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Design, fabrication and performance evaluation of animal feed chopping machine

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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 has always been a challenge in the livestock sector. Poor feed resources management, especially those of the bulky and fibrous crop residue is one of the constraints. Forage chopping is considered to be part of crop residue management, a common process done by most local farmers in livestock feeding. This process is laborious and takes more. To alleviate this, using forage chopper is an important remedy. The primary goal of this study was to design, fabricate, and evaluate the performance of the forage chopper machine. The performance of the machine was evaluated using sorghum forage variety (Chelenko) with treatments of the engine seed, feed rate and feed thickness using factorial design with three replications. The heights mean chopping capacity of (581.24 kg/h), the finest of (shortest) mean cut length (6.23 mm), the heights chopping efficiency of (0.97) and the mean lowest fuel consumption of (0.50 ml/s) was recorded. The operation speed was observed to be highly significant among the treatments, at significance level of 0.01. Based on the result obtained, it is recommended to use a power source with higher horse power and speed and electric motor in areas where electric power is available to avoid vibration.

Key words: Design, fabrication, feed chopper machine, sorghum forage variety (Chelenko).

INTRODUCTION

Ethiopia is believed to have the largest livestock population in Africa. This livestock sector has been contributing considerable portion to the economy of the country, and still promising to rally round the economic development of the country. It also plays an important role in providing export commodities, such as live animals, hides, and skins to earn foreign exchanges to the country. The estimate of cattle for the rural and pastoral sedentary areas at country level is to be about 65.35 million. Out of this total cattle population, the female cattle constitute about 55.90% and the remaining 44.10% are male cattle. It is indicated that 97.76% of the total cattle in the country are local breeds. The remaining are hybrid and exotic breeds that accounted for about 1.91 and 0.32%, respectively (CSA, 2020).

The Ethiopian population will grow from present 102 to

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almost 190 million in the next three decades, out of which 76 million people will live in cities and towns vis-à-vis 19 million today. These changes will trigger consumption for all livestock products to increase tremendously. Between 2015 and 2050 demand for milk and beef is estimated to grow by about 5.5 million tonnes and 0.9 million tonnes or 145 and 257% increase, respectively, with similar or higher growth rates for demand of other animal source foods (FAO, 2019).

Some of the challenging constraints in the livestock production includes (based on beef cattle production and marketing systems) lack of feed resource, equipment and input that would improve quality (Alemneh and Getabalew, 2019).

The available feed resources include natural pasture, crop residue, improved forage and agro-industrial byproducts of which, the first two contribute the largest share. Currently, with the rapid increase of 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 et al., 2017.

Research and development over the last two decades have been identifying and testing different species of pasture and forage crops forages in different agro-ecological zones, and a promising result were obtained. Feed quality and quantity, post-harvest handling, ecological deterioration, overgrazing, lack of seed and planting materials are among the major challenges (Kebede et al., 2017).

Feeding dairy cattle un-chopped forages is associated with selective feed consumption and high feed wastage. Although majority of farmers still rely on the use of rudimentary hand tools implements, notably the machete for chopping forage, use of such implements is time consuming and is associated with drudgery and health hazards (Muhammad et al., 2018).

The quality of crop residues and roughages can be improved by both chemical and physical methods. Physical treatment of residues prior to chemical treatment improves materials acceptance of chemical treatment. Physical treatment includes, chopping, shredding, grinding and pelleting. The indications are that grinding and pelleting of fibrous materials increases the surface area exposed to microbial attack and accelerates the flow rate of digesta through the gastro-intestinal track; this grinding and/or pelleting results in higher intake, up to 30% more. Studies in Sudan also showed that physical treatment of bagasse was more feasible than chemical treatment (Jibrin et al., 2013).

