Engineering and Technology Journal e-ISSN: 2456-3358

Volume 09 Issue 12 December-2024, Page No.- 5665-5670

DOI: 10.47191/etj/v9i12.15, I.F. – 8.227

Development and Performance Evaluation of Animal Feed Chopper

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ABSTRACT: Ethiopia's livestock population is the largest in Africa; however, different factors or constraints limit the full exploitation of the agricultural sector in general and the livestock "sub-sector" in particular. In the country, the availability, quality, and quantity of feed have always been challenges in the livestock sector. This process is laborious, and it takes longer. To alleviate this problem, using maize and sorghum stalks is an important remedy has chopped. The developed machine consist the part of frame made up of angle iron 40mmx40mmx4mm, chopper house *made from sheet-metal 2 mm thickness, cutter blades:- was the main functional unit made up of treaded milled steel that performs the chopping action with a cutting depth of 1 cm and a cutting length of 6 cm and was made up of 6 mm thickness and 4cm width developed to cut the feed to the recommended lengths with reasonable consistency.* Therefore, the developed machine was evaluated. The research was conducted at Jimma Agricultural Engineering Research Centre (JAERC), Kersa districts to evaluate the machine's performance in terms of chopping efficiency, throughput capacity, and cutting efficiency at different speeds of the cutter shaft. The output of the chopper was found to be a remarkable achievement. The performance of the machine was evaluated with treatments of the maize and sorghum stalks, engine speed and feed rate 9kg/min, 11kg/min and 13 kg/min using a factorial design with three replications. The highest mean chopping capacity of maize and sorghum stalk ((776.80 kg/hr, 778.00 kg/hr)), the finest (shortest) mean cutting length of maize and sorghum stalk ((1.03 cm, 0.97 cm)), the highest chopping efficiency of maize and sorghum stalk ((98.91%, 99.12%)) were recorded. The operational speed was observed to be highly significant among the treatments, at 5% significance level. Based on the results obtained, it is recommended that the machine can be demonstrated for small to medium-scale farmers.

INTRODUCTION

Ethiopia has the largest livestock population in Africa (Getabalew, 2019). This livestock sector has been contributing a considerable portion to the economy of the country and is still promising for the economic development of the country (FAO, 2018). It plays role in increasing export commodities, such as live animals, hides, and skins, to earn foreign exchange (CSA, 2020). The estimate of cattle at the country level is about 65.35 million (Alemneh and Getabalew , 2019). Out of this female cattle constitute about 55.90%, and the remaining 44.10% are male cattle (CSA, 2020). This indicated that 97.76% of the total cattle in the country are local breeds.

The others are hybrid and exotic breeds and accounted for about 1.91 and 0.32%, respectively (CSA, 2020). Between 2015 and 2050, demand for milk and beef is estimated to grow by 5.5 and 0.9 million metric tons respectively, with similar or higher growth rates for other animal-based foods (Ababa and Feyissa, 2017). Some of the challenging constraints in livestock production include (based on beef cattle production and marketing systems) a lack of feed resources, equipment, and input improve quality (Shrinivasa and Khadatkar , 2021).

The available feed resources include natural pasture, crop residue, improved forage, and agro-industrial byproducts, of which the first two contribute the largest share. With the rapid increase in human population and increasing demand for food, grazing lands are steadily shrinking by being converted to arable lands and are restricted to areas that have little value (Kebede and Ababa , 2017). Research and development over the last two decades have focused on identifying and testing different species of pasture and forage crops and forages in different ecological zones.

Feed quality and quantity, post-harvest handling, ecological deterioration, overgrazing, and a lack of seed and planting materials are among the major challenges. Forage chopping is one of the common post-harvest management practices done by most local farmers. Most farmers harvest forage grass from its stem, chop it into short lengths, and mix it with the other constituents (Lazaro and Turuka, 2014). Feeding dairy cattle uncut forages is associated with high feed waste.

