Design, Construction, and Performance Evaluation of Banana Stem Chopper for Livestock Feed

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Abstract. Livestock farming plays a vital role in ensuring food security and sustainable agriculture. However, feed availability remains a significant challenge, particularly in regions where conventional feed sources are scarce. In this context, banana stems have emerged as a potential alternative feed resource due to their abundance and nutritional value. This paper presents the design, construction, and performance evaluation of a novel Banana Stem Chopper, intended to enhance the utilization of banana stems as livestock feed. The novelty of the Banana Stem Chopper for Livestock Feed lies in the construction of the chopper emphasizes the use of locally available materials. This aspect of the design ensures that the technology can be replicated and adopted in various regions, especially in rural communities where resources might be limited, making it accessible to a broader range of farmers. The banana steam chopper was built using materials that could be found in the local area and was operated by a 6.5 horsepower engine that ran on gasoline. The chopping mechanism included a drum that rotated and had two blades. The banana stems were inserted into the chopper through a container and were cut into smaller fragments. The performance of the chopper was evaluated in terms of its chopping capacity, power consumption, average thickness of shredding and production rates. The chopper was able to chop banana stems at a rate of 49 kg/hr and consumed 6.5 kW of power. The average thickness of shredding was found to be 9.50 mm, 7.7 mm and 4.43mm.

Keywords: Banana Stem Chopper; Livestock Feed; Agricultural Byproduct; Sustainable Agriculture; Feed Resources.

1 Introduction

Increasing global demand for livestock products is putting considerable pressure on feed resources. Traditional feed sources are often limited by seasonality, high cost and competition with human food needs [1]. In this context, banana peel, an agricultural by-product, is a promising potential feed source for livestock due to its high nutritional content and wide availability. However, their use as animal feed is hampered by their fibrous nature and challenging handling characteristics. The present study aims to address this issue by developing a specialized banana stem chopper that can effectively process banana stems into digestible feed for livestock.

M. U. H. Al Rasyid and M. R. Mufid (eds.), *Proceedings of the International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023)*, Advances in Engineering Research 230,
https://doi.org/10.2991/978-94-6463-364-1_110

The study conducted by the author in Kupang Regency of East Nusa Tenggara Province is one of the producing districts in Timor Island, with extensive banana plantations in various areas such as Amarasi and Kupang Timur district; as a result, there is a significant abundance of banana stems, which are often considered as agricultural waste after harvesting the banana fruit. In many rural areas of Kupang regency, banana peel is traditionally used as fodder for livestock, including cattle, pigs, goats and sheep. Farmers often chop the stems by hand or with simple tools to make them more accessible to the animals. While banana stems have potential as livestock feed, there are challenges in processing them effectively. Their fibrous composition requires specific handling techniques or mechanical processing to ensure that animals can digest them properly.

The primary objective of this study is to design and construct a specialized banana stem chopper that effectively processes banana stems into digestible and nutritious livestock feed. By achieving this objective, the study aims to promote the use of banana stalks as an alternative and sustainable feed resource, thereby addressing feed scarcity issues; this research also seeks to create a chopper design that is practical, cost effective and user friendly. By using locally available materials and simple assembly techniques, the Banana Stem Chopper will be made accessible to smallholder farmers and rural communities, encouraging widespread adoption and implementation.

2 Related Works

Various studies have been conducted in an effort to develop banana stem waste as an animal feed ingredient have demonstrated as follows;

Mowafy, A. E., El Shazly, M. A., Eliwa, A. A., & Wasfy, K. I. carried out a study that discusses the construction and evaluation of a machine designed to chop residues of banana plants. The study explores different operating parameters such as cutting knife speed, feeding rate, span time after harvesting, and cutting knife edge shape. The goal is to determine the machine's productivity, chopping efficiency, energy requirements, and total costs. The results suggest that the optimal values for the machine's productivity are achieved with a cutting knife speed of 26.16 m/sec (1250 rpm), a serrated knife edge, a feeding rate of 800 kg/hr, and a span time of 6 days after harvesting. Additionally, the article highlights the potential use of banana stem waste for the production of cellulose-based products [2].