Forage chopping is one of the common post-harvest management practice done by most local farmers. In most localities, farmers harvest forage grass from its stem, chop it into short length and mix it with the other constituents. This process takes a lot of time and is laborious, especially in a large-scale unit. To alleviate this challenge, forage chopper is used to cut/chop forage as a replacement for manual chopping (Lazaro et al.,1999) The main parameter of cutting tool is the knife edge angle and the moisture content of the plant material, whereas, for machine working performance, the main parameter is the cutting rotational speed. The theoretical length of cut is also another parameter that determines the machine's performance, determined by the advance of the feed mechanism between the successive knives. It can be adjusted by changing the speed of feed mechanism or number of knives on the cutter-head (Shrinivasa et al., 2021).

Considering all the challenges encountered in the livestock production with respect to the availability, quality and quantity of animal feed in the country, this project was proposed to design and manufacture animal feed chopping machine based on the appropriate technical requirement, availability of raw material and affordability to the end users. The machine was manufactured and evaluated as per the required technical standard and the result is presented in this paper.

General objectives

It is intended to develop animal feed chopping machine powered by diesel engine for small to medium holder farmers in the livestock sector of Ethiopia.

Specific objectives

1) To design animal feed chopping machine powered by diesel engine, that can chop forage grass as well as residue of corn and sorghum.
2) To fabricate the designed prototype of the machine which powered by diesel engine with power rating of 5hp.
3) To evaluate the performance of the newly constructed machine

METHODS

Design and fabrication

The feed chopper machine was fabricated at Melkassa Agricultural Research Center in Agricultural Engineering Research Department Workshop located at Melkassa about 117 km away from the capital Addis Ababa.. The design of the machine was based on related information gathered from books and the internet having the same concept as of forage chopper machine (Tekeste, 2020) along with data on the test material that was used. The design 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.

Parts of the machine

The machine consisted of six (6) major components (Figures 1 and 2) as follows: (1) feed inlet (2) blade holder plate (3) cutting blade (4) chopper house (4) frame stand assembly (5) power transmission assembly, and (6) material outlet.

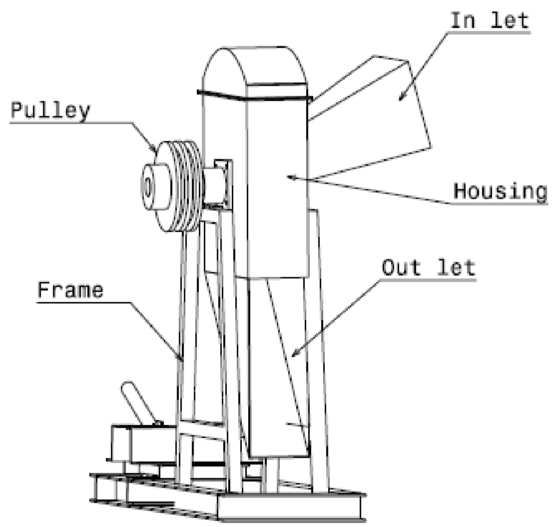

Figure 1. Schematic drawing of parts.

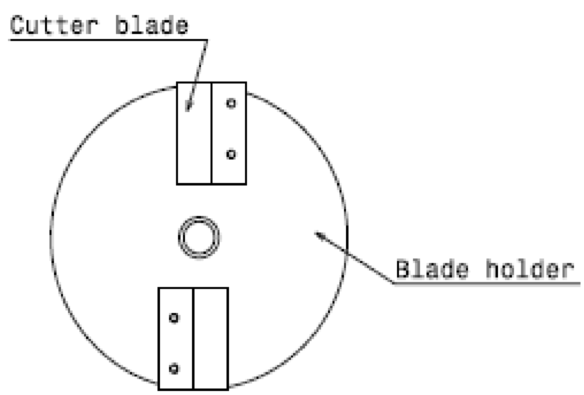

Figure 2. Schematic drawing of cutting unit.

Feed inlet: Part of the machine where the feed is put and prepared prior to feeding into the machine.

