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Development and Performance Evaluation of a Poultry Bird Defeathering Machine

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Abstract: *The poultry processing industry is under high demand due to the increasing demand for chicken meat worldwide, especially in Sub-Saharan Africa, where manual defeathering is the norm. The primary objectives of this study were the design, construction, and performance evaluation of a chicken defeathering machine using locally accessible materials. Standard equations and formulae were used in the design of the machine's main parts, which include the electric motor, sheave, belt, pulley, bearing, feather plate, rubber fingers, cylindrical drum, and rubber pluckers. Fifteen cockerel chickens of different weights were evaluated at three different speeds of 450, 500, and 550 rpm in order to assess the performance of the chicken feather plucking machine. The data obtained was analyzed using Excel 13. The highest defeathering efficiency of 84.49% was recorded at a machine speed of 450 rpm, followed by a defeathering efficiency of 81.70% at a machine speed of 500 rpm, while the lowest defeathering efficiency of 80.98% was recorded at a machine speed of 550 rpm, respectively. The highest plucking time of 22.80 s was recorded at a machine speed of 450 rpm, followed by a plucking time of 20.40 s at a machine speed of 500 rpm, while the lowest plucking time of 19.80 s was recorded at a machine speed of 550 rpm, respectively. It will take an average of 21.00 seconds to defeat a medium cockerel used for the testing of the defeathering, which implies that the developed defeathering machine can defeat 171 chickens per hour. The machine is powered by a 5.5-hp, three-phase electric motor and has a production cost of $250, with the construction materials being locally available at affordable costs. The machine is recommended to both small and medium-scale farmers and food processors due to its simplicity, cost-effectiveness, and improvement over the previous ones in terms of efficiency and capacity.*

Keywords: *Design, Fabrication, Capacity, Efficiency, Testing*

1. INTRODUCTION

Developing a machine to remove feathers from chickens is a cost-effective method used by automated poultry processing facilities to increase the volume of poultry products they process daily by eliminating the need to remove feathers by hand for meat preparation. Poultry used to be manually de-feathered, which involved removing the feathers by hand after soaking them in hot water. Because manual de-feathering takes a long time, this method causes bottlenecks in the production line that produces poultry meat. According to research, de-feathering a bird by hand requires at least ten minutes [1]. Additionally, it is not very hygienic because workers risk burns and skin infections by dipping their hands into the hot, dirty water. Effective mechanization of the poultry-to-meat processing is therefore required. Furthermore, a variety of machines that can handle both a large and small number of chickens have been developed for the de-feathering process [2]. A poultry de-feathering machine can process an average-sized bird (~3.6 kg) in 30 seconds, indicating a better process economy [3]. The labor-intensive and slow manual processing method has not proven economically viable for large-scale production. Various de-feather mechanisms, including rubber fingers, rotating plates, drums, and angle bar mechanisms, are used in mechanical defeathering [4].

A number of important procedures that are involved in the production of ready-to-cook poultry meat contribute to the high price of poultry meat on the market. Slaughter, de-feathering techniques involving scalding and feather plucking, eviscerating, chilling, deboning, packing, and storage is the most important steps in the poultry processing industry. Slaughtered chickens are scaled, which entails soaking them in hot water to soften the follicles surrounding the feathers, before the defeathering process. The de-feathering procedure is acknowledged as one of the most labor-intensive and technically demanding of the various poultry processing operations [1].

The de-feathering machines are common in most developed countries, but because of their high cost, local chicken processors don't usually use them right now. A domestic defeathering machine designed to handle fewer than five birds sold for between $532.5 and $3000, Adetola et al. [1]. This is a significant price for the average Nigerian. It is imperative that the de-feathering problem associated with the chicken processing industry be addressed. This calls for the process to be effectively mechanized in order to promote quality, safety, ergonomics, and economical operation [1]. In a study published in 2017, Nwachukwu[5] evaluated the performance of a motorized defeathering machine for chickens that could pluck 17 birds in an hour and had 89.27% defeathering efficiency. It was concluded that the defeathering machine was effective for small-scale chicken farmers and recommended for modification to increase its efficiency. Sharif [6] reported a developed defeathering machine in which less than 2% of the wings and legs of the chicken were broken, 5% of the skin was torn, and 95% of the feathers were removed. A modified chicken defeathering machine with a 26 cm radius drum was found to have optimum speed of 125 rpm in 60 seconds. He suggested that in the future designs that rubber fingers should be used in the defeathering machine. Furthermore, Ugwu et al. [7] evaluated and improved the functionality of a machine intended to pluck feathers. The study revealed that the machine could complete a pluck at 400 rpm in an average of 22.8 seconds. According to the study, the machine's speed and the kind of poultry birds used also affect how well the machines function.