However, the majority of farmers still rely on the use of rudimentary hand tools, notably the machete and sickle, for chopping forage (Moharrery, 2016). The use of traditional implements is time-consuming and associated with drudgery and health hazards. Animal feed chopping machine with capacity 581.24 kg/hr was developed by (Yonas, 2021). Physical treatment includes chopping, shredding, grinding, and pelleting ((Jibrin and Amonye , 2013). Considering all the above challenges, the generation of new technology for processing animal feed is very important. To solve this problem, this project was made to develop and evaluate animal feed chopping machines.

MATERIALS AND METHODS

Materials

The materials required to construct the prototype were:
Sheet metal, Angle iron, Flat iron, Square pipe, Shaft, Bolts and nuts, etc.

Lab equipment

Stopwatch for time measuring, Digital tachometer for measuring speed, Digital oven dry for measuring moisture content, Measuring tape and caliper for measuring length and width of crop straw/residues, etc.

Methodology

Description of Study Areas

The feed chopper machine was fabricated at Jimma Agricultural Engineering Research Center (JAERC) in the workshop by using locally available material. The experiment was carried out at Jimma zone, Kersa district, located at 7° 45’N & 37°5’E.

Design Procedure

The development of the machine was based on related information gathered from locally available sources and the internet, which had the same concept as the forage chopper machine, along with data on the test material that was used.

Design Aspects

The main design aspects considered during chopper development were cost and complexity of fabrication, energy requirement, ergonomic factor, maintainability, material strength, kinematics, and style. Considering these design aspects, an axial feed-type chopper without a conveyor was selected for this project. The machine is based on the principles of an axial, in which size reduction is accomplished by the cutting effects of rotating knives against small stationary knife plates welded on the drum.

Since the knives are swinging, there is less likelihood of risk even if hard, inert material accidentally gets into the chopping chamber. Feed enters the chamber from the top of the chopper, and size reduction is done by the rotating knives. Finally, the output is discharged from the bottom of the machine. The knives cut the stalk and other residues until they become small enough to pass through the side bottom screen.

Design Requirements

The development of the machine was based on the following criteria: (a) Availability of the materials, (b) Simplicity and ease of machine operation and repairs, (c) Adaptability of the machine to small-scale farm owners,(d) Small in size to transport from place to place (e) Less number of component (f) Low manufacturing cost (g) Easy to assemble and Maintainability and also power sources.

Design calculations of parts of the machine

Weight of feeding hopper

A rectangular shape of the hopper was used in the construction of the animal feeding hopper. The weight was calculated as follows: The mass of the feeding hopper material was computed using the following equations (ITSI-SU, 2011).

$$M_F = A_F \times t \times \rho f ------------ (1)$$

$$M_F = 0.12m^2 \times 1.5 \times 10^{-3}m \times 7850kg/m^3$$

$$M_F = 1.413kg$$

The weight of the feeding material was computed using the following equations (Gat, 1988) $W_F = M_F \times g$ ----------------- (2)

$$W_F = 1.413kg \times \frac{9.81m}{s^2} = 13.86N$$

Main frame

The main frame generally consists of four legs and is made up of angle iron 40 mm x40 mm x 4 mm.

The whole machine was mounted over the legs.

Design of shaft

The shaft was subjected to a twisting moment. To find the diameter of the shaft when the shaft was subjecting moment (torque) only.

$$\frac{T}{J} = \frac{\tau}{r} ---------(3)$$

Where: T = Twisting moment or torque acting on the shaft.

J = Polar moment of inertia of the shaft about the axis of rotation

τ = Torsional shear stress and r = Diametric distance from the neutral axis to the outermost fiber.

The allowable shear stress for the shaft material was calculated as

$$\tau = \frac{\sigma_u}{2fs} -----------(4)$$

$$\tau = \frac{560Mpa}{2 \times 3.5} = 80Mpa$$

Where, σ_u =560 Mpa for carbon steel , fs = factor of safety 3.5

From the equation(4)

$$T = \frac{\pi}{16\tau \times d^3} ---------- (5)$$

The diameter of the shaft by considering twisting the shaft

$$T = \frac{\pi}{16\tau \times d^3} = 50000$$

$$d^3 = (50000 \times 16)\frac{80}{\pi}, d = 14.27mm$$

Shaft subjected to bending moment

When the shaft is subjected to bending moment only, then the maximum stress was given by $\frac{M}{I} = \frac{\sigma b}{Y}$ (6)

Where M = bending moment, I = moment of inertia of cross shaft σb = bending stress, y = distance from the neutral axis to the outermost fiber.

