# Design and Development of Cross-Flow Type Sorghum Chopper for the Cattle Feed Industry

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**Abstract.** Abstract. The objective of the research is to apply a chopper machine to process forage from sorghum plants for cattle feed and adopt a crop-livestock integrated system to support sustainable agriculture. A cross-flow type chopper machine has been developed for chopping sorghum crops at 7 t/h design capacity and cutting length of less than 10 mm. The machine consists of a cylinder chopper which is designed at 420 mm diameter, 540 mm length, and 1500 rpm. and a feeding conveyor. It has 18 pieces of cutting blades, installed at six rows around and three rows alternately along the chopper cylinder to minimize power requirement and vibration. The power requirement was 2.07 kW and 32.23 kW for feeding and chopping respectively. The performance test has been conducted at the farmer group in Kendit Sub-District, Situbondo district, and showed that the capacity was 7.2 t/h at 3-9 mm cutting length.
Keywords: cattle feed, sorghum, cross flow type chopper, chopping cylinder, feeding conveyor

## 1 Introduction

The concept developed in this study is to apply a chopper machine to process forage made from local plants for cattle feed according to the principles of Low external input and sustainable agriculture. Beef production in Indonesia in 2019 is 262.68 thousand tons, this amount is still insufficient to meet domestic demand, so 160.60 thousand tons are still imported. One important component in supporting the development of cattle production is the availability of feed that is of high nutritional value, inexpensive and available throughout the season. More than 65% of production cost of cattle is feed cost [1]. Material feed For cattle ruminants must contain sufficient nutrition such as: fiber, fat, protein, energy and minerals. Good quality of feed formulation should consist of forages and concentrates in certain composition is called complete feed (Figure 1). Complete feed can be made from local resources, such as biomass, agro-industry by-product and added by high nutrition supplements.

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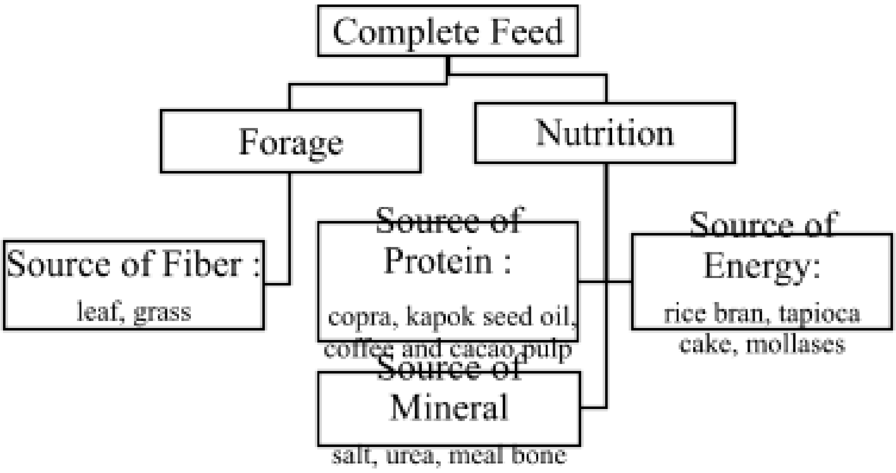



**Fig. 1 .** Raw material of complete feed for feed cattle ruminants in the palm-cattle integration system

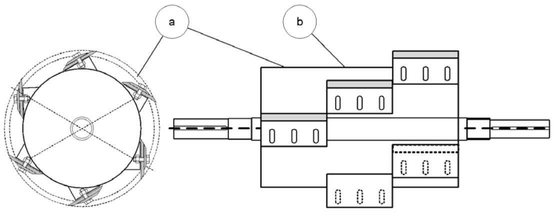
Situbondo is one regency in Java that has high cattle population with a number of cows are 180,000 [2]. Source of existing cattle feeds originally from biomass crops such as rice, corn, soybeans, sorghum and sugarcane. Beside it, the Situbondo district is surrounded by sugar plant that produces molasses as source of energy for feed. The business of processing cattle feed made from sorghum is growing in Situbodo district. Demand for sorghum plant which is sliced in 0.2-1.0 length, as a source of forage is growing rapidly. The technology for processing sorghum plant biomass has begun to develop in this district, especially sorghum chopping machines with a small capacity of less than 1 ton/hour and packaging of chopped sorghum using airtight plastic bags. Farmers sell sorghum plants to mini feed processors/factories and managers of mini feed mills sell to farming communities. The integration between sorghum-growing farmers and the sorghum biomass processing industry for feed as well as cattle breeders needs to be better integrated using various technologies. ICAERD in 2021 has conducted researc h to design and develop chopper machines. The cross flow type chopper was selected because this type is suitable for large capacities (> 1 t/h) and requires less energy than the axial type [3].