Tanimola et al. [4] in southwest Nigeria developed a bird de-feathering machine that can remove feathers for 360 mature birds in an hour, regardless of the species of bird. In controlled testing conditions, the machine gave a 96 percent defeathering efficiency. The optimal operating parameters for a chicken slaughtering system in Vietnam were reported by Nguyen et al. [8]. According to the study, 67 degrees Celsius is the ideal scalding temperature, and 80 seconds is the ideal scalding time.

Researchers suggested that a number of parameters have been investigated and that, henceforth, factors such as plucking angle, speed, type of bird, and scalding temperature should be taken into account in order to successfully optimize and improve the defeathering machine's efficiency for improved poultry bird processing, which benefits farmers by generating higher incomes and providing high-quality food for the public. Despite coming in a variety of sizes and shapes, including small and large machine types, scaling and picking machines which are primarily used for the processing of poultry products remain relatively unknown in Nigeria's poultry processing business or industry, primarily because of their expensive design. Today, the majority of poultry products sold in Nigeria are processed by hand. User-friendly, dependable, and effective poultry processing equipment is required to prevent accidents and infections from chicken cadavers that might happen during some of the processing procedures.

Processing birds includes transporting and catching them, killing and bleeding them, scalding and picking (removing the feathers), removing the head, oil glands, and feet, deboning and dissecting them, packaging, storing them, and then distributing them. Feather removal is the most expensive and time-consuming procedure out of all of these. Regional variations exist in their acceptance and demand. For example, a driving pulley mechanism that rotates a cylindrical drum embedded with a rubber-finger matrix powers the Mueller poultry picker electrically [9]. A collection bowl for the feathers that are plucked is also incorporated into the design. However, Gordon designed the plucked so that the drums could rotate counter-clockwise by attaching an extended two-pulley shaft to an electric motor. The rubber fingers on the drum rotate to pluck the feathers because of the centrifugal forces acting on the holders and fingers, the fingers take on positions that are radial to the drums. The feather is removed from the carcass by wiping the ribbed surfaces of the fingers. Environmental issues and requirements related to public health affect the majority of these slaughterhouses in Nigeria. The safety of the food is not taken into consideration during these unregulated slaughter operations. As such, contaminated food puts everyone's health at risk worldwide particularly with young children, pregnant women, the elderly, those with underlying medical conditions, and infants. In light of this, the goal of this project is to create a low-cost, effective machine for de-feathering chicken that will enhance food safety, hygiene, and the de-feathering procedure used in the production of chicken meat. Due to their high cost and effectiveness, most defeathering machines are out of reach for local farmers and food processors despite the fact that researchers from all over the world have published a variety of findings with varied modifications over the years to improve the design and efficiency of these machines. Therefore, user-friendly, dependable, and efficient poultry processing equipment is required to meet the steadily increasing demand for poultry meat.

