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ORIGINAL RESEARCH ARTICLE

DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A MANUALLY OPERATED MEAT MINCING MACHINE

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ABSTRACT

In this study, a manually operated meat mincing machine was designed, constructed and its performance evaluated. The machine consists of; a single start worm auger called the shaft, a four-blade crosshead knife, a perforated plate, handle, mincing cover and a mincing head which comprised a hopper and an anchor bracket. All components of the machine were fabricated from locally available materials (stainless and mild steel) and based on the determined design parameters. The auger, mincing head, the crosshead knife and perforated plate were constructed from stainless steel material. Mild steel was used for the construction of the anchor bracket, mincing head cover and handle of the machine. These components were fabricated using the process of measurement, marking, cutting and joining. Vernier caliper and steel rule were used for measurement, scriber used for marking, center lathe machine, drilling machine, hark saw, hand snip and hand files were used for cutting. While arc welding and bolting were used the joining process. The auger had a shaft diameter of 0.025 m, worm diameter of 0.05 m and a total length of 0.22 m. The mincing head had an internal diameter of 0.052 m and external diameter of 0.06 m. The result shows that the machine can mince $0.4\,kg$ *fresh meat in* 14.11 *seconds,* $0.4\,kg$ *of perboiled meat in* 13.80 *seconds and* $0.4\,kg$ *of overcooked meat in* 13.20 *seconds. The critical load of the auger which is the major component of the machine is* $526.8\,kN$ *with a maximum stress of* $190{,}571.41\,N/m^2$*. The efficiency of the machine was 50% at a velocity ratio of 0.88 and mechanical advantage of 1.8 with a total production cost of seven thousand three hundred and ninety two naira (₦7,392). The machine will serve as a means of providing minced meat to children, elderly and the sick especially in rural areas that have no access to electricity.*

1.0 Introduction

Meat is an edible animal product in form of muscle, connective, fatty tissue and frequently bones. Humans have been consuming meat throughout history because is recognized as an important source of protein, vitamins and minerals. However, certain categories of consumers such as children, elderly and the sick will better consume the meat with ease if minced. Mincing is a process of cutting up meat or other foods such as onions, garlic, and celery into small pieces for consumption. This process can be performed by the use of a simple machine which can be specifically design based on peculiar needs especially in the production and preparation of domestic food materials for consumption. The process involves moving the product forward in a working chamber, feeding it through some knives pushed against a perforated plate. A rotating screw (worm) with uniform or variable thread pitch is used. The peculiarity of the screw is the pre-grinding of raw meat and the creation of pressure sufficient to move the product through the cutting mechanism without squeezing contained liquid phase therein. Screws are divided into cylindrical and conical; with constant or variable pitch; the number of turns; the number of threads of the screw; thread count, the profile of the thread; with or without trimming. The cutting tool of the mincing machine consists of fixed plates and rotating knives. Fixed cutting plates are made in the form of discs with round holes and are paired to cutting parts with rotating knives (Brennan, 1976); Anar et al., 2019).

There are different kinds of mincing machines being used today, these range from simple manually operated tabletop to complex electrically powered. However, their design depends on the peculiar need or process desired from the machine and its source of power(Brennan, 1976; Balami, 2000). Considering electric power challenges in the country today this study aims to design and construct a manually operated cost effective meat mincing machine from locally available raw materials. The machine major components are single start worm auger (shaft), a four-blade cross-shaped knife, perforated plate, luck nut, handle, hopper and a mincing head. The prepared meat to be minced is first feed through the hopper on the mincing head, the single start worm auger pushes the meat through the cross-shaped knife. The meat comes out through the perforated plate as a minced meat to be collected for use. Design parameters such as the yield stress of the load bearing components and capacity of the machine are determined to avoid failure. Performance and efficiency of the machine is also determined. The machine will provide a means for processing meat that can be easily consumed by children, elderly and the sick. It will also process meat for preservation, packaging and as well enhance and encourage wide application of meat in a variety of products. Moreover, it will also be most suitable for rural areas which have no access to electricity.

2. METHODOLOGY

2.1 Material selection and design of machine components

Materials used for the construction of the mincing machine are selected based on their strength, corrosion resistance, cost and local availability. It is required that material selected for the construction of components that will have direct contact with the meat should not react with the meat during the mincing process. Therefore, stainless steel is selected for the machine's components that will directly interact with the meat. These components include the hopper, mincing head, auger, perforated plate and the crosshead knife. Other components that have no direct contact with the meat such as handle and lock nut, were made from mild steel.

