DEVELOPMENT OF CONTINUOUS MAIZE DEHULLING, CLEANING AND MILLING MACHINE

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ABSTRACT

A continuous maize dehulling, cleaning and milling machine was developed. The machine consists of three sections for dehulling, cleaning and milling which processes the maize to the desired product. The dehulling speed was 450rpm while the milling speed was 2333rpm. The dehulling efficiency of the machine at initial maize cob moisture content of 0 -1.33% ranges from 61.94% to 77.16% at longitudinal axial dimension of 10-17.7cm and mass of cob range of 58 – 116.66g, while the throughput capacity ranges from 13.32 to 23.4kg/hr for the same range of axial length and weight. The axial dimension and weight of the cob affected the dehulling efficiency and throughput capacity. The efficiency of dehulling decreased with increase in the axial length and reached the minimum of 61. 94% at 13.6cm before it started to increase again reaching the maximum of 77.16% at 15.5cm. The sieve analysis showed that the product from the mill consists of fine flour, coarse flour, broken grain and whole grain. The milling efficiency ranged from 38.91 – 50.86% with a throughput capacity of 37.84 – 50.89kg/hr.

KEYWORDS: Dehulling, cleaning, milling, maize, design

1. INTRODUCTION

Maize botanically known as "Zea mays" is a tall grass that has large ears with many seeds and belongs to the family gramineae. It is the most important crop grown in many countries of the world after wheat (Simonyan et al., 2010; Okaka, 1997). It has a wide variety of food uses and rank second after wheat in world grain production (Hawkworth, 1985; Purse Glove, 1992; Osagie and Eka, 1998). The kernels (grains) can be eaten directly or used as components of many food products. Yellow dent is used primarily as livestock feed while white dent is used for human consumption as meal and cereals. Maize is also used in the manufacturing of non food products including ceramics, drugs, paints, paper goods and textiles (Benton Jones Jr, 2003). Maize can be processed into different products for various end uses at tradition level and on an industrial scale. Large proportion of agricultural products utilized in developing countries is processed manually. However, significant changes are occurring throughout the developing countries in the processing of grains for major uses. The tendency is the adoption of simple processing machine for shelling, cleaning and milling. Maize processing starts mainly from harvest and the bulk of the processing work is done on its dehuling of the kernels from its cob, cleaning of the kernel before it is processed into another form for consumption or storage. These operations are done manually with hand and with some traditional methods, using hand tool which make the process laborious, less productive, time consuming and it does not support large scale post harvest processing, especially for commercial and industrial purposes. However it has been observed that some areas in Nigeria uses mechanical method to dehull and mill their maize, but most of the existing machine were designed for a single unit operation. This slows down the rate of processing and involves series of machines for each unit operation. These machines occupy valuable spaces and are not cost effective. Also valuable time is wasted in moving the processed maize from one machine to the other.

This research paper presents a low cost combine maize dehauling, cleaning and milling machine for small holder farmers in Nigeria. The improvement, production, adoption and commercialization of this locally produced prototype combine maize dehuling, cleaning and milling machine will not only save foreign exchange for the country but will also create job for the teaming youths of this country. It will also save power and cost of performing different unit operation and accommodate a lesser space in the farm.

2. MATERIALS AND METHODS

2.1 Design Considerations

Engineering design has to do with the various activities that lead to proper and effective development of machines and engineering processes. In the design of the combined maize dehuling, cleaning and milling machine, the following factors were considered:

1. Strength of material should withstand the forces acting in the various component of the machine
2. Reduction in drudgery associated with the traditional method of dehuling and milling
3. Higher capacity than the traditional method of dehuling and milling
4. Physical and aerodynamic properties of the maize and the chaff as a falling body was considered
5. Form and size of the machine based on human ergonomic and anthropometry
6. More efficient use of power, space and time in unit operations in the farm

2.2 Components Design

The various components were designed based on the established relationship as presented in the machine design text book by Khurmi and Gupta (2007).

Hopper Design

The hopper was designed to accommodate the maximum linear dimension of maize (17.7cm) determined by preliminary measurement of the cobs during the determination of the physical properties of the maize and the cobs.