2. MATERIALS AND METHOD

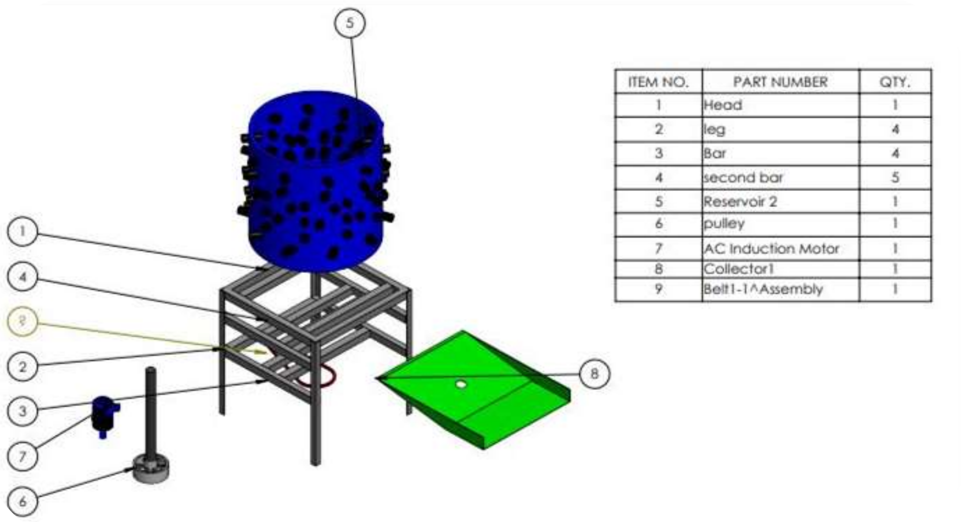
A defeathering machine is a mechanical device used in the poultry processing industry to remove feathers from birds.

2.1 Machine Description and Working Principle

Figure 1 presents the exploded view of the developed De-Feathering Machine. The machine consists of an electric motor, rubber fingers, a cylindrical drum, a sheave, a belt, a pulley, a bearing, feather plate, and rubber pluckers. Torque is transferred from the machine's electric motor to the sheave via a belt and pulley, and then it is transferred to the shaft, which is supported by two bearing assemblies. A stationary cylindrical drum studded with rubber pluckers and studded with feather plates made of rubber fingers are rotated by a shaft. In about twenty seconds, the rubber pluckers grasp the feathers and rotate to de-feather the bird. After that, the carcass was almost completely cleaned and stripped, ready for the worktable. Due to centrifugal force and gravity, the feathers fly off the feather plate in a 3 cm-wide area between the feather plate and the cylindrical drum.

2.2 Design Consideration of the Machine

The de-feathering machine's design took into account a number of factors, such as affordable, locally sourced materials, a straightforward concept, precision in design, robustness, and durability. An efficient and financially viable chicken defeathering machine was designed and built using easily obtained and reasonably priced materials (suitable technical materials that could yield the best performance in service). The selection of materials for the machine's construction is determined by factors such as material properties, affordability, suitability, and accessibility.



ITEM NO.	PART NUMBER	QTY.
1	Head	1
2	leg	4
3	Bar	4
4	second bar	5
5	Reservoir 2	1
6	pulley	1
7	AC Induction Motor	1
8	Collector1	1
9	Belt1-1^Assembly	1

Figure 1: Exploded view of de-feathering machine

2.3 Design Analysis of the Machine Component Parts

2.3.1 Design of the volume of the plucking chamber

[khurmi and Gupta [10] reported the formulae for determining the volume of the plucking chamber using Equation 1.

$$V = \frac{1}{3}(R^2 - r^2)\pi h \quad (1)$$

Where V is the volume of the hopper; R is the radius of the upper opening of the chamber which is equal to 0.50 m, r is the radius of the lower part of the chamber which is equal to 0.30 m and h is the height of the hopper which is equal to 0.40 m. Substituting the values of R, r and h into Equation 1, therefore volume of the plucking chamber = 0.0670 m^3.

2.3.2 Design of the plucking chamber capacity

The plucking chamber capacity was determined using Equation 2 as recommended by [11].

$$P_c = \rho V \quad (2)$$

Where P_c is the plucking chamber capacity, ρ is the density of chicken sample = 1113 kg/m^3 and V is the volume of plucking chamber = 0.0670 m^3. Substituting the values of ρ and V into Equation 2, therefore plucking chamber capacity = 74.60 kg

2.3.3 Angular velocity

The angular velocity was determined using Equation 3 as recommended by [10].

$$V = \frac{\pi DN}{60} \quad (3)$$

Where V is the angular velocity in m/s, D is the diameter of the rotating drum in mm = 400 mm, N is the speed of the driven machine in rpm = 720 rpm. Substituting the values of D and N into Equation 3, therefore the angular velocity is 15.08 m/s.