Abdul Rohman, M. Abdul Wahid, Sari Widji Utami., Anis Usfah, 2019 conduct a study to design and develop a machine for cutting banana stems to enhance livestock feed production through fermentation. This machine has been devised to segment banana stems into efficient small pieces for employment as animal feed. The article accentuates the abundance of banana stems as a raw material and the accessibility of the aforementioned machine. The fermentation process is elucidated as a means to optimize the utilization of banana stems as livestock fodder. The article underscores the simplicity and applicability of the fermentation technology for farmers in the village of Sumberejo. Additionally, the nutritional content of banana stems is also addressed [3].

In 2019, Hisar Alexander Manullang devised a banana stem chopping machine for livestock feed, featuring rotational speeds of 550 rpm and 900 rpm powered by a 7 HP engine. These banana stems can be optimized, possess market value, and serve as livestock fodder. The processing of these banana stems aims to minimize the escalating costs associated with livestock feed. The chopping apparatus consists of two steel plate blades repurposed from grass-cutting implements. Given the prevailing manual approach to banana stem processing within the community, Hisar Alexander Manullang emphasizes the imperative of a banana stem chopping machine to facilitate livestock farmers in ensuring a consistent feed supply [4].

According to a study conducted by Agustinus, F., & Minggawati, I. (2019), it was found that banana stems contain various nutrients such as dry matter (BK) of 9.8%, total ash of 18.4%, crude fat (LK) of about 3.2%, crude fibre (SK) of 31.7%, and crude protein (PK) of about 8.8%. Animal feed derived from agricultural and plantation waste has low nutritional value, therefore efforts are needed to improve its quality through the application of technology in processing this banana stem waste [5]

In 2020, Basuki, B. N., conducted a research study titled "Utilization of Handle Grinder as a Multi-Functional Livestock Feed Chopper Machine to Assist the Community of Babadan Village in the Ngrambe Sub-District of Ngawi Regency." The objective of the study was to facilitate the process of chopping banana stems into supplementary livestock feed within the aforementioned community. Basuki asserted that the developed chopper machine exhibited high capacity for chopping banana stems while maintaining low power consumption. By employing a handle grinder as the driving mechanism for the chopping machine, the anticipated outcome was the achievement of finely chopped animal feed, along with reduced operational time, ranging between 5 to 10 minutes per day [6].

In another study, Ratna Dewi, 2021 devised a livestock grass chopping machine employing a type of strip blade. The prevailing method for chopping elephant grass amongst farmers remains rooted in tradition, involving the use of a machete. While this technique is deemed effective for small-scale livestock owners, it proves less efficient for medium and large-scale farmers due to the considerable time and effort it consumes. The utilization of a machete or similar sharp implements is perceived as unsafe, further yielding unevenly sized chopped fodder. According to Ratna Dewi, the introduction of this grass chopping machine is imperative, particularly for larger-scale livestock keepers, in order to streamline the process of fodder preparation [7]

Melly, S., A, I., Lubis, U. K., Anggita, W., Mahendra, H. M. A., and Guswanda, G. (2023) carried out a study with the primary objective of designing and fabricating an automated banana stem chopper. This apparatus was subsequently subjected to rigorous performance testing and a comprehensive technical-economic evaluation. The development of the banana stem chopper adhered to a methodical approach that encompassed both functional and structural considerations. The integral constituents comprising the machine's configuration encompassed elements such as the frame, chopping chamber, blade, shaft, inlet, chopping outlet, as well as a 1 Hp electric motor. In practical operation, the machine harnesses the rotational force generated by the electric motor, which is then conveyed through the iron shaft to facilitate the turning motion of the blade holder. This holder houses two blades configured to rotate in a clockwise manner, resulting in efficient slicing of the banana stems. The machine has the capacity to process 1,348 kg/hour, generating chopped sections characterized by an average thickness of 2 cm. An in-depth cost analysis reveals a foundational cost of Rp. 10.91/kg and a corresponding break-even point of 15,939.6 kg/year during operational utilization [8].