For a round solid shaft, a moment of inertia is found by

$I = \frac{\pi}{64d^4}$ and $Y = \frac{d}{2}$ substitution in equation (6)

$$M = \frac{\pi}{32\times\sigma_b\times d^3} ---------- (7)$$

The maximum bending moment of the carbon steel was,

M = 424320 Nmm.

Substituting the above values to determine the diameter of the shaft

$$M = \frac{\pi}{32\times\sigma_b\times d^3} = 42320\text{Nmm} = \frac{\pi}{32\times 160\text{Mpa}\times d^3} =$$

d^3 = 27013.05mm = d = 30 mm

The mass of the shaft was calculated by the following equation

$$M = \rho \times v -------------- (8)$$

The shaft is made up of carbon steel with a density of 7853 kg/ m^3.

$$V = A \times L = \frac{\pi d^2}{4} \times L = (\pi \times \frac{(0.03)^2 \times 0.7}{4}) = 4.95 \times 10^{-4} m^3$$

The mass of shaft material was computed using the following equations (Gat, 1988)

$$M_S = 4.95 \times 10^{-4} m^3 \times \frac{7850kg}{m^3} = 3.89kg$$

The weight of the shaft was estimated using the following equations:-

$$W_s = M_s \times g = 3.89\text{kg} \times \frac{9.81\text{m}}{s^2} = 38.12.$$

Blade holder: This is part of the machine to which the cutting blades made up from sheet metal 6mm were welded on the drum, which serves to cut the stalks.

Selection of the Drive Belt

V-belt and pulley arrangements were used in this work to transmit power from the engine to the roller shaft. The main reasons for using the V-belt drive were its flexibility, simplicity, and low maintenance costs. Additionally, the v-belt can absorb shocks thereby mitigating the effect of vibratory forces (Khurmi & Gupta, 2007).

Determination of Belt Length

The length of the belt appropriate to drive the system was calculated using the equation given below by (Shigley, 2001). Assume the distance between the driver pulley and the driven pulley, is 399.27 mm according to the frame structure. The center distance (C) of driven pulleys was given by:

$$C = \frac{90}{2} + 431.89 + \frac{90}{2} = 521.89 \text{ mm}$$

$$L = 2C + \frac{\pi}{2((D_1+D_2)+(D_2-D_1)^2)\div 4C} --- \quad (9)$$

$$L = 586.62\text{mm} + 1043.78\text{mm} + 46\text{mm} = 1676.4 \text{ mm}$$

Where: L = belt length, m; C = center distance between pulleys, m; D_2 = pitch diameter of driven pulley, m; D_1 = Pitch diameter of driver pulley, m. Since the calculated length of the v belt is equal to the closest standard belt the exact center distance is also correct.

Selection of Bearing

Bearings selection was made following the American Society of Mechanical Engineers (ASME) standards. The bearings are pillow block ball bearings (single row, deep groove radial bearing). Radial bearings, number 205 with internal bore diameter, outer diameter, and width of 30 mm, 52 mm, and 15 mm, respectively, were selected as recommended by (Khurmi and Gupta, 2007).

Chopper house: This is the unit that houses and supports all the functional units made from sheet-metal 2 mm thickness.

Cutter blades: This is the main functional unit made up of treaded milled steel that performs the chopping action with a cutting depth of 1 cm and a cutting length of 6 cm and is made up of 6 mm thickness and 4 cm width developed to cut the feed to the recommended lengths with reasonable consistency.

Power transmission assembly: This is done by mechanical operation. It is made up of an engine, belt, shaft, and pulley.

Figure 1a:- View by CATIA

Figure 1b:- Animal feed chopper during field test

Machine operation

The machine is powered by a 7-hp engine with a maximum operating speed of 1200 rpm. The chopping machine was fitted with a pulley of 26 cm diameter through B-belt. The pulley and belt drive on the machine drives the chopping assembly through the shaft. During the operation, the feed chopper machine first pushes the engine sit lever forward, loosens the belt tension, and then starts the engine using the cranking system on the engine. After starting, the engine pulls the engine sit lever back, tensioning the driving belt, and then puts the locking pin on the engine sit and adjusts the engine to the appropriate speed.

