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Research Article

Modification and Performance Evaluation of a Multi-crop Thresher for Animal Feed Chopping Purpose

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Abstract

The greatest livestock population in Africa is found in Ethiopia. Still, several limitations prevent the agricultural industry as a whole and the livestock "sub-sector" in particular from being properly utilized. For cattle farmers in the nation, feed supply, quality, and quantity have always been problems. Using maize and sorghum stalks is a crucial solution for reducing this issue. Therefore, the part of the machine was modified due to the cutting blades were bolted on the drum with a cutting depth of 1 cm and a cutting length of 6 cm, and were made up of sheet metal 6 mm thick and 4 cm wide to cut the feed to the recommended lengths with reasonable consistency. The research was conducted at Jimma Agricultural Engineering Research Centre (JAERC), Dedo districts, to evaluate the machine's performance in terms of chopping efficiency, throughput capacity, and cutting efficiency, at different speeds of the cutter shaft. It was discovered that the chopper's output was an amazing accomplishment. Using a factorial design with three replications, the machine's performance was assessed using sorghum and maize stalks treated for engine speed, feeding rate, and crop stalk. The finest (shortest) mean cut length of the maize and sorghum stalks (1.09 cm, 0.99 cm), the highest chopping efficiency of the maize and sorghum stalks (97.54%, 98.15%), and the highest mean chopping capacity of the stalks (897.90 kg/hr, 898.98 kg/hr) were reported. At a significance level of 0.05, the operation speed was found to be very significant among the treatments. It is advised that small- to medium-sized farmers see a demonstration of the machine based on the outcomes.

Keywords

Chop Length, Cutting Efficiency, Throughput Capacity

1. Introduction

Ethiopia is home to Africa's largest population of livestock [6]. This sector of the livestock industry has been making a significant contribution to the national economy and continues to show promise for future growth [3]. Additionally, it is crucial in supplying export goods like live animals, hides, and skins so that the nation can generate foreign exchange [3]. About 65-35 million cattle are thought to be in the nation's rural and pastoral sedentary areas [5]. Of this total population of cattle, approximately 55 percent are female, and the remaining 44 percent are male [3].

It is estimated that local breeds account for 97-76% of all cattle in the nation. The remainder, or roughly 1 point 91 and 0 point 32 percent, are hybrid and exotic breeds [3]. With comparable or greater growth rates for other animal-based foods, the demand for milk and beef is predicted to increase by roughly 5 to 5 million metric tons and 0 to 9 million metric

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tons, or 145 and 257 percent, respectively, between 2015 and 2050 [1]. Based on systems for producing and marketing beef cattle, some of the difficult limitations in livestock production include a shortage of feed resources, tools, and inputs that would enhance quality [13].

The most significant portion of the available feed resources comes from agro-industrial byproducts, crop residue, natural pasture, and improved forage [9]. Due to the current rapid population growth and rising food demand, grazing lands are gradually being reduced in size as they are turned into arable land and confined to low-value areas [12]. Finding and evaluating various species of pasture and forage crops and forages in various ecological zones has been the main focus of research and development during the past 20 years. Overgrazing, ecological degradation, post-harvest handling, feed quality and quantity, and a shortage of seed and planting materials are some of the main issues.

One common post-harvest management practice used by the majority of local farmers is forage chopping. Physical treatment includes chopping, shredding, grinding, and 1pelleting [8]. Farmers typically cut forage grass into short lengths and harvest it from its stem, then combine it with other ingredients. Uncut forage feeding is linked to increased feed waste in dairy cattle. Forage is still primarily chopped by most farmers using crude hand tools, such as the sickle and machete [11]. Such tools are "time-consuming" to use and are linked to unpleasant tasks and health risks. A 511 kg/hr dual animal feed chopper and milling machine was created by Jimma Agricultural Engineering Research Center [14]. It is crucial to develop new technology for processing animal feed in light of the aforementioned difficulties. To address this issue, the project's goal was to adapt and assess crop threshers for use in cutting animal feed.

2. Materials and Methods

2.1. 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.

2.2. Methodology

2.2.1. Description of Study Areas

The feed chopper machine was fabricated at Jimma Agricultural Engineering Research Center (JAERC) in the workshop by using locally available materials. The experiment was carried out at Jimma zone, Dedo district, located at 7°31’0” N & 36°52’0” E The part of the machine was modified at the drum with an attachment of the cutting blade by bolt and nut for chopping purposes, and the detachment of the cutting blade for threshing purposes. This machine is used for multi-purpose drum replicable.