3 Material and Methods

The design parameters, such as the cutting mechanism, a motor driver, shaft, bearings and machine capacity have been calculated. The result of the calculated design parameters was being used for fabrication:

3.1 The cutting Mechanism

The cutting system of a banana stem chopper is typically a rotating blade with multiple sharp teeth that attached or connected to the shaft. The banana stem is fed into the machine through a hopper, and the rotating blade shreds the stem into small pieces. The shredded pieces of banana stem are then passed out through the discharge chute. The cutting mechanism depicted in figure 1, while the blade construction is shown in figure 2.

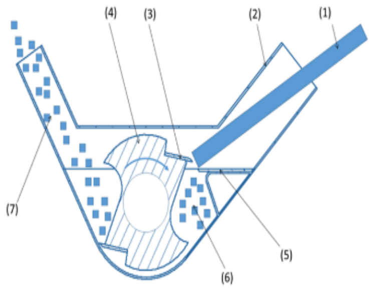

Image description:

1. Banana stems to be chopped;
2. Upper case (inlet);
3. Chopping knife tied to the drum;
4. Drum;
5. Fixed knife;
6. Chopped banana stems; and
7. Exhaust hooper.

Fig. 1. The Cutting Mechanism.

The blade cutting force (F_{blades}) can be found using the equation:

$$F_{blade} = m\omega^2 r \qquad (1)$$

Where: F_{blades} = cutting force of the knife (N); **m** = mass of the knife load (kg); **ω** = angular velocity (rad/sec); **r** = Radius (mm); Since: angular velocity (w) = 6.28 rad/sec; the mass of the knife load (m) = 4 Kg; The radius of the knife attached on to the drum (r) = 0.022 m; Then the then the force acting on the chopping knife is: 4 kg x (6.28 rad/s)^2 x 0,022 m = 19.72 N.

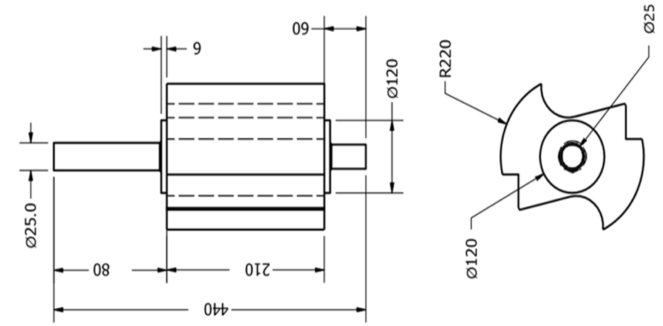

Fig. 2. The blades construction.

3.2 Selection and calculations of motor drive

The driving motor functions as the source of power needed to move the shaft in the rotation system. The power and rotation generated by the driving motor are transmitted by the transmission system to move the shaft and drum. The required motor driver power:

$$P = \frac{T/1000(2\pi.\frac{n2}{50})}{102} \tag{2}$$

Therefore, P = 3.5 Kw. By considering the planned power safety factor, the required power becomes:

$$P_d = P \text{ x } f_c \tag{3}$$

P_d = 3.5 x 1.4 = 4.9 Kw = 4.9 x 1.34 = 6.5 HP

3.3 Shaft diameter

The chopper shaft is a revolving component located in the shredder chamber, and it is fitted with the drum. As its near end is supported by two bearings, the banana stem chopping shaft is designed to endure both torsional and bending loads that it is subjected to during operation. Consequently, the banana steam chopping shaft diameter (ds), can be calculated using equation [9]:

$$d_s = \left[\frac{5,1}{\tau_a}.\sqrt{(k_m \ x \ M)^2 + (k_t \ x \ T)^2}\right]^{1/3} \tag{4}$$

Where: n = The planned knife rotation (rpm); ds = shaft diameter (mm), *T* = Torque (N.m); *Km*= Torsional moment correction factor vallue 1.0 – 1.5, *Kt* = flexural factor value 1.2 – 2.3, *Ta* = allowed shear stress.