The machine is design to be anchored to a bench or table for effective mincing operation. The prepared meat to be minced is first feed through the hopper on the mincing head, the single start worm auger pushes the meat through the four cross-head knife, the knife mince the meat as it rotates against the perforated. The meat comes out through the perforated plate as a minced meat to be collected for use. The required power for the operation is transmitted manually through the handle to the auger. The auger as it rotates pushes the meat towards the cross-knife. In performing the mincing meat operation, the auger is subjected to torsional stress and bending and considering the auger as a power transmission shaft the ability of the shaft (auger) to effectively function under these loading condition depends on its diameter (Khurmi and Gupta, 2007), thus the shaft diameter (d) is determined from Equation 1.

$$d = \sqrt[3]{\frac{16T}{\pi\tau_a}} \qquad (1)$$

where: T is the twisting moment (torque) and τ_a is the allowable shear stress of the material (for stainless steel grade ASTM 201 India as given by Khurmi and Gupta, 2007 is $205 \times 10^6\ \mathrm{N/m^2}$). The outside diameter of the single start worm auger ($\mathrm{D_o}$) which determines the internal diameter of the mincing head is determined from Equation 2 (Khurmi and Gupta, 2007).

$$D_O = d + 1.0135P_n \qquad (2)$$

where: P_n is the circular pitch of the auger taken to be between 0.024.5 as according to Khurmi and Gupta, 2007 is between 0.024 to 0.025 m for single start worms. The twisting moment (torque) is determined from Equation 3.

$$T = \frac{P\,X\,60}{2\pi N} \qquad (3)$$

where: P is the power due to an applied force by an average person (according to Balami, 2000 is $293.4\ \mathrm{N/s}$) at the handle and at a defined revelation per minute N. The ultimate shear stress of the shaft is determined from Equation 4 considering a factor of safety (F.S.) of 5 at an allowable working stress τ_a of $41 \times 10^6\ \mathrm{N/m^2}$ (allowable working stress of stainless steel).

$$\tau_u = \frac{\tau_a}{F.S.} \qquad (4)$$

The stress distribution (σ_s) along the shaft (auger) length from $\mathrm{L} = 0$ to $\mathrm{L} = \mathrm{L_s}$ due the applied critical load ($\mathrm{F_{crh}}$) of the auger and is determined from Equations 5 and 6 respectively.

$$\sigma_{s\,0\rightarrow Ls} = \frac{T\ x\ L_s}{A_s\ x\ \delta L_s} \qquad (5)$$

$$F_{crh} = \frac{C\pi^2 E_h A_h}{\left({}^{L_h}/_{k}\right)^2} \qquad (6)$$

where: $\mathrm{L_s}$ is the length of the shaft (auger) m, $\delta\mathrm{L_s}$ is change in the shaft length, $\mathrm{A_s}$ is the cross-sectional area of the shaft (m^2), and T is the twisting moment (torque) Nm. While C is a constant depending upon the end condition for the handle ($\mathrm{C} = 2$ for single point load application handle), $\mathrm{E_h}$ is Modulus of elasticity of the material (for mild steel and as given by Khurmi and Gupta (2007) is $2.1 \times 10^{11}\ \mathrm{N/m^2}$, $\mathrm{A_h}$ is cross-sectional area of the handle, $\mathrm{L_h}$ is the length of the handle and ${}^{\mathrm{L_h}}/_{\mathrm{k}}$ is the slenderness ratio of the handle.