2.2.2. Modified Part (Cutting Blades)

This is the part of the machine to which the cutting blades are bolted on the drum. 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.

Figure 1. *Modified Part.*

2.2.3. Chopper House

This is the unit that houses and supports all the functional units made up of sheet metal 2 mm. It supports the shaft and bearing assembly and is bolted to the frame stand assembly at four different points.

2.2.4. Power Transmission Part

This is done by mechanical operation. It is made up of an engine, a belt, a shaft, and a pulley.

Figure 2. *Photo taken during machine evaluation on the field.*

2.2.5. Machine Operation

The machine's 7-hp engine can reach a maximum speed of 1400 rpm. The chopping machine was equipped with a B V-belt to drive a pulley with a diameter of 26 cm. The belt drive and pulley drive push the chopping assembly through the machine's shaft. The feed chopper machine first pushes the engine seat lever forward and releases the belt tension before starting the engine using the cranking mechanism.

Pulling back the engine sit lever after starting causes the engine to tire the driving belt. After fixing the engine seat's locking pin, it modifies the engine's speed to the appropriate setting. Once the necessary adjustments have been made, the stalk is fed into the machine via the inlet to start the cutting process. After the stalk is chopped, it is collected at the outlet. While the machine was being operated, it was essential to pay close attention and inspect its components to prevent any malfunctions. The engine must be shut off, and the machine must be cleaned and oiled after the operation.

2.2.6. Data Collection Procedures

To prevent failure in the operation, the following procedures were meticulously followed: (1) before testing the feed chopper, all required materials were collected, including crucial tools required in case of any adjustments. (2) To verify that the machine and its components were operating properly, the machine was left to run for ten minutes before the desired feed was fed. (3) The inlet received a predetermined quantity of feed for chopping. (4) Every operation's time was recorded (at both the start and the end). (5) A sample is taken from every trial for chopper evaluation.

2.2.7. Machine Evaluation

To test the machine, maize and sorghum stalks were utilized. The machine's efficiency, capacity, and cutting length were assessed. Each test's chopped sample was gathered during the test period.

I. The Length of the Cut (cm)

$$L_{th} = 6000\frac{Vf}{\lambda knc}$$

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

II. Cutting Efficiency (%)

The cutting efficiency was calculated as follows:

$$\eta c = \frac{(L_{ac} - L_{th})}{L_{ac}} \times 100$$

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

2.2.8. Determination of Throughput Capacity (kg/min)

$$Throughput = \frac{Ma(kg)}{T(s)}$$

Where: - Ma is the mass of the materials and T is the time taken.

2.2.9. Experimental Design and Statistical Analysis

Three primary factors were used in these experiments: two crop stalks (sorghum and maize), three feeding rates (11, 13, and 15 kg/min), and three engine speeds (1000, 1200, and 1400 rpm), with three replications. The experiments were conducted using a factorial design. ANOVA, or analysis of variance, was used to examine all experimental data. Using Stata 8.0, the analysis was completed. To separate the treatments that differed at a 5 percent significance level, LSD was used.

3. Results and Discussion

Table 1 and Table 2 show the results of testing the prototype with maize and sorghum stalks. Table 1 displays the findings from the data analysis conducted following the machine's evaluation on the maize stalk, while Table 2 displays the findings from the analysis of the sorghum stalk. These included the average performance parameter values and the analysis of variance (ANOVA) tables, which show how the treatments significantly impacted the machine's performance.

Findings from the ANOVA showed that the combination of feed rate and operation speed had a significant effect on cutting efficiency, chopping capacity, and cutting lengths of a machine. The cutting efficiency was 97.54% when 11 kg/min of maize stalk was fed to the machine at 1400 rpm, at the highest cutting efficiency. The highest mean chopping capacity was 897.90 kg/hr obtained when the machine was fed 15 kg/min of maize stalk at an operation speed of 1400 rpm. The finest (shortest) mean cut length (1.09 cm) was obtained when the machine was fed by 15 kg/min at an operation speed of 1400 rpm. The mean chop length produced by the prototype was near the acceptable range of 1 to 4 cm required to maintain proper rumination and salivation [2, 7]. Analysis of Variance revealed there are significant pairwise differences among the means of chopping length.