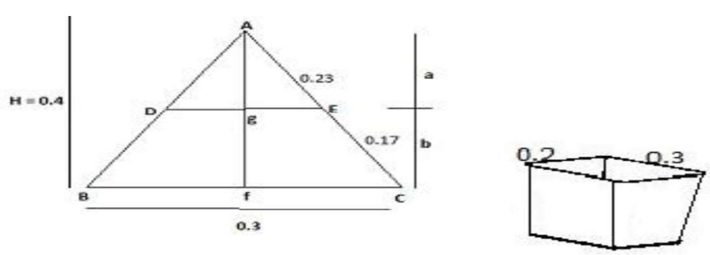

Figure 1. Outline of the hopper

The hopper is in the form of an inverted frustum of a pyramid BCDE (Fig. !). Therefore the volume of the hopper is the difference of the two rectangular based pyramids with side ABC and ADE. Therefore the volume of the hopper was calculated as 0.006757m3.

Dehauling Barrel

The dehauling unit comprises of the dehauling barrel made up of a cylindrical drum lined horizontally with round galvanized steel bars (Fig. 2). Thickness of the galvanized steel bars was calculated by assuming that the projections of the bars are cantilevers (Ahemen and Raji, 2008). If the shear stress at the bottom of the projection is τ, the horizontal force F (force at removal of maize kernel) per unit length of projection L, is given by the following expression, Stephens (1988):

$$F = \tau tL \tag{1}$$

Where t is the thickness of steel sheet/plate/bars required, L is 2 mm (measured), and F is 728.52 N (Ahemen, 2008). Using the maximum shear stress theory on failure relationship stated by Krutz *et al*. (1984)

$$\tau = \frac{1}{2}\, tensile\ stress \quad (2)$$

The ASTM-A621 AISI-DQ gave the tensile stress of low carbon steel as 430 MPa (430 N/mm2). Therefore the shear stress at the foot of the projection is calculated as 215 N/mm2. Substituting the values into Equation 1, gives the dehuling barrel bar thickness as 1.7 mm. The total weight of the dehulling drum assembly was obtained as 33.6 N.

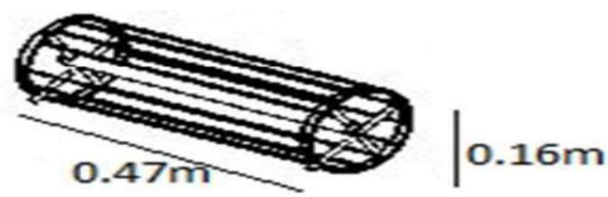

Figure 2: Outline of the dehuling drum

The dehuling barrel has the shape of a cylinder. Therefore the volume is given by

$$V = \pi r^2 h \quad (3)$$

V = 0. 00945m^3

Circumference of the base of the barrel

$$Circumference = 2\pi r \quad (4)$$

Circumference is calculated as 0. 0527m

Belt Design

The configuration of the belt is shown in Fig. 3

Diameter of driver (D_1) = 80mm = 0.08m

Diameter of the driven (D_2) =?

Number of turns of the driver N_1 = 1200rpm (electric motor speed)

Number of turns of the driven N_2 = 450rpm. This is selected since the dehuling speed that will give low maize damage, but high dehuling output is between the range of 300-650 rpm (Fashina and Abdulahi, 1994)

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (5)$$

Therefore D_2 is calculated as 0.213m

Length of belt (L) is given by

$$L = \frac{\pi}{2}(D_1 + D_2) + 2x + \frac{(D_1 - D_2)^2}{4x} \quad (6)$$

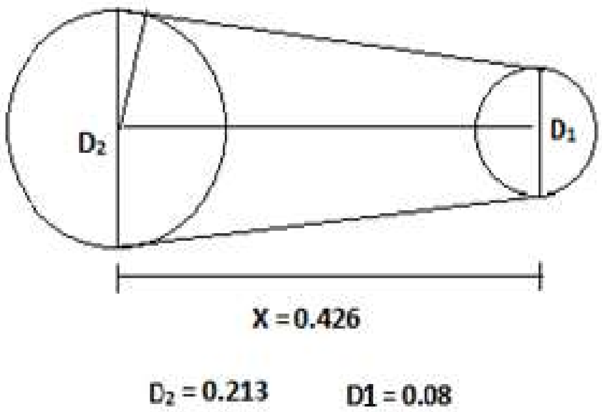

Figure 3: Belt outline

X is the center distance
Therefore L is calculated as 1.3226m

Angel of lap (θ) is given by

$$\theta = (180 - 2\alpha)\,\pi/180 \tag{7}$$

θ is calculated as 2.823 rad.
Tension on the belt is given as

$$2.3 \log \frac{T_1}{T_2} = \mu\theta cosec\beta \tag{8}$$

μ = coefficient of friction between the belt and pulley
T_1 = Tension on the tight side of the belt
T_2 = Tension on the slack side of the belt
β = Grove angle of pulley.