Blade holder: This is the part of the machine to which the cutting blades are bolted, which also serve as a fly wheel to store rotational energy. It is made up of a 15-mm thick and 30-cm diameter milled steel.

Cutter blades: This is the main functional unit made up of treaded milled steel that performs the chopping action. They are two in number arranged at 180° with a cutting depth of 3 cm and a cutting length of 10 cm designed to cut the feed to the recommended lengths with reasonable consistency.

Chopper house: This is the unit which houses and supports all the functional units. The cutting assembly is made of 3-mm thick mild steel with a width of 14 cm, height of 40 cm and breadth of 36 cm. it supports the shaft and bearing assembly and is bolted to the frame stand assembly at four different points.

Base and stand assembly: This is considered as the backbone of the machine that supports all the functional parts of the machine. It is made up of RHS bars and U channel to assure the durability of the materials.

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

Materials and instruments: The materials and instruments used in evaluating the machine includes: (1) feed chopping machine (2) weighing scale, (3) stopwatch (in seconds: milliseconds), (4) pen and papers, (5) plastic bags, (6) digital camera, (7) open and adjustable wrenches (8) Vernier caliper with 0.5-mm precision, and (9) graduated cylinder.

Machine operation

The forage chopper machine is powered by a 5hp diesel engine with a maximum operation speed of 3000. The engine was fitted with a pulley of 10 cm diameter drive and the chopping machine was fitted with a pulley of 20 cm diameter through B-bet. The pulley and belt drive on the machine drives the chopping assembly through the shaft. During operation, the feed chopper machine first push the engine sit lever forward, loosening the belt tension, and then starts the engine using cranking system on the engine. After starting, the engine pulls the engine sit lever back, tensioning the driving bet, 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 forage into the machine through the inlet. During chopping, the chopped forage will be collected at the outlet. It is important to be attentive and inspect the machine parts during operation to prevent any machine breakdown. After the operation is done, the engine should be switched off, and the machine should be cleaned and oiled (Figures 3 and 4).

Data gathering procedures

The following processes were carefully followed: (1) 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. (2) The machine was allowed to run for 20 min before feeding the desired feed to check the functionality of the machine and its parts. (3) A specific amount of feed was supplied at the inlet for chopping. (4) The time taken to chop each sample was taken for every operation (at both commencement and climax) (5) Sample from each trial is taken for laboratory assessment. (6) The amount of fuel consumed for each trial was measured using graduated cylinder.

Machine evaluation

Sorghum forage variety (Chelenko) was used for evaluating the machine. The machine was evaluated for its capacity, work quality (cutting length) and efficiency. Factorial experimental design with three replications was used. Analysis of variance (ANOVA) was used to determine the differences among the treatment means. The variables or treatments of the study were the engine seed, feed rate and fed thickness. Two different engine speeds (1500 and 2500 rpm), two different average feed thicknesses and two different feed rates (5 and 3 kg) were used to conduct the evaluation.

During the test, two sets of forage average thickness diameter of 10 and 25 cm, with a weight of 3 and 5 kg, 12 samples (6 each from a total of 24 samples), were weighed and made ready. In the first set, the machine was adjusted to an operation speed of 1500 rpm and the test conducted for the first set of 12 samples. In the second

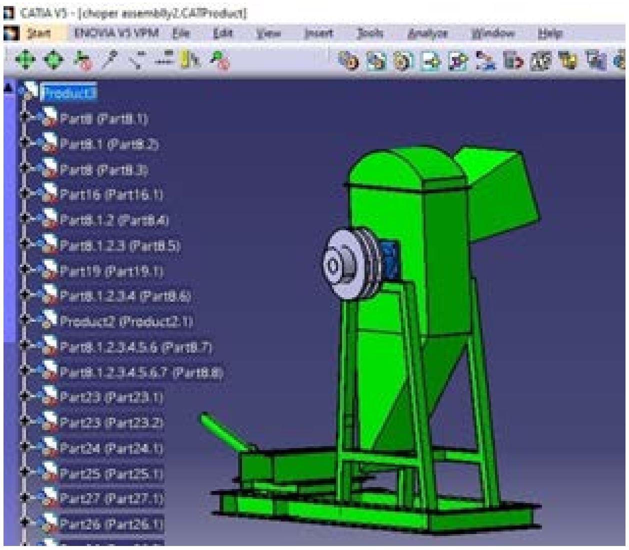

Figure 3. CAD drawing of the chopper.