2.2 Components construction and assembly

The meat mincing machine is constructed based on the design parameters of the individual components machine. All component's geometrical parameters (dimensions) are based on the diameter and length of the shaft (auger), which is the fundamental component of the machine. The auger is machined on a center lathe machine from a 0.05 m diameter and 0.22 m long stainless steel material. A single start worm with a pitch of 0.084 m at the first stage and 0.054 m at the second stage is machine on the material. From the end side of the long pitch worm the diameter of the shaft is reduce to 0.02 m to a length of 0.03 m, while on the opposite side the shaft diameter is reduce to 0.025 diameter to length of 0.025 m as in Figure 1. All measurements were carried out with a Vernier caliper and the component is finished after machining with a hand file after machining. The auger is housed in the mincing head which is also machined on a center lathe machine. The mincing head was fabricated in three parts and thereafter the parts were welded together using 12 G stainless steel welding electrodes as in the assembly drawing in Figure 6. The first part is 0.170 m diameter with a length of 0.250 m stainless steel material. This material was machined on a center lathe based on the dimensions in Figure 2a. The second part of the mincing head was fabricated from mild steel material based on the dimension in Figure 2b. It was a bench work fabrication process that involved measurement, marking cutting, dicing, tapping and welding. The third part was fabricated from 0.002 m stainless steel plate based on the dimension in Figure 2c. The process of fabrication involved measurement, marking, cutting and welding on a workshop bench.

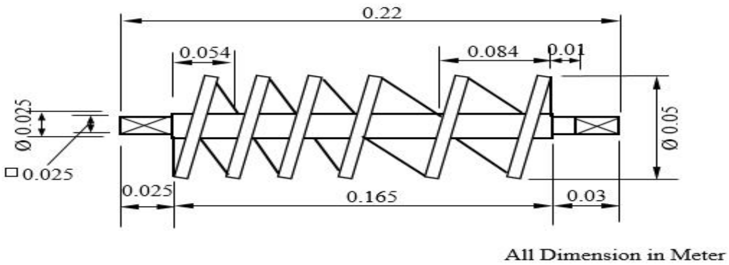

Figure 1: Single start variable pitch worm auger (Shaft)

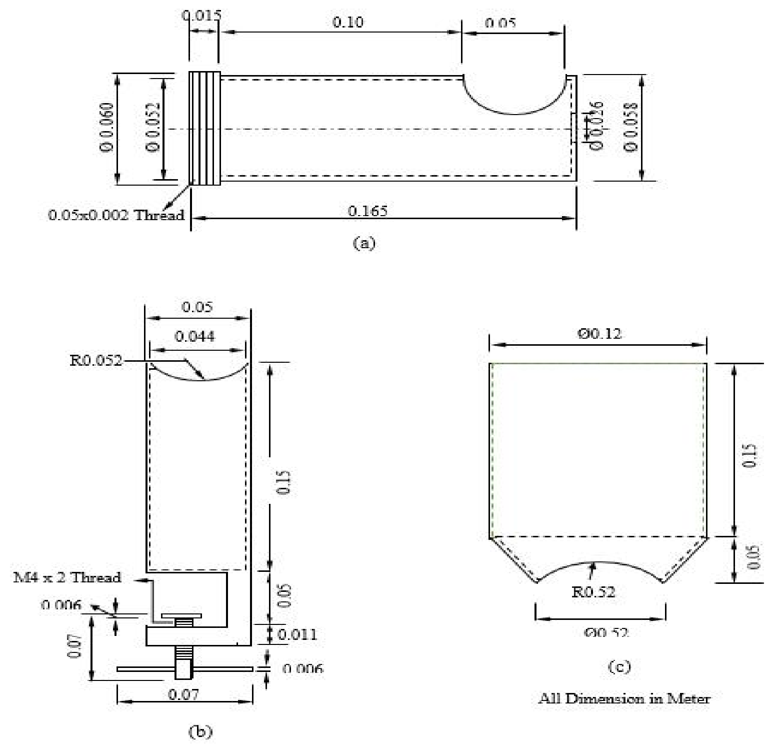

Figure 2: The parts of the mincing head

The mincing head cover was machined on a center lathe from 0.8 m diameter and 0.8 m long stainless steel material base on the dimension in Figure 3a. The fabrication process of the mincing head cover involved meaurement using vernier caliper, removal of material using the center lathe machine and finishing using a hand file. The perforated plate which was also produced from the same material was fabricated using the same method used for the production of the mincing head cover based on the drawing in Figure 3b. However the 0.006 m diameter holes marked based on the drawing in Figure 3b, punched using a centre punch and drilled on a piller drilling machine.