The coefficient of friction for rubber belt on cast iron or steel operating on dry surface is $\mu = 0.3$ (Ogunwede 2003).

Using groove angle for v-grooved pulley for belt type A
$2\beta = 34^0$
Therefore $\beta = 17$
$T_2 = 18.1677\, T_2$

$$T_1 = T - T_c \tag{9}$$

T is the maximum tension on the belt, T_c is the centrifugal tension on the belt

$$T_c = Mv^2 \tag{10}$$

Where M is the mass of the belt (mass = Area x length x density)
V = Velocity

$$T = \delta\, x\, a \tag{11}$$

δ is the allowable stress
Area was calculated as 104 mm^2
T_c was calculated as 3.466N
Assuming allowable stress 2Nm^{-2}
T was calculated as 208N
T_1 was calculated as 204.53N
T_2 was calculated as 11.26N
Power transmitted by belt

$$P = (T1 - T2)\, V \tag{12}$$

P was calculated as 972.148kw ~ 1.303hp

Design of Shaft

Bending moment of shaft due to the belt tension

$$M = (T_1 + T_2 + 2T_c) \times 2d. \tag{13}$$

M was calculated as $95Nm$

Equivalent twisting moment

$$Te = \sqrt{(T\hat{}2 + M\hat{}2\,)} = \pi/16 \times \tau \times d^3 \tag{14}$$

Where d is the diameter of the shaft and τ is Share stress

$$\text{But } T = \frac{power \times 60}{2 \times \pi N_2} \tag{15}$$

T_e is calculated as 95Nm
Maximum permissible stress for shaft with allowance for key ways = 42 MPa ~ 42 x 10^6 Nm
d was calculated as 23mm but 25mm was used given a 2mm factor of safety.

Force Required to Dehull Maize

$$F = m\,\omega^2\, r \tag{16}$$

where:
F = centripetal force;
m = mass of dehuller
ω = angular velocity;
r = radius of dehuller.
F was calculated as 623.267N

Determination of Dehulling Torque

The torque, *T*, is given by:

$$T = F \times r \tag{17}$$

where:
F = Force available on the dehuller
r = radius.

T was calculated as 49.8614Nm^{-1}

Power Delivered by Shaft along the Length of the Dehuller

The power is given by

$$power = (T_1 - T_2)v \tag{18}$$

The power is calculated as 727W = 0.727kW

2.3 Design of the Milling Section

The various equation applied in the designing of the shaft for the dehuling section was also applied in the milling design the following results were derived

N_1 = Rotational speed of electric motor = 1200rpm
D_1 = Diameter of driver = 0.08m
D_2 = 0.0411m
N_2 = 2333rpm
$L = 0.858\ m$
Angle of lap $(\theta) = 3.05\ rad$
Tension on the belt

$$T_1 = 290.5N$$

$T_2 = 6.72N$
Power transmitted by belt p
P = 1662.95W
d = 14.5mm

2.4 Design of the Cleaning Section

The terminal velocity of the maize kernel and the chaff which is a function of their weight was used in the design of the cleaning section. The cleaning basically involves the use of blower. The air velocity should be in between the terminal velocity of the two materials to be separated. The terminal velocities were calculated with the equation given by Sitkei (1986)

$$V_{cv} = \sqrt{\left(\frac{2Gg}{C_w A\rho}\right)} = \sqrt{\left(\frac{4d\rho_w wg}{3C_w\rho}\right)} \tag{19}$$

Where V_{cv} is the terminal velocity of the particles
G is the resistance force identical to the weight of the body
d is the diameter of the particle
ρ is the density of the air
ρ_w is the specific weight of the particles
A is the cross sectional area
g is the acceleration due to gravity
w is the weight of the particles
C_w is the drag coefficient calculated from the Reynolds number