- The allowed shear stress (*Ta*) can be found using equation

$$\tau_a = \frac{\tau_b}{sf_1.sf_2.} \tag{5}$$

Where: *Tb* = tensile strength; *Sf* = first safety factor, *Sf2* = second safety factor. The tensile strength value for machine construction carbon steel (S45C) is 58 kg/mm2

Thus; Ta = 58/(6.6 x 3.0) = 58/18 = 3.22 Kg/mm^2

- Power transmission torque (T) can be found using equation

  $$T = (974 \times 10^5) \times (P_d/n) \tag{6}$$

  Where: Pd = The required motor driver power; n= motor driver rotation speed (Rpm),

  Thus: T = (974 x 10^5) x (4.9/3600) = 1325.72 Kgmm

- Bending moment correction factor (*Km*) = 2.0 collision correction factor (*Kt*) = 1.5 the biggest moment can occur (M) = 2688 N/mm.

Thus, by using the formula (4), then the value of shaft diameter can be calculated, d_s = 20.84 mm. The shaft diameter chosen is 25 mm.

3.4 Bearings Selection and Calculation

The bearings used are single row deep groove ball bearings with balls that can only withstand radial loads.

$$C = F_e \left[\frac{L_b}{10^6}\right]^{1/3} \tag{7}$$

Therefore, C = 10835.01 N. Based on the C value obtained and compared with table 4.12 in the attachment, bearing No. 6205 Deep grove ball bearing with the following dimensions: Inner diameter = 25 mm; Outer diameter = 52 mm; Width = 15 mm

3.5 Finding Machine Capacity

To calculate the product capacity of a banana stem waste chopping machine, you will need to know the following: drum diameter; drum length; drum speed; feed rate. The following formula can be used to calculate the machine capacity (Kg/hour):

$$c_p = d_v \; x \; d_f \; x \; f_r \tag{8}$$

Where: c_p = Product capacity; d_v = drum volume; d_f = drum fills per hour; and f_r = feed rate; Since the drum volume d_v =

$$d_v = \pi \, x \, r^2 \, x \, L \tag{9}$$

And the Drum fills per hour (d_f) =

$$d_f = d_s \, x \, 60 \tag{10}$$

Where: r = drum radius; L = drum length; d_s = drum speed;
If the drum diameter = 220 mm; Drum length = 210 mm; drum speed = 3600 revolutions per minute; feed rate = 100 kilograms per hour; therefore the product capacity of the machine would be calculated as follows; The drum volume d_v = 3.14 x 110^2 x 210 = 7,978,740 mm^3 = 7.97874 m^3; The Drum fills per hour d_f = 3600 x 60 = 216,000; The Product capacity = 7.97874 x 216,000 x 100 = 172,152,000 kilograms per hour.

4 Result and Discussion

4.1 Machine parts and construction

Please The results of calculated design parameters were being used calculation done in section 4, have been used for construction and fabricating of the banana stem waste chopping machine, the machine that will be fabricated consists of several constituent components, Figure 3 shows the machine design and construction, while figure 4 shows the finished banana steam chopper.

1. Single cylinder gasoline motor is used as a source of power and rotation, which in operation is used to rotate the drum and chopping knife through the intermediary shaft and fixed clutch. The driving motor used in the banana stem chopping machine is a YAMAOKE Type YX200 gasoline motor, 6.5 Hp, with a maximum rotation of 3600 Rpm. Figure 3 shows the machine design and construction

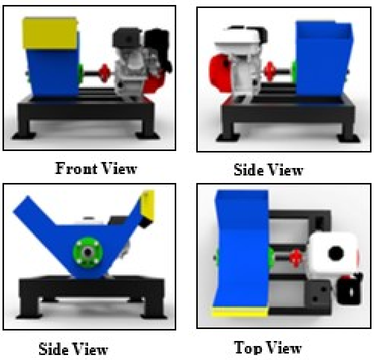

Fig. 3. Machine design and construction.