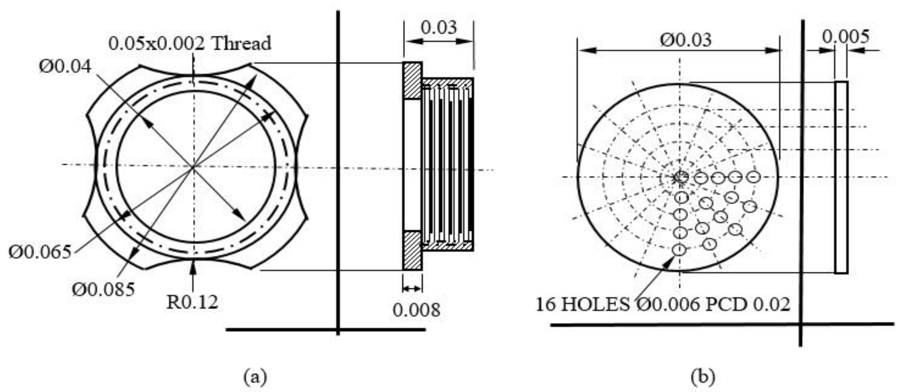

Figure 3: Mincing head cover and perforated plate

The cross-head knife was produce from 0.06 m diameter and 0.03m long stainless steel material on a centre lathe machine and a pillar drilling machine based on the dimension in Figure 4. Shaping the knifes, the centre square hole and sharping the knifes were carried on a workshop bench vice using a steel rule for measurement, scriber for marking, hark saw and set of files for cutting and shaping.

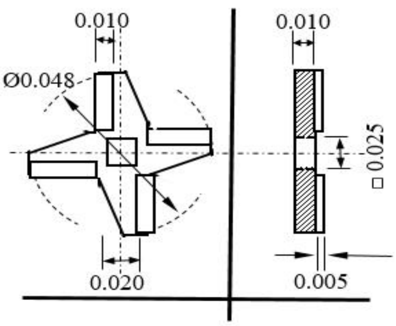

Figure 4: The cross-head knife

The handle of the machine was fabricated from 0.03 m diameter mild steel shaft and 0.05 m width 0.01 m height and 0.03 m long mild steel bar based on the dimension in Figure 5. The fabrication involved machining the 0.03 m diameter shaft on a centre lathe and cutting and filing the mild steel bar in a bench vice to the dimension in Figure 5. The finished sections were the welded together as in Figure 5.

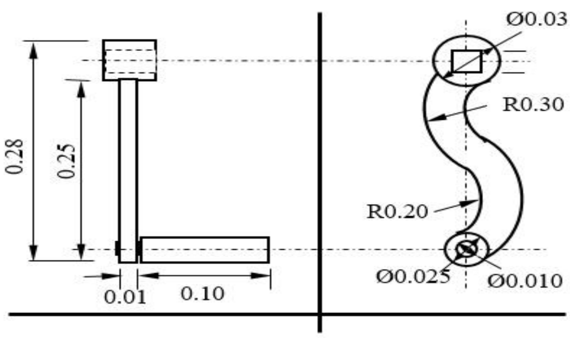

Figure 5: The mincing machine handle

All fabricated machine components were cleaned and assembled as in Figure 6 for performance analysis based on the numbers in the sketch. The parent component was the barrel and hopper. Number 1 was inserted first in the parent component, followed by component numbers 2, 3, 4, 5, 6, 7 and finally 8 which is anchoring the machine a bench or table for use.