The air flow rate at the chute outlet is calculated from the continuity equation

$$Q = AV \tag{20}$$

A is the area of the fan blade
V is the air velocity

2.5 Description of the Machine

The machine figure 4 and 5 consist of three sections for dehulling, cleaning and milling. The hopper, dehuling components, the cleaning components and the milling components are supported by a steel frame made of angle steel bar of 50 mm x 50mm x 5mm. The frame support the entire weight of the machine. The blower and dehulling barrel were fabricated from 1.6mm gauge iron plate. The first section is the dehulling section which removes the maize kernel from the maize cob. The maize cob is fed through a hopper in the shape of an inverted frustum of a pyramid made up of 2.5mm mild steel plate that is welded at an angle of repose of 27^{o} (Richey et al., 1961) to 2.5mm gauge cylindrical barrel. The maize cob moves by gravity into the dehuling chamber. The dehuling chamber consists of the housing barrel made of 1.6mm gauge mild steel and a rotating dehuling drum lined horizontally with a 1.7mm thick round iron bars to remove the maize kernel from the cobs. The dehulling drum is powered by the electric motor through the v- belt and 25mm gauge mild steel shaft. The smooth round horizontal bars on the drum strike the maize on impact and detach the grains from the cobs. The dehulled maize and the chaff pass through a sieve with 6mm round hole size (Olugbogi, 2004) located directly under the dehuling barrel while the cob is transported by gravity through a discharge chute. The dehulling barrel was inclined to allow the cob to move by gravity out of the housing barrel. The grain and chaffs leaving the sieve falls by gravity into another collector chute which discharges into another inclined chute located below a centrifugal blower. The blower is constructed with iron plate to generate enough air streams that can overcome the terminal velocity of the chaff. The blower is driven by a pulley via pulley and belt assembly and powered by the electric motor. As the grains and chaff falls into this chute, the blower cleans the grain by winnowing the chaff while the grain falls into the inclined chute and moves by gravity into the milling hopper. The milling shaft passes through the mill hopper into the milling chamber. The portion of the milling shaft inside the mill hopper is attached worms which helps in agitating the maize kernel and also convey them into the milling chamber. The milling chamber consists of attriton disc or burr, which and consists of one adjustable and one rotating hard surface circular plates, which rotates with relative motion that reduces the grain size to fine flour. The size of the product depends on the clearance between the plates. The milled maize leaves the final discharge chute were they are collected and bagged. All the moving components of the machine derive their power from a single prime mover (3hp electric motor)

Figure 4. The combined maize dehuling, cleaning and milling machine

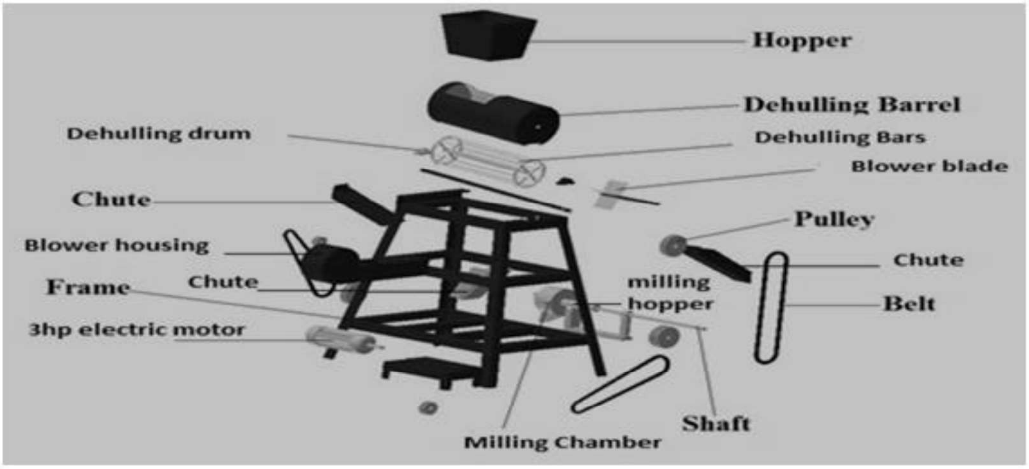

Figure 5: Exploded view of the combined maize dehuling, cleaning and milling machine