2.3.4 The force required to remove the feather (Centrifugal force)

The centrifugal force required was determined using Equations 4 - 8 as recommended by [10].

$$f = \omega v \quad (4)$$

$$v = \omega r \quad (5)$$

$$f = \omega^2 r \quad (6)$$

$$f = \frac{v^2}{r} \quad (7)$$

$$F_c = mf = \frac{mv^2}{r} \quad (8)$$

Where f is the force in N, ω is the angular speed in rad/s, v is the velocity in m/s = 15.08 m/s, r is the radius of the rotating drum in mm = 0.20 m, F_c is the centrifugal force in N and m is the average mass of the birds in kg = 7.25 kg. Substituting the values of m, v and r into Equation 8. Therefore, the centrifugal force of 8.24 kN was obtained.

2.3.5 Design for shaft

The diameter of the shaft was determined using Equation 9 as recommended by [10].

$$F_c = \frac{\pi d^2}{4} \quad (9)$$

Where F_c is the centrifugal force in N = 9400 N, d is the shaft diameter of the defeathering machine in m. Substituting the value of F_c into Equation 9, therefore the shaft diameter of 0.0173 m was obtained. The shaft diameter of 0.020 m was used for the fabrication of the defeathering machine

2.3.6 Shear stress

Khurmi and Gupta [10] reported Equation 10 for determination of maximum shear stress for a beam of circular section.

$$i_{max} = {}^{4}\!/_{3}\, i_{ave} \quad (10)$$

$$i_{av} = \frac{F_c}{A} = \frac{F_c}{\pi d^2/4} \quad (11)$$

Where i_{max} is the maximum shear stress in N/m^2, i_{ave} is the average shear stress in N/m^2, F_c is the centrifugal force in N = 9400 N, A is the cross-sectional area in m^2 = 0.0003142 m^2. Therefore, the average shear stress = 2.95 N/m^2.

2.3.7 Length of belt

The length of the open belt was determined using Equation 12 as recommended by [10].

$$l_o = \frac{\pi}{2}(D_1 + D_2) + 2c + \frac{(D_2+D_1)^2}{4c} \quad (12)$$

Where L_o is the Length of belt in m, D_1 is the diameter of driver pulley in m = 0.15 m, D_2 is the diameter of driven pulley in m = 0.30 m, C is the centre distance between the pulleys in m = 0.60 m. Substituting the values of D_1, D_2 and C into Equation 12. Therefore, the open belt of 1.99 m was obtained. The belt length of 2.00 m was used.

2.3.8 The power required for the De-feathering machine

1. **Power required to rotate the feather plate:** The power required to rotate the feather plate was determined using Equation 13 respectively as recommended [12]. The angular velocity of the rotating plate was calculated using Equation 14.

$$P_r = W_p R_P \omega_p \quad (13)$$

$$\omega_p = \frac{2\pi N}{60} \quad (14)$$

Where, P_r is the power required to rotate the feather plate in kW, W_p is the weight of the rotating plate which is equal to 7.00 N, R_P is the radius of the rotating plate which is equal to 0.20 m, ω_p is the angular velocity of the rotating plate = 150.82 rad/s, N is the speed of the driver in rpm = 1440 rpm. Substituting the values of W_p, R_P and ω_p. Therefore, P_r = 211.15 W

2. **Power required to de-feathering:** The power required to de-feather the bird was determined using Equation 15 as recommended by [12]. Torque of the de-feathering chamber was calculated using Equation 16.

$$P_d = T_s \omega_d \quad (15)$$

$$T_s = \frac{\pi d^3 \mathrm{T}}{16} \quad (16)$$

Where, P_d is the power required to de-feather the bird in Kw, T_s is the torque of the de-feathering chamber, ω_d is the angular velocity of the de-feathering chamber =150.82 rad/s, d is the mean diameter of the de-feathering chamber = 0.40 m, T is the shear stress of the de-feathering chamber =1791N/m2, T_s is the torque of the de-feathering chamber = 22.51 Nm. Substituting the values of T_s and ω_d. Therefore, the power required to de-feather the bird = 3395 w.