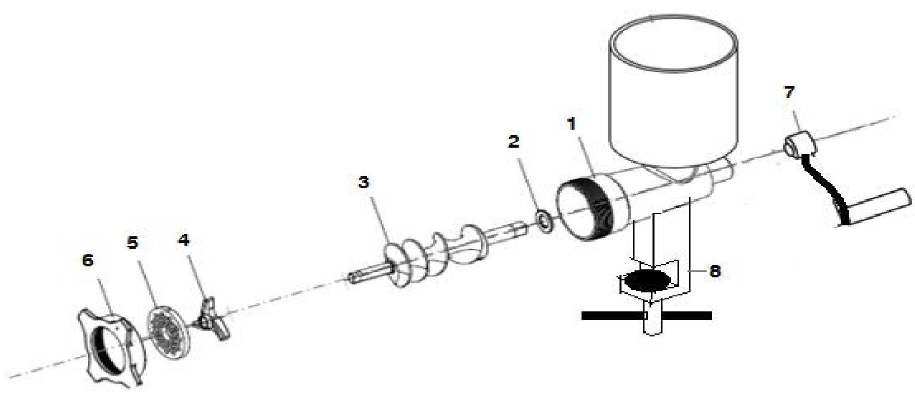

Figure 6: Assembly Sketched of the mincing machine

2.3 Performance evaluation

The performance of the machine was evaluated by mincing and analysis of three samples beef of the same mass (0.40 kg). The first sample was fresh meat, the second was parboiled while the third was overcooked. The mass of each sample of meat was taken before and after mincing using a digital weighing machine (Clark Model 153) with respect to time and number of handle turns applying approximately the effort. The outcome of the analysis was used to determine the performance of the machine. Assuming approximately same magnitude of effort was applied at the handle for a predetermined handle speed (10, 20, 30, 40 and 50) the mass of each sample of the minced beef was taken with respect to time. This was used to determine the velocity ratio mechanical advantage and efficiency of the machine as in Equation 7, 8 and 9 respectively.

$$VR = \frac{D_L}{D_F} \tag{7}$$

$$MA = \frac{W_a}{F_a} \tag{8}$$

$$\eta = \frac{VR}{MA} \tag{9}$$

where: VR is the velocity ratio, D_L is $0.22\ \mathrm{m}$ distance moved by the meat during mincing, D_F is $0.25\ \mathrm{m}$ distance moved by the applied load, MA is the mechanical advantage of the machine, W_a is $528\ \mathrm{N}$ effort required to mince $0.4\ \mathrm{kg}$ of meat. According to Food Production (2010) $1320\ \mathrm{N}$ is required grind of $1\ \mathrm{kg}$ meat. Also F_a is $293.4\ \mathrm{N}$ the available load that is the approximate effort provided by an average person according to Balami (2000), and η is the efficiency of the machine.

3. RESULTS AND DISCUSSION

The design of the mincing machine auger (shaft) shows that the shaft has a root diameter of 0.025 m and a worm diameter of 0.050 m based on a circular pitch of 0.0245. According to Khurmi and Gupta (2007) circle pitch of single start worm is between 0.024 to 0.025 m. Given a tolerance of 0.002 m and based on a worm diameter of 0.050 m, the mincing head internal diameter used was 0.052 m. Based on these dimensions the auger and mincing head were fabricated from stainless steel material and according to Oyelade et al. (2004), materials to be used for the construction mincing machines should be a material that will not react with the product to be minced. The twisting moment on the auger Tis due to an applied load of $293.4\ \mathrm{N}$ is $93.38\ \mathrm{Nm}$. The design result also shows that the ultimate shear stress of the auger is $8.2 \times 10^6 \frac{\mathrm{N}}{\mathrm{m}^2}$. This was determined based on stainless steel allowable working stress of $4.1 \times 10^7\ \mathrm{N/m^2}$ and a factor of safety of 5. The critical of the auger is determined as $526.8\ \mathrm{kN/m2}$ and this is less than $4.1 \times 10^7\ \mathrm{N/m^2}$ the allowable working stress of the auger material. According to Khurmi and Gupta (2007), for shaft to withstand a defined working load the critical load must be less than the allowable working load of the shaft material.

The stress distribution along the auger length L_s from 0 to $0.22\ \mathrm{m}$ due to twisting moment in cause of mincing is $190{,}571.41\ \mathrm{N/m^2}$ at the point of load application when L_s is $0.022\ \mathrm{m}$ and drops to $190.57\ \mathrm{N/m^2}$ when L_s is 0.22 mas shown in Figure 7. This shows that the maximum stress $190{,}571.41\ \mathrm{N/m^2}$ the auger will be subjected to during mincing is also less than $4.1 \times 10^7\ \mathrm{N/m^2}$ the allowable working stress of the auger material (stainless steel).