Figure 4. Proto type of the chopper.

set, the machine was adjusted to an operational speed of 2500 rpm and the test was conducted for the second set of 12 samples. During the test time taken, fuel consumption and copped sample from for each sample test was collected. The chopped samples were taken to the laboratory and 12 chopped feed samples from each sample were taken to the laboratory where it was randomly collected and their cut lengths measured and recorded.

Theoretical and actual lengths of cut

The theoretical lengths of cut (L_{th}), cutting efficiency and chopping capacity were calculated using the following equations according to Srivastava et al. (2013).

$$L_{th} = \frac{60000V_f}{\lambda_k n_c} \quad (1)$$

Where: L_{th} = Length of cut, V_f = Feed velocity (m/s), n_c = Cutterhead rotational speed (rpm), and λ_k = Number of knives on the cutter head.

After each chopping treatment, random samples were taken from chopped material to the laboratory and separated by sieves into three categories (small, medium, and large) to determine the actual mean of cutting length (L_{ac}).

Cutting efficiency

The cutting efficiency was calculated as follows:

$$\eta_c = \frac{L_{ac}}{L_{th}}\, x\, 100 \quad (2)$$

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

Chopper capacity

The theoretical capacity (T_{th}) is expressed by the following relationship:

$$T_{th} = \frac{\rho_f A_t L_c \lambda_k n_c}{6\, x\, 10^8} \quad (3)$$

Where: T_{th} = Theoretical capacity (kg/s); ρ_f = Density of forage in the thereat (in kg/m^3); A_t = Thereat area (cm^2); L_c = Theoretical length of cut (mm); λ_k= Number of knives on cutterhead, and n_c = Speed of cutterhead (rpm).

RESULTS AND DISCUSSION

Tables 1 to 4 show the results obtained from the analysis of the data collected after the evaluation of the machine. These comprised the mean values of the performance parameters and the analysis of variance (ANOVA) tables which describes the significance of the treatments in affecting the performance of the machine.

Table 1 show the mean values of cutting lengths (mm) and efficiency (%), chopper productivity (kg/h) and efficiency (%), fuel consumption (l/h) and the analysis of variance (ANOVA). The machine was evaluated using forage sorghum variety (Chelenko) with two different sizes of thickness (10 and 25-mm diameter) at two different feed rates of 3 and 5 kg with two different machine operation speeds of 1500 and 2500 rpm.

The highest mean chopping capacity (581.24 kg/h) was attained when the machine was fed by 3 kg of freshly harvested Chelenko with thickness of 10 mm diameter chopped at operation speed of 2500 rpm. The finest (shortest) mean cut length (6.23 mm) was obtained when the machine was fed by 5 kg of Chelenko with thickness of 25 mm diameter chopped at operation speed of 2500 rpm. The heights chopping efficiency (0.97) was attained

Table 1. The mean values of cutting lengths (mm) and efficiency (%), chopper productivity (Kg/h) and efficiency (%), fuel consumption (l/h).