3. **Total power requirement of the machine:** The total power (P_t) requirement of the machine is the sum of power required to rotate the feather plate (P_r) and the power required to de-feather (P_d) the chicken. The total power (P_t) requirement of the machine was determined using Equation 17 as recommended by [12].

$$P_t = P_r + P_d \quad (17)$$

Where, P_t is the total power requirement of the machine in W, P_r is the power required to rotate the feather plate in W and P_d is the power required to De-feather the chicken in W. Substituting the values of P_r and P_d. Therefore, the total power requirement of the machine (P_t) = 3606.15 w = 3.61 Kw. Therefore, 4.00 Kw or 5.5 Hp electric motor will be used.

2.4 Machine Performance Evaluation Parameters

2.4.1 The defeathering efficiency

The defeathering efficiency was determined using equation 18 as recommended by [13].

$$Ed = \frac{Mi}{Mi+Mf} X\ 100 \tag{18}$$

Where Ed is the defeathering efficiency in %, Mi is mass of feather removed by machine in kg; Mf is the mass of feather removed by hand in kg.

2.4.2 Defeathering capacity

The defeathering capacity was determined using Equation 19 as recommended by [9].

$$Cd = \frac{NCP}{Tt} \tag{19}$$

Where Cd is the defeathering capacity in kg/hr, Ncp is the number of chickens processed in kg and Tt is the total time taken in hr.

2.5 Experimental Procedure

A thermometer (used to determine the scalding temperature), a stopwatch, a collecting bowl, and a live chicken are among the tools and supplies used. The efficacy of the chicken feather plucking machine was tested on fifteen cockerel chickens of varying weights at three distinct rpm ranges: 450, 500, and 550. The live chicken's weight was measured and noted. The birds were scalded by heating a lag container partially filled with water on a gas stove. To periodically check the water's temperature, a thermometer was introduced. The water's temperature after it had already boiled was measured and recorded. A digital stopwatch was used to record the amount of time it took to scald one of the chickens after it had been slaughtered and submerged in the hot water. After turning on the chicken defeathering machine and carefully placing the already-scalded chicken inside the defeathering chamber, the defeathering time was noted. After defeathering, the chicken's weight was measured and noted. Both the weight of the feathers removed by hand (Mf) and the feathers removed by the machine (Mi) were recorded after they were gathered. After giving the machine a thorough cleaning, the process was carried out for the remaining chickens. Figure 1 shows the pictorial view of the developed poultry bird defeathering machine.

Figure 1: A Poultry bird defeathering machine

2.6 The Production Cost Estimate of the Defeathering Machine

The production cost estimate of the machine is presented in Table 1.

Table 1: Components of the machine, dimensions and Cost

S/N	Components	Dimension	Value	SI Unit	Cost in $
1	Machine frame	Length	500	mm	45
		Width	290	mm	
		Height	700	mm	
2	Bearing	Diameter	25	mm	20
3	Electric motor	Ratings	0.75	kW	60
			1	hp	
			1400	r/mm	
4	Shaft	Length	500	mm	30
		Diameter	17	mm	
5	Belt	Length	2000	mm	5
6	Collecting plate	Length	600	mm	10
		Height	100	mm	
		Width	300		
7	Defeathering chamber	Diameter	430	mm	30
		Height	370	mm	
8	Pulley	Diameter	210	mm	10
			170	mm	
			50	mm	
9	Rubber fingers	Diameter	15	mm	40
		Length	100	mm	
	Total				250

2.7 Statistical Analysis

The data obtained was analysed using Excel 13 (Version 13, 2021, California, USA).