Table 1. *Effect of feeding rate and operation speeds 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)
Maize stalk	11	1000	85.65^{g}	648.00^{i}	3.80^{a}
		1200	91.18^{d}	653.20^{h}	2.90^{d}
		1400	97.54^{a}	658.33^{g}	1.82^{f}
	13	1000	83.26^{h}	767.84^{f}	3.40^{b}
		1200	89.19^{e}	773.63^{e}	2.33^{e}
		1400	95.59^{b}	778.67^{d}	1.23^{h}
	15	1000	81.73^{i}	887.25^{c}	3.01^{c}
		1200	87.28^{f}	892.98^{b}	1.59^{g}
		1400	93.24^{c}	897.90^{a}	1.09^{i}
CV			0.53	0.11	2.61
$LSD_{(0.05)}$			0.81	1.24	0.11

Where, CV = coefficient of variation, LSD = least significant 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 feeding rates of 11, 13, and 15 kg/min with three different machine operation speeds of 1000rpm, 1200rpm, and 1400 rpm. The analysis of variance (ANOVA) revealed that the combination of 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 (98.15%) was obtained when the machine was fed 11 kg/min of maize stalk at an operation speed of 1400 rpm. The highest mean chopping capacity, 898.98 kg/hr, was obtained when the machine was fed 15 kg/min of maize stalk at an operation speed of 1400 rpm. The finest (shortest) mean cut length (0.99 cm) was obtained when the machine was fed by 15 kg at an operation speed of 1400 rpm. The mean chop length produced by the prototype was near the acceptable range of 1 to 4 cm required to maintain proper rumination and salivation, as cited by [2, 10, 15]. Analysis of Variance revealed there are significant pairwise differences among the means of chopping length.

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

Crop-Residues	Feed rate (kg/min)	Operation speed (rpm)	Cutting Efficiency (%)	Chopping Capacity (kg/hr)	Cutting length (cm)
Sorghum stalks	11	1000	89.52^{f}	649.01^{i}	3.64^{a}
		1200	94.23^{cd}	654.40^{h}	2.73^{cd}

Crop-Residues	Feed rate (kg/min)	Operation speed (rpm)	Cutting Efficiency (%)	Chopping Capacity (kg/hr)	Cutting length (cm)
		1400	98.15[a]	659.52[g]	1.65[e]
		1000	88.21[g]	768.80[f]	3.27[b]
	13	1200	93.11[d]	774.56[e]	2.14[d]
		1400	96.35[b]	779.39[d]	1.13[g]
		1000	83.44[h]	888.75[c]	2.84[c]
	15	1200	91.23[e]	893.99[b]	1.32[f]
		1400	95.09[c]	898.98[a]	0.99[h]
CV			0.71	0.10	3.45
$LSD_{(0.05)}$			1.14	1.23	0.13

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

4. Conclusions and Recommendations

4.1. Conclusions

Based on the feeding rate and operating speed, it resulted in the conclusion that was also mentioned in the performance evaluation result: the machine can chop to its maximum capacity. The capacity increases to its peak performance level as the machine runs faster. The cut length and cutting efficiency of the feed are also impacted by the machine's speed. The feed cut length increases when the operating speed decreases and decreases when the operating speed increases. The efficiency of the machine increases with its speed.

In a factorial design with three replicates, the machine's performance was measured using sorghum and maize stalks treated differently for engine speed, feeding rate, and crop stalk. For the stalks of sorghum, the average cutting speed was 898.98 kg/hr and the average cutting speed was 897.90 kg/hr, respectively. The highest (most efficient) chopping efficiency (97.54, 98.15%) was observed for the stalks of sorghum and maize, respectively, and the highest (shortest) cutting lengths (1.09 cm, 0.99 cm) were observed for the stalks of sorghum and maize.

4.2. 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 1400 rpm of speed and a 15 kg/min feeding rate.

Abbreviations

CV	Coefficient of Variation
Lth	Length of Cut
LSD	Least Significant Difference
Ma	Mass of Material
Nc	Cutter Head Rotational Speed
T	Time
Vf	Feed Velocity

Author Contributions

Husen Bona: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Husen Abagissa: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Teshome Wakeyo: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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