2.6 Performance Test Procedures

A bulk sample of threshed and dried cobs of yellow maize variety was procured from the open market near Umudike Nigeria. They were examined to ascertain the quality. Some samples were collected to determine the initial moisture content. The moisture content ranged from 0.5 – 1.33%w.b. The maize cobs were grouped based on its length and intermediate diameter after determining some of their physical properties. The maize cob within the length range of 9.6 - 17.7cm which forms the mode of the distribution was selected. The machine was evaluated based on dehulling time, weight of completely removed grain, weight of grain remaining on the cob, at different feeding weight and moisture content at a constant operating speed. Before the dehulling, the machine was switched on and run on no load for 15minutes to enable the machine to stabilize. The maize cob was fed through the hopper one after the other. The stopwatch was used to time the dehulling and milling. This was completed in triplicate. The weight of the completely removed grain and grain remaining on the cob and the time of dehulling were recorded and used in performance evaluation. Also the milled flour was sieved to separate the fine, coarse, whole and broken grain.

2.7 Performance Criteria

Throughput Capacity and Efficiency

Throughput capacity and efficiency for the dehulling were calculated using the formula according to (Onwualu et al., 2006). The throughput capacity (T_p) in kg/hr is given as

$$T_p = \frac{W_a}{T_t} \tag{19}$$

Where W_a the total weight of material handled, which include dehulled and undehulled maize grain.
T_t is the total time taken in handling the material
The efficiency is the percentage of the ratio of the total weight of grain actually handled W_a(kg), to the total weight of grain removed from the cob W_t(kg)

$$\eta = \frac{W_t}{W_a} \times 100 \tag{20}$$

$$Milling\ efficiency = \frac{Coarse\ flour + Fine\ flour}{Total\ milled\ sample} \times 100 \tag{21}$$

3. PERFORMANCE EVALUATION RESULTS

The result of the test of the performance evaluation of the prototype motorized combined maize dehulling, cleaning and milling machine is shown in Figures 6, 7, 9 and 9 at different axial length, weight, moisture content and speed of 450 rpm for dehuller and 2333 rpm for milling. Figure 6 and 7 showed that the dehulling efficiency ranges from 61.94% to 77.16% at longitudinal axial dimension of 10-17.7cm and mass of cob range of 58 – 116.66g, while the throughput capacity ranges from 13.32 to 23.4kg/hr for the same range of axial length and weight. The axial dimension and weight of the cob affected the dehulling efficiency and throughput capacity. The efficiency of dehulling decreased with increase in the axial length and reached the minimum of 61. 94% at 13.6cm before it started to increase again reaching the maximum of 77.16% at 15.5cm. However the dehulling throughput capacity increased with increase in axial length of the cob reaching the maximum value of 23.4kg/hr at 13.4cm. The dehulling efficiency also decreased with increase in cob weight. The efficiency of milling was calculated at the first milling run. The sieve analysis showed that the product from the mill consists of fine flour, coarse flour, broken grain and whole grain. Although the cobs could be regarded as dry cobs (0-1.33%), however the individual moisture content varied and this was considered when analyzing the milled product at the first milling run. Moisture content and the weight of the grain affected the milling efficiency and throughput as shown in Figure 8 and 9. The milling efficiency ranged from 38.91 – 50.86% with a throughput capacity of 37.84 – 50.89kg/hr. The milling efficiency increased with increase in moisture content and weight of maize grain while the throughput capacity decreased with the weight of maize grain at the first run of milling. The increase in milling efficiency might be because of the moisture content of the maize grain which is almost 0%. The cleaning efficiency of the grain was evaluated by visual examination of the preliminary run with the mill hoper closed and dehulled maize grain collected in small plastic bowl. The grain was approved to be clean by several observers. The values above show a good performance for the motorized maize dehulling, cleaning and milling machine.