3. RESULTS AND DISCUSSIONS

3.1 Effect of Machine Speed on Defeathering Efficiency

Table 2 presents the effect of machine speed on defeathering efficiency. The highest defeathering efficiency of 84.49% was recorded at a machine speed of 450 rpm, followed by a defeathering efficiency of 81.70% at a machine speed of 500 rpm, while the lowest defeathering efficiency of 80.98% was recorded at a machine speed of 550 rpm, respectively. This result indicates that machine speed has an influence on defeathering efficiency; an increase in machine speed leads to a decrease in defeathering efficiency. This might be due to the optimum speed required for efficient operation of every machine, and once the optimum machine speed is attained, any increase in machine speed will lead to a decrease in the efficiency of the machine. This might be because of the stiffness, diameter, spacing, and number of birds per task of the rubber feeders used in the defeathering machine. The birds suffer less harm because the rubber fins pluck the feathers rather than cutting them. The greatest defeathering efficiency was attained, which was less than that of [14] and [5], who achieved 86.80% and 89.27%, respectively, but higher than that of [15], at 82%, and [13], at 81.8%. The machine's efficiency is dependent on both its speed and the type of poultry it produces [7]. Adejumo et al. [16] used two bird breeds—Isa Brown and Cockerel—to test a feather plucking machine at speeds of 225, 312, 369, and 426 rpm. According to reports, the defeathering machine worked better at 426 rpm as opposed to 225 rpm, and the Cockrell produced better plucking results.

Table 2: Effect of machine speed on defeathering efficiency

S/N	Efficiency of the machine in % at 450 rpm	Efficiency of the machine in % at 500 rpm	Efficiency of the machine in % at 550 rpm
	81.53	81.30	79.40
	96.21	84.43	78.90
	82.72	79.78	82.30
	81.40	80.80	80.20
	80.60	82.40	84.10
Mean	84.49	81.70	80.98
Maximum	96.21	84.43	84.10
Minimum	80.60	79.78	78.90

3.2 Effect of Machine Speed on the Plucking Time of the Defeathering Machine

Table 3 presents effect of machine speed on the plucking time of the defeathering machine. The highest plucking time of 22.80 s was recorded at machine speed of 450 rpm, followed by the plucking time of 20.40 s at machine speed of 500 rpm while the lowest plucking time of 19.80 s was recorded at machine speed of 550 rpm respectively. This is consistent with findings from other researchers that the defeathering machine's speed can be increased from 225 to 426 rpm to achieve the machine's optimal performance [7, 18].

Table 3: Effect of machine speed on the plucking time of the defeathering machine

S/N	Plucking Time of the Machine in s at 450 rpm	Plucking Time of the Machine in s at 500 rpm	Plucking Time of the Machine in s % at 550 rpm
	25.00	20.00	19.00
	22.00	22.00	21.00
	20.00	19.00	18.00
	23.00	21.00	21.00
	24.00	20.00	20.00
Mean	22.80	20.40	19.80
Maximum	25.00	22.00	21.00
Minimum	20.00	19.00	18.00

3.3 The Defeathering Capacity

Based on Table 3, it can be inferred that the developed defeathering machine can defeather 171 chickens per hour, as it takes an average of 21.00 seconds to defeather a medium cockerel used for testing. David [17] states that if birds are manually defeathered, it takes five minutes to accomplish the goal of 12 birds per hour. Consequently, an hourly average of 171 chickens was produced using this design. It was intended for the machine to hold one or two birds per process. There was little or negligible damage to the carcass of the chicken after slaughter. The defeathering capacity of the machine is 171 chickens per hour, which represents a high value when compared to some of the chicken defeathering machines developed by other researchers. The defeathering capacity value was higher than that developed by [9], which was 107 chickens per hour, but lower when compared to the machine developed by [4], which is 360 chickens per hour. The low value is associated with the capacity of the electric motor, which generated a low speed, and other factors such as scalding.

4. CONCLUSIONS

A medium-size poultry defeathering machine had been designed, fabricated, and tested. The developed machine is an improvement over the existing ones in terms of efficiency, capacity, cost, simplicity of construction, and operation, which make it easily accessible and affordable to local farmers and food processors. The machine is recommended to chicken meat processors due to its time restriction, simplicity of use, and sanitary processing of poultry meat.

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