2. The drum: is a shaft that has been designed to bind and carry chopping knives that allow the chopping process to occur. The drum is made of low Carbon steel for machine construction or equivalent to S235JR according to DIN EN 10025-2 steel standard. The drum is also made with a large mass resulting in high inertia so that cutting energy efficiency can be achieved.
3. Chopping knife consists of two hardened impact resistant steel blades equivalent to S460Q as per steel standard DIN EN 10025-6. The two chopping knife blades are sharpened at a good cutting angle and discharge angle and are fastened in such a way on the drum, that they provide great momentum as the drum rotates. The sudden shrinkage of momentum when the knives collide with the banana stem supported by the fixed knives generates a shear force large enough to cut the banana stem.
4. The fixed blade: is made of the same material as the chopping blade. The fixed blade ensures that the banana stem is well supported so that the cutting process can occur properly.
5. Seated bearings or pillow blocks. are utilized as shaft supports so that the shaft remains in position while bearing cutting loads. This component also ensures smooth shaft rotation.
6. The clutch: serves to forward power and rotation from the motor to the shaft. This component is made of low carbon steel equivalent to S235JR and is fastened to both shafts using pegs and bolts.
7. Lower case serves as a bearing support component, this component is made of low carbon steel equivalent to S235JR.
8. Upper Case: is made of low carbon steel equivalent to S235JR, serves as an input hopper and outlet of chopped results.
9. The frame: is the main component made of low carbon steel equivalent to S235JR in the form of a U profile with a size of 75 x 45 x 5 mm, functioning as a holder for all the components that make up the banana stem chopping machine.

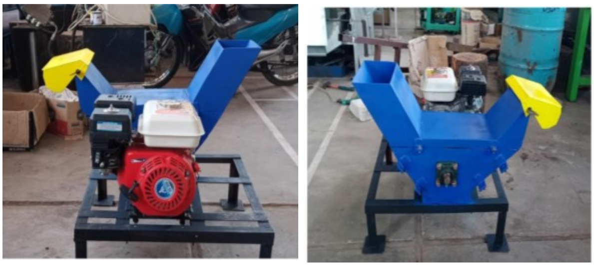

Fig. 4. Assembled banana steam chopped machine.

4.2 Principal operation of the machine

The principal operation of a banana stem chopper for livestock feed is to cut the banana stems into small pieces that can be easily eaten by animals. This is done using a series of rotating blades that are powered by an electric motor or a gasoline engine.

The banana stems are first fed into the chopper through a hopper. The blades then cut the stems into small pieces, which are then ejected from the chopper through a discharge chute. The size of the pieces can be adjusted by adjusting the spacing between the rotated blades and the fixed blades.

Here is the procedures on how to operate the banana stem chopper:

1. Make sure that the chopper is properly assembled and that the blades are secure.
2. Adjust the spacing between the blades to achieve the desired chop size.
3. Connect the chopper to a power source.
4. Start the chopper and feed the banana stems into the hopper, make sure that the banana stems are clean and free of dirt and debris before chopping them, If the banana stems are too long or the diameter of the banana steam is bigger that the hopper inlet, cut them into shorter and smallest pieces before feeding them into the chopper.
5. Be careful not to overload the chopper, as this can damage the blades and reduce the efficiency of the chopper.
6. Collect the chopped banana stems from the discharge chute;
7. Clean the chopper thoroughly after each use.

4.3 Performance evaluation

Performance evaluation is a crucial part of the machine development process. Once the design, manufacture and assembly stages are completed, testing is required to determine how the machine is performing, what problems have occurred and where improvements can be made. The intended evaluation was focused on the machine's production rates and the thickness of the chopped results.