<table>
<tr><th rowspan="5">Treatment</th><th colspan="8">Feed thickness (diameter) (mm)</th></tr>
<tr><th colspan="4">10 mm</th><th colspan="4">25 mm</th></tr>
<tr><th colspan="4">Operation speed (rpm)</th><th colspan="4">Operation speed (rpm)</th></tr>
<tr><th colspan="2">1500</th><th colspan="2">2500</th><th colspan="2">1500</th><th colspan="2">2500</th></tr>
<tr><th colspan="4">Feed rate (kg/s)</th><th colspan="4">Feed rate (kg/s)</th></tr>
<tr><th></th><th>3</th><th>5</th><th>3</th><th>5</th><th>3</th><th>5</th><th>3</th><th>5</th></tr>
<tr><td>Cutting length mm</td><td>12.25</td><td>12.20</td><td>8.54</td><td>8.05</td><td>11.62</td><td>13.50</td><td>8.57</td><td>6.23</td></tr>
<tr><td>Cutting efficiency (%)</td><td>0.88</td><td>0.87</td><td>0.97</td><td>0.96</td><td>0.83</td><td>0.84</td><td>95</td><td>0.96</td></tr>
<tr><td>Capacity (kg/h)</td><td>232.71</td><td>298.58</td><td>581.24</td><td>575.37</td><td>233.55</td><td>310.79</td><td>551.43</td><td>569.32</td></tr>
<tr><td>Fuel consumption</td><td>0.69</td><td>0.96</td><td>0.95</td><td>1.00</td><td>0.72</td><td>0.54</td><td>0.50</td><td>1.01</td></tr>
</table>

Table 2. Analysis of variance (Response: Capacity interims of treatment Vs Replication).

Parameter	Df	Sum square	Mean square	F value	Pr(>F)
Treatment	7	558634	79805	88.6635	4.621e-11***
Rep	1	132	132	0.1469	0.7069
Residuals	15	13501	900		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1'' 1.

Table 3. Analysis of variance (ANOVA) for capacity (Response: Capacity).

Parameter	Df	Sum square	Mean square	F value	Pr(>F)
Speed	1	541555	541555	683.6815	2.324e-16***
Feed_rate	1	9023	9023	11.3914	0.003178**
Feed_Size	1	195	195	0.2465	0.625223
Speed: Feed_rate	1	6444	6444	8.1350	0.010193*
Residuals	19	15050	792		

Table 4. Analysis of variance (ANOVA) for cut length (Response: Cut-length).

Parameter	Df	Sum square	Mean square	F value	Pr(>F)
Speed	1	123.942	123.942	62.0832	1.473e-07***
Feed_rate	1	0.375	0.375	0.1878	0.66936
Speed:Feed_rate	1	8.120	8.120	4.0674	0.05735.
Residuals	20	39.928	1.996		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

at operation speed of 2500 rpm when the machine was fed with 3 kg of Chelenko with thickness of 10 mm diameter, and the mean lowest fuel consumption (0.50 ml/s) was recorded while the machine was fed with 3 kg of Chelenko with thickness of 10 mm diameter operating at a speed of 2500 rpm.

According to the ANOVA table (Table 2), the variability in the performance of the machine does not depend on the replication of the trial, but is only due to the treatments. It was also indicated that the capacity of the machine is highly dependent on the operation speed of the machine. The result in Table 3 shows operation speed and feed rate has highly significant effect of speed and on capacity. The interaction also has significant effect on capacity but feed size does not. Table 4 shows that only speed has highly significant effect on cut length.

Neither feed rate nor the interaction has significant effect.

CONCLUSION AND RECOMMENDATION

In general, as observed in the evaluation result, the machine can attain its highest capacity based on the operation speed. 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 feed, the machines efficiency and fuel consumption. The faster the operation speed the shorter the feed cut length, and the slower the speed the longer the cut length. The faster the operation speed of the machine the higher its efficiency and the lower fuel consumption.

Recommendations are made to improve the capacity as well as efficiency of the machine. Based on evaluation result, some recommendations could be done with respect to the power source and house power. Since in most of the evaluation parameters an increase in operation speed improves the performance of the machine, it is recommended to use a power source with higher horse power and speed. Moreover, using diesel engines is mostly subjected to vibration so that, it is better to use electric motors to avoid vibration in areas where electric power is available.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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