling, 96% for cleaning, and 45% for grinding were observed with the following combinations: a feed rate of 50 kg and a concave clearance of 45 mm, a feed rate of 45 kg and a concave clearance of 40 mm, and a feed rate of 40 kg and a concave clearance of 45 mm.

The performance evaluation found that dehusking-shelling efficiency increased with increasing feed rate and concave clearance. The increase in dehusking-shelling (2016) efficiency with increasing feed rate could be attributed to the increased impact force of the raspbar on the undehusked maize. This is consistent with the findings of a study on shea butter nuts by Shehu et al. (2018). The increase in dehusking-shelling efficiency with increasing concave clearance could be attributed to the increased space for impact and rubbing actions in the dehusking-shelling chamber. This is in agreement with the findings of Ugwu and Omoruyi

Table 2: Effect of Machine Speed of 600 rpm, Feed Rate and Concave clearance on Machine Efficiency

Run	MC (%)	MS (rpm)	FR (kg)	CC (%)	DSE (%)	CE (%)	GE (%)	TMG (min)
1	16	600	45	40	62	96	75	19
2	16	600	45	40	62	97	74	19
3	16	600	45	40	62	96	74	19
Total sum	**48**	**1800**	**135**	**120**	**289**	**289**	**223**	**57**
Mean value	**16**	**600**	**45**	**40**	**61**	**96**	**74**	**19**
4	16	600	40	45	63	96	66	18
5	16	600	40	45	63	96	48	19
6	16	600	40	45	63	97	44	19
7	16	600	40	45	63	97	61	17
Total Sum	**64**	**2400**	**160**	**180**	**253**		**219**	**73**
Mean Value	**16**	**600**	**40**	**45**	**63**		**55**	**18**
8	16	600	50	45	64	98	66	34
9	16	600	50	45	56	97	61	25
Total sum	**32**	**1200**	**100**	**90**	**120**	**195**	**127**	**59**
Mean value	**16**	**600**	**50**	**45**	**60**	**97**	**64**	**30**
10	16	600	45	50	67	96	63	20
11	16	600	45	50	60	97	74	22
12	16	600	45	50	62	96	64	21
Total sum	**48**	**1800**	**135**	**150**	**189**	**289**	**201**	**63**
Mean value	**16**	**600**	**45**	**50**	**63**	**96**	**67**	**21**

MC =moisture content, *MS* =machine speed, *FR* =feed rate, *CC* =concave clearance *DSE*=dehusking-shelling efficiency, *CE*=cleaning efficiency. *GE*=grinding efficiency *TMG*=time required for the material to be grounded.

Effect of Machine Speed of 800 rpm, Feed Rate and Concave Clearance on Machine Efficiency.

Table 3 presents the results of the impact of varying feed rates and concave clearances on the efficiency of dehusking - shelling, cleaning, and grinding, while maintaining a constant machine speed of 800 rpm. The efficiency metrics were measured as mean values and fell within the ranges of 62% to 69% for dehusking - shelling, 97% to 98% for cleaning, and 49% to 78% for grinding. The evaluation explored different combinations of feed rates (ranging from 40 to 50 kg/h) and concave clearances (ranging from 40 to 50 mm).

Notably, the most favorable efficiency results were achieved under specific conditions: a feed rate of 40 kg and a concave clearance of 50 mm yielded the highest mean values of 69% for dehusking – shelling efficiency, 97% for cleaning efficiency, and 78% for grinding efficiency. Other combinations that demonstrated superior efficiency were recorded at the feed rates of 40 kg/h to 50 kg/h and a concave clearance of 40 mm to 50 mm, as well as a feed rate of 45 kg/h and a concave clearance of 45 mm.

In contrast, less favorable efficiency outcomes were observed when using a feed rate of 50 kg and a concave clearance of 40 mm, resulting in mean values of 62% for dehusking - shelling and 49% for grinding.

The investigation also considered cleaning efficiency across different machine speeds (600 rpm, 800 rpm, and 1000 rpm), as shown in Tables 2, 3, and 4. The highest cleaning efficiency was achieved at a machine speed of 800 rpm, while the lowest was observed at 1000 rpm. There was slight difference in cleaning efficiency between the machine speeds of 800 and 1000 rpm. Importantly, the cleaning efficiency observed in this study is in line with that reported by Balami *et al*. (2012) for castor seed dehusking and shelling machine.

Table 3: Effect of Machine Speed of 800 rpm, Feed Rate and Concave Clearance on Machine Efficiency.