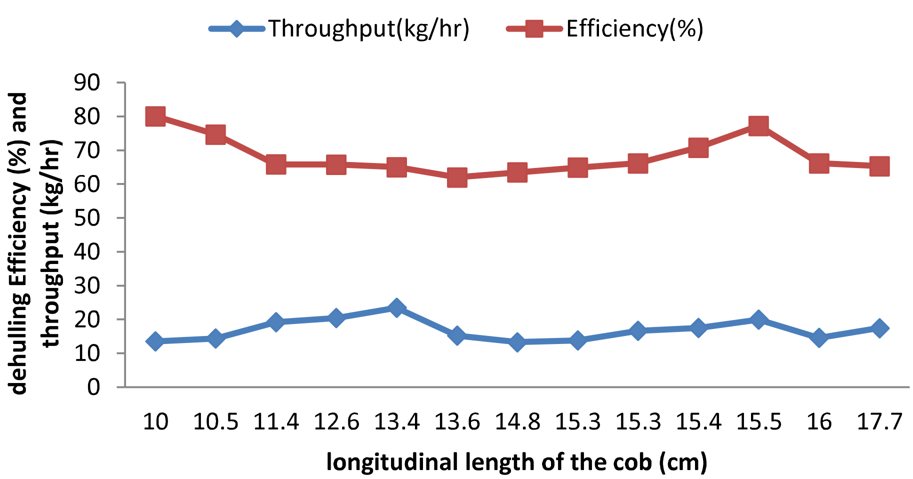

Figure 6: Throughput capacity, dehulling efficiency and longitudinal length of the cob.

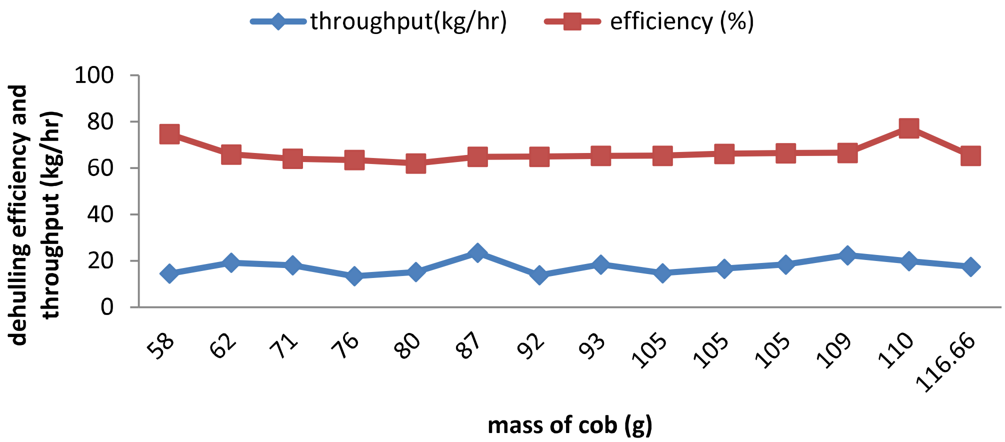

Figure 7: Throughput capacity, dehulling efficiency and mass of the cob.