After proper adjustment, the chopping starts by feeding the stalk into the machine through the inlet. During chopping, the chopped stalk is collected at the outlet. It was important to be attentive and inspect the machine parts during operation to prevent any machine breakdowns. After the operation is done, the engine should be switched off, and the machine should be cleaned and oiled.

Data Collecting Procedures

The following processes were carefully followed: All the necessary materials were gathered before testing the feed chopper machine, which includes important tools needed in case of any adjustment to avoid failure in the operation. The machine was allowed to run for 10 min before feeding the desired feed to check the functionality of the machine and its parts. A specific amount of feed was supplied at the inlet for chopping. The time taken to chop each sample was taken for every operation. Sample from each trial is taken for machine evaluation.

Machine Evaluation

Maize and Sorghum stalks were used for evaluating the machine. The machine evaluated for its capacity, cutting length, and cutting efficiency. During the test time taken, fuel consumption and chopped sample from each sample test was collected.

The Length of the Cut

$$Lth = 60000\frac{Vf}{\lambda knc} \quad -------(10)$$

Where: Lth = Length of cut(cm), V_f = Feed velocity (m/s), n_c = Cutter head rotational speed (rpm), and λ_k = Number of knives on the cutter head.

Cutting Efficiency (%)

The cutting efficiency was calculated as follows:

$$\eta c = \frac{(Lac - Lth)}{Lac} \times 100 ----- (11)$$

Where: ηc = Cutting efficiency; Lac = Actual length (mm), and L_{th} = Theoretical length (mm).

Throughput Capacity (kg/min)

$$\text{Throughput} = \frac{M}{T} -------- (12)$$

Where:- M =Mass (kg), and T =Time (s)

Experimental Design and Statistical Analysis

These experiments were performed using a factorial design with three main factors (two crop stalks, three feeding rates, and three engine speeds) and three replications. All experimental data were analyzed using the analysis of variance (ANOVA). Analysis was done using Stata 8.0. The treatment means that were different at a 5% level of significance were separated by using LSD.

RESULTS AND DISCUSSION

Each sample was weighed and measured (mass before chopped) and passed to the inlet into the cutting unit, which was coming into contact with the cutter blade. The chopped materials were collected through the outlet. The time taken to chop was recorded at the sample. The collected materials were weighed as a mass after being chopped. Each test was replicated three times. The prototype was tested using maize stalk, and sorghum stalk, and the results are presented in Tables 1 and 2. Table 1 shows the results obtained from the analysis of the data collected after the evaluation of the machine on maize stalk, and Table 2 on sorghum stalk.

Table 1 shows the mean values of cutting efficiency (%), chopping capacity (kg/hr), and cutting length (cm). The machine was evaluated using maize stalks at three different feeding rates of 9, 11, and 13 kg/min with three different machine operation speeds of 800,1000 and 1200 rpm. The analysis of variance (ANOVA) revealed that the feeding rate and operation speed had a significant effect ($p<0.05$) on the cutting efficiency, chopping capacity, and cutting lengths of a machine. The highest cutting efficiency was 98.91% obtained when the machine was fed at 9 kg/min of maize stalk and operational speed of 1200 rpm.

The highest mean chopping capacity was 776.80 kg/hr obtained when the machine was Fed 13 kg/min of maize stalk at an operation speed of 1200 rpm. The finest (shortest) mean cut length (1.03 cm) was obtained when the machine was fed by 13 kg/min at an operating speed of 1200 rpm. The mean chop length produced by the prototype was near to the acceptable range of 1 to 4 cm required to maintain proper rumination and salivation as sited by (Awgichew and Tullo, 2019). Analysis of Variance reveled there has significant pairwise differences among the means of chopping length.

Table 1. Effect of feeding rate and operation speed on the mean values of cutting efficiency (%), chopping capacity (kg/hr), and cutting length (cm) of a machine on maize stalks.