Run	MC (%)	MS (rpm)	FR (kg)	CC (%)	DSE (%)	CE (%)	GE (%)	TMG (min)
1	16	800	40	40	68	97	44	19
2	16	800	40	40	68	97	52	15
3	16	800	40	40	68	97	52	16
Total sum	**48**	**2400**	**120**	**120**	**204**	**291**	**148**	**50**
Mean value	**16**	**800**	**40**	**40**	**68**	**97**	**49**	**17**
4	16	800	50	40	62	97	71	27
5	16	800	50	40	62	97	65	27
6	16	800	50	40	62	97	71	27
Total sum		**2400**	**150**	**120**	**186**	**291**	**207**	**81**
Mean value		**800**	**50**	**40**	**62**	**97**	**69**	**27**
7	16	800	45	45	64	97	76	24
8	16	800	45	45	62	96	75	18
9	16	800	45	45	62	96	82	25
10	16	800	45	45	62	98	71	18
11	16	800	45	45	60	96	81	25
12	16	800	45	45	60	97	74	18
13	16	800	45	45	62	97	75	23
14	16	800	45	45	60	98	97	18
15	16	800	45	45	62	97	71	17
Total sum		**7200**	**405**	**405**	**554**	**850**	**702**	**186**
Mean value		**800**	**45**	**45**	**62**	**98**	**78**	**21**
16	16	800	40	50	70	97	50	18
17	16	800	40	50	70	97	52	14
18	16	800	40	50	68	96	54	15
Total sum		**2400**	**120**	**150**	**208**	**290**	**156**	**47**
Mean value		**800**	**40**	**50**	**69**	**97**	**78**	**17**
19	16	800	50	50	60	98	60	28
20	16	800	50	50	60	97	67	30
21	16	800	50	50	70	97	65	20
Total sum		**2400**	**150**	**150**	**190**	**292**	**192**	**78**
Mean value		**800**	**50**	**50**	**63**	**97**	**64**	**26**

MC =moisturecontent, *MS* =machine speed, *FR* =feed rate, *CC* =concave clearance *DSE*=dehusking-shelling efficiency, *CE*=cleaning efficiency, *GE*=grinding efficiency *TMG*=time required for the material to be grounded.

Effect of Machine Speed of 1000 rpm, Feed Rate and Concave Clearance on Machine Efficiency.

Table 4 presents the results of investigating the influence of feed rate and concave clearance on the efficiency of dehusking - shelling, cleaning, and grinding, while maintaining a constant machine speed of 1000 rpm. The mean efficiency values for dehusking - shelling, cleaning, and grinding ranged between 64% and 68%, 93% and 96%, and 62% and 72%, respectively. These values were derived from combination of feed rates and concave clearances ranging from 40 to 50 kg and 40 to 50 mm, respectively.

The highest mean efficiency values were achieved under specific conditions: 68% for dehusking – shelling, 96% for cleaning and 72% for grinding. These values were attained when the feed rate and concave clearance were set at 45 kg and 40 mm, 40 kg and 45 mm, and 50 kg and 45 mm, respectively. Conversely, the lowest mean efficiency values were 64%, 94%, and 62% for dehusking - shelling, cleaning and grinding, respectively.

The evaluation also noted an increased grinding efficiency, rising from 49% to 78% as the feed rate was increased. This increase was attributed to increased interaction between the kernels and the hammer head. This observation aligns with a previous studies conducted by Helmy *et al*. (2007), which revealed that augmenting the number of drum hammer heads from 4 to 8 resulted in increased machine output.

Table 4: Effect of Machine Speed of 1000 rpm, Feed Rate and Concave clearance on Machine Efficiency

Run	MC (%)	MS (rpm)	FR (kg)	CC (%)	DSE (%)	CE (%)	GE (%)	TMG (min)
1	16	1000	45	40	69	97	72	22
2	16	1000	45	40	69	94	62	20
3	16	1000	45	40	69	94	74	19
Total sum	**48**	**3000**	**135**	**120**	**202**	**289**	**208**	**61**
Mean value	**16**	**1000**	**40**	**40**	**67**	**95**	**69**	**20**
4	16	1000	40	45	65	96	71	24
5	16	1000	40	45	63	97	66	23
6	16	1000	40	45	63	96	70	22
Total sum	**48**	**3000**	**120**	**135**	**191**	**289**	**207**	**69**
Mean value	**16**	**1000**	**40**	**45**	**64**	**96**	**69**	**23**
7	16	1000	50	45	64	98	67	20
8	16	1000	50	45	64	97	77	21
9	16	1000	50	45	64	86	73	21
Total sum	**48**	**3000**	**150**	**135**	**192**	**281**	**217**	**62**
Mean value	**16**	**1000**	**50**	**45**	**64**	**93**	**72**	**22**
10	16	1000	45	50	67	97	65	18
11	16	1000	45	50	69	96	61	26
12	16	1000	45	50	67	96	61	19
Total sum	**48**	**6000**	**135**	**150**	**203**	**289**	**187**	**63**
Mean value	**16**	**1000**	**45**	**50**	**68**	**96**	**62**	**21**

MC =moisturecontent, *MS* =machine speed, *FR* =feed rate, *CC* =concave clearance *DSE*=dehusking-shelling efficiency, *CE*=cleaning efficiency, *GE*=grinding efficiency *TMG*=time required for the material to be ground.

CONCLUSION

A comprehensive maize-based animal feed processing machine was developed and evaluated. The machine speed, concave clearance and feed rate had influence on the performance of the machine. The developed machine had a capacity of 40 kg/h, dehusking-shelling efficiency of 68%, cleaning efficiency of 98% and grinding efficiency of 78%. These efficiencies were achieved at a feed rate of 45 kg/h, concave clearance of 50 mm, and machine speed of 1000 rpm. The developed machine will help to reduce the labour-intensive tasks of manual maize processing and cost of procuring or maintaining different processing machines for dehusking, shelling, cleaning, grinding processes.

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