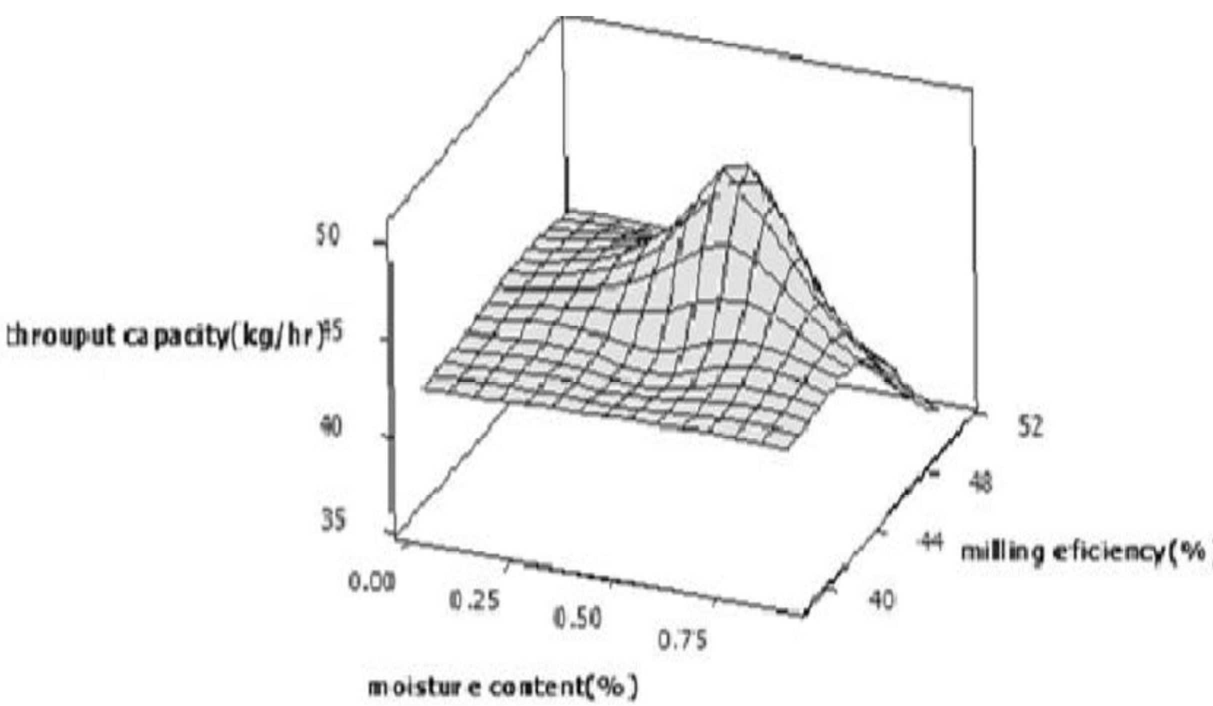

Figure 8: surface plot of moisture content, milling efficiency and throughput capacity

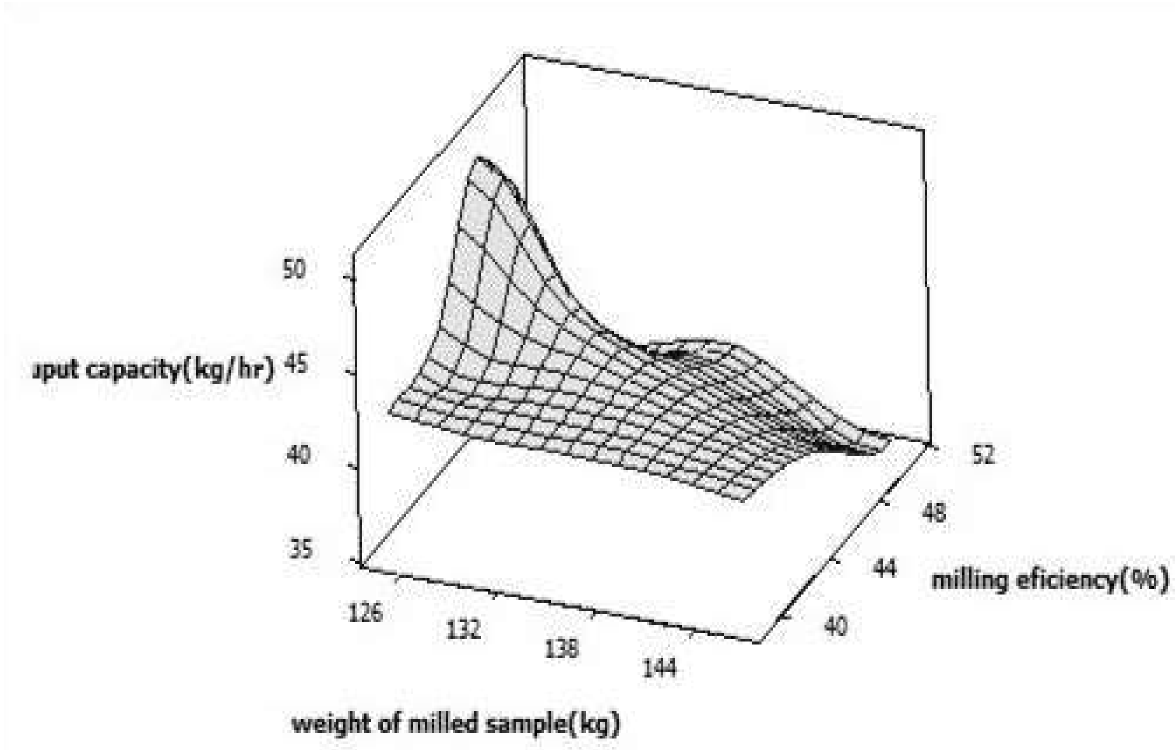

Figure 9: Surface plot of weight of milled sample, milling efficiency and throughput capacity

Figure 10: Sieve samples of milled grain

4. CONCLUSION

A machine for dehulling, cleaning and milling of maize was developed. The overall performance of the machine is above average.

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