Crop residues	Feed rate (kg/min)	Operation speed(rpm)	Cutting Efficiency(%)	Chopping Capacity(kg/hr)	Cutting length (cm)
	9	800	90.18^{f}	528.50^{i}	3.61^{a}
		1000	95.11^{d}	534.00^{h}	2.60^{d}

		1200	98.91^a	539.02^g	1.72^f
Maize stalk	11	800	89.00^g	642.11^f	3.17^b
		1000	94.04^e	651.03^e	2.03^e
		1200	97.68^b	658.40^d	1.03^h
	13	800	88.00^gh	758.06^c	3.01^c
		1000	93.07^ef	769.00^b	1.55^g
		1200	96.36^c	776.80^a	1.03^hi
CV			1.03	0.16	2.89
LSD(0.05)			1.03	1.82	0.11

Where, CV = coefficient of variation, LSD = least significance difference.

Table 2 shows the mean values of cutting efficiency (%), chopping capacity (kg/hr), and cutting length (cm). The machine was evaluated using sorghum stalks with the same sizes of thickness at three different feed rates of 9, 11, and 13 kg with three different machine operation speeds of 800,1000 and 1200 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the cutting efficiency, chopping capacity, and cutting lengths of a machine. The highest cutting efficiency was 99.12% obtained when the machine was fed 9 kg/min of sorghum stalk at an operation speed of 1200 rpm.

The highest mean chopping capacity was 778.00 kg/hr obtained when the machine was fed 13 kg/min of sorghum stalk at an operation speed of 1200 rpm. The finest (shortest) mean cut length (0.97 cm) was obtained when the machine was fed 13 kg at an operation speed of 1200 rpm. The mean chop length produced by the prototype was near to the acceptable range of 1 to 4 cm required to maintain proper rumination and salivation as sited by (Awgichew and Tullo, 2019). Analysis of Variance reveled there has significant pairwise differences among the means of chopping length.

Table: 2 Effect of feed rate and operation speed on the mean values of cutting efficiency (%), chopping capacity (kg/hr), and cutting length (cm) of a machine at sorghum stalks.

Crop Residues	Feed rate (kg/min)	Operation speed(rpm)	Cutting Efficiency(%)	Chopping Capacity(kg/hr)	Cutting length (cm)
	9	800	91.02^g	529.30^i	3.51^a
		1000	94.95^d	534.80^h	2.53^c
		1200	99.12^a	539.99^g	1.68^e
Sorghum stalks	11	800	89.68^h	644.20^f	3.04^b
		1000	93.79^e	652.01^e	2.03^d
		1200	97.67^b	659.70^d	1.03^f
	13	800	88.54^i	760.09^c	2.95^bc
		1000	92.49^f	770.50^b	1.93^de
		1200	96.44^c	778.00^a	0.97^fg
CV			0.57	0.15	8.88
LSD(0.05)			0.93	1.81	0.34

Where, CV = coefficient of variation, LSD = least significance difference.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It is concluded, as observed in the performance evaluation result, that the machine can attain its highest capacity for chopping based on the operational speed and feeding rate. As the machine operates at higher speed, the capacity increases to its highest possible performance. The speed of the machine also affects the length of cut of the stalk, and cutting efficiency. The faster the operational speed, the shorter the feed cutting length, and the slower the speed, the longer the cutting length. The faster the operation speed of the machine, the higher its efficiency.

The performance of the machine was evaluated using sorghum stalk, and maize stalk, with treatments of crop stalk, the cutting speed, and feeding rate using a factorial design with three replications. The highest mean chopping capacity of maize and sorghum stalk (776.80 kg/hr, 778.00 kg/hr) respectively, the finest (shortest) mean cut length of maize and sorghum stalk (1.03 cm, 0.97cm), the highest chopping efficiency of maize and sorghum stalk (98.91%, 99.12%) respectively. The highest mean chopping capacity of maize and sorghum stalks were (776.80 kg/hr, and 778.00 kg/hr) at an engine speed of 1200 rpm respectively.

RECOMMENDATIONS

The following recommendations should be carried on:-

The machine should be recommended to demonstrate for small to medium farmers.

The machine should be recommended to operate at 1200 rpm of operating speed and 13 kg/min feeding rate.

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