The following procedures were used for the performance test: the tests were carried out by varying the knife spacing (the gap between the rotating knife on the drum shaft and the fixed knife) from 18 mm. 16 mm and 14 mm with a chipping time of 5 minutes. The chopping results at each knife spacing are then collected for weighing and measuring the thickness of the chopped results, the procedure being as follows: (1). Prepare the chopping machine, banana stems and other supporting equipment such as scales, stopwatches and containers for collecting the chopping results. (2). Start the motor by pressing the on/off button lightly. (3). Insert the banana stems to be chopped into the chopper through the feed funnel. (4). Push the banana stem into the machine so that the tip of the banana stem touches the chopping blade until the banana stem is chopped. (5). Allow to chop for 5 minutes. (6). Collect the chopped product and weigh it using a digital scale. (7). Select 10 chopped banana stem samples to measure their thickness.

This procedure is then repeated for 16 mm and 14 mm knife spacing. Process and analyze the test data in terms of the weight of the chopped banana stems within 5 minutes and the thickness of the chopped results.

Equation (11) may be used to calculate the machine's production rate.

$$P_r = T_{wo} / T_o \qquad (11)$$

Where: P_r = production rate (Kg/hour), T_{wo} = weight of waste plastics discharge from the hopper (Kg), T_o = time needed to shred the plastics = 5 minutes = 0.083 hour

Functional testing is the latest form of testing method for the banana steam chopper machine's design, which aims to validate whether the design results can operate according to the anticipated design. The testing process involves verifying the machine's vital components, elucidating its functionality, and detecting any potential design faults. The trial will decide whether the machine's operations are precise, reliable, and efficient as intended. If the design is inadequate, adjustments must be made to enhance its performance. Table 1 and table 2 shows the test outcomes.

Table 1. Performance Test Results

Blade distance (mm)	Average thickness of shreds (mm)	Shredded Weight (Kg)	Shredding time (h)
18	9.50	3.40	5 min = 0.083 h
16	7.70	3.90	5 min = 0.083 h
14	4.43	4.10	5 min = 0.083 h

Table 2. The production rates

Blade distance (mm)	Production rates (Kg/H)
18	40.96
16	46.98
14	49.39

From the data obtained in table 1 and table 2 it can be seen that: in the first experiment with a blade spacing of 18 mm the chopping machine can produce chopped banana stems weighing 3.4 Kg with an average thickness of 9.50 mm during the set time, then in the same time with a blade spacing of 16 mm the chopping machine is able to chop banana stems weighing 3.9 with an average thickness of 7.7 mm, then in the third experiment with a blade spacing of 14 mm the banana stem chopping machine can produce chopped 4.1 Kg with an average thickness of 4.43 chopped results. The data in the table above also shows that by adjusting the distance between the knives, the user can adjust the thickness of the chopped results as desired.

5 Conclusion

This paper has presented the design, construction, and performance evaluation of a banana stem chopper for livestock feed. The chopper was designed to be simple, efficient, and durable, and to be suitable for use by small-scale farmers.

The chopper was constructed using locally available materials and was powered by a 6.5 hp Single cylinder gasoline motor. The chopping mechanism consisted of a rotating drum with two knives. The banana stems were fed into the chopper through a hopper and were chopped into small pieces.

The performance of the chopper was evaluated in terms of its chopping capacity, power consumption, average thickness of shredding and production rates. The chopper was able to chop banana stems at a rate of 49 kg/hr and consumed 6.5 kW of power. The average thickness of shredding was found to be 9.50 mm, 7.7 mm and 4.43mm.

Overall, the banana stem chopper was found to be a simple, efficient, and durable machine that is suitable for use by small-scale farmers to chop banana stems for livestock feed.

6 Acknowledgment

This study was supported by the State Polytechnic of Kupang's annual research program of 2023. We extend our gratitude to the director of State Polytechnic of Kupang for providing the funding. Additionally, we acknowledge the support of the head of the mechanical engineering workshop, and it is with great pleasure that we recognize our research team's contributions to the successful completion of this project.

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