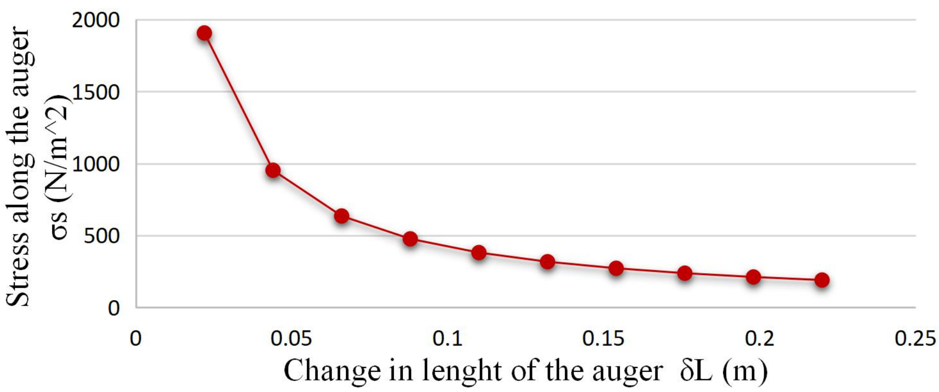

Figure 7: Stress distribution along the length of the auger

Based on the design parameters of the components of the mincing machine the components are fabricated, assembled tested for performance as shown in Figure 8.

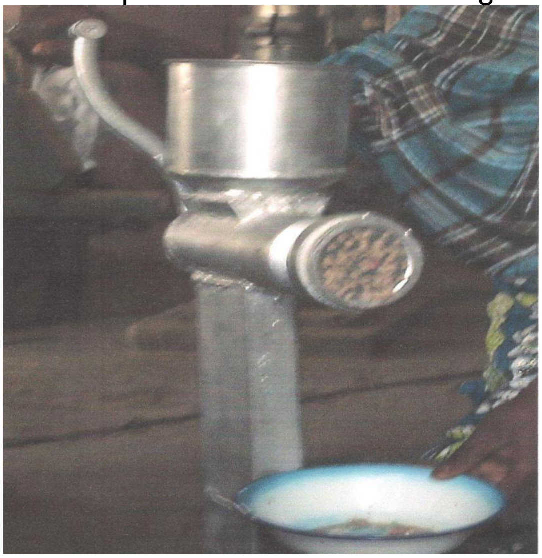

Figure 8: The mincing machine under evaluation

The result of the performance analysis of the three samples tested shows that 0.4 kg of fresh, parboiled and overcooked meat was minced in 14.10, 13.80 and 13.20 seconds respectively. The mass of the fresh, parboiled and overcooked weighed after mincing were 0.30, 0.20 and 0.23 kg respectively as in Table 1. The result also shows that less time was taken to mince the parboiled and the overcooked meat as compared with the time taken for the fresh meat. However, the mass of ejected meat of the parboiled and overcooked meat was also less with only 50 % and 57.5% of the meat minced and ejected by the machine at an applied effort of 293.4 N and 30 rpm. According to Food Production and Processing (2010) and also as reported by Sunday and Ndaliman (2015), mincing machines generally succeed in mincing and ejecting between 70 to 80 % of the meat. Although this percentage is only realistic in large motorized mincing machines, 40 to 50% is as well achievable in optimized small manually operated machines.

Table 1 Performance analysis of the mincing machine

Sample	Mass of meat before mincing m_b (kg)	Mass of meat after mincing m_a (kg)	Time taken t (sec)
Fresh meat	0.40	0.30	14.10
Boiled meat	0.40	0.20	13.80
Overcooked meat	0.40	0.23	13.20
Average	0.40	0.24	13.67

All the three sample of the minced meat (fresh, parboiled and overcooked) were minced homogenously by the machine as shown in Figure 9a, b and c.

(a) (b) (c)

Figure 9: Samples of the minced meat by the machine

The velocity ratio (VR) and mechanical advantage (MA) of the machine were determined as 0.88 and 1.8 respectively. From the two parameters the efficiency of the machine is 50%.

4. CONCLUSION

The manually operated meat mincing machine was designed and its performance evaluated. The result shows that the machine can mince $0.4\,\mathrm{kg}$ fresh meat in 14.11 seconds, $0.4\,\mathrm{kg}$ of parboiled meat in 13.80 seconds and $0.4\,\mathrm{kg}$ of overcooked meat in 13.20 seconds. The critical load of the auger which is the major component of the machine is $526.8\,\mathrm{kN}$ with a maximum stress of $190{,}571.41\ \mathrm{N/m^2}$. The efficiency of the machine is 50% at a velocity ratio of 0.88 and mechanical advantage of 1.7996 with a total production cost of seven thousand three hundred and ninety two naira (₦7,392). The machine will serve as a means of providing minced meat to children, elderly and the sick especially in rural areas that have no access to electricity.

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