The results of other studies show that there are differences in water content along the corn stalks, i.e. lower water content at the top of the stalks results in a more brittle behavior [4], this also indicates lower tensile strength. The bevel angle of the blade plays a role in chopping effectiveness. The results of the study found that the optimal blade angle for cutting sorghum stems is 36o with an energy requirement of 22 J [5].

## 2 Material and method

The research location is on 50 ha of sorghum planting area in Klatak village, Kendit sub-district, Situbondo Regency with an average productivity of 40 tons of sorghum stalks/ha and harvesting 2 times a year, 4000 tons of sorghum biomass material will be produced. In this design, the biomass to be processed is targeted to be 50 to 60% of the total sorghum biomass harvested with a machine working day of 60 days in one year with a machine operation of 6 h/d. So based on these data [6], a chopper machine with a capacity of approximately 7 tons/hour is needed.

The designed of chopper is the cylindrical or cross-flow type with chopping blades mounted around the chopping cylinder alternately along the chopping cylinder so that the required power and vibration due to cutting can be minimized (Figure 2). The flat belt conveyor is used to transport the sorghum stalks from the truck to the chopping section. The sorghum stem clamp consists of a pair of finned pipe rollers, the upper part of which is pressed with spring through a chain transmission system (Figure 3) to feed and clamp the sorghum stalks to the chopper so that the chopped length can be adjusted according to the needs in the field. The chopped results will be packaged in an airtight plastic bag for the fermentation process, so the length of the chopped cannot be more than 10 mm so as not to puncture the plastic bag. The system for transmitting power from the drive motor to the chopper section uses a V Belt, while the belt conveyor and clamp use a sprocket and chain.




**Fig, 2.** Cross flow type chopper cylinder with intermittent alternate knife (a) around chopper cylinder (b)

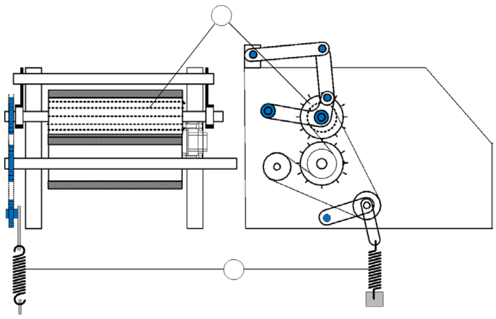


**Fig. 3.** Feeding roller with ribbed rolled (a) and spring (b) for clamp the biomass to be fed to the chopper

Some of the characteristic data of sorghum stalks are approximated by the characteristic data of corn stalks which have been widely studied. The shear test rig designed in this study (Figure 4) used a blade with a bevel angle of 28o to calculate the chopping power required for the sorghum stalks (Table 1).

**Fig. 4.** Test equipment (Test Rig) sorghum and corn stem shearing force with corner sharpness blade (bevel angle) 28o

In order to calculate the capacity and dimensions of the chopper machine, it is necessary to calculate the data volume of the biomass to be chopped and the characteristics of the biomass, the type of the chopper, and the motor engine. The required data is approximated by the biomass data of corn stalks, similar to those of sorghum stalks. The average bulk density of corn stalks was 127.3 kg/m3, and the porosity of stems and leaves were respectively 58.5% and 86.06% or an average of 72.2% at 64% stem moisture content [7]. The tensile properties of corn stalks at the bottom close to the ground reach a maximum value of 67.2 MPa [8]. The results of other studies show that there are differences in water content along the corn stalks, i.e. lower water content at the top of the stalks results in a more brittle behavior [4], this also indicates lower tensile strength. In the design of this chopper, measurements of the shear stress of the sorghum stem are carried out to calculate the chopping power. The angle of the blade plays a role in the effectiveness of the chopping. The research results obtained that the optimal blade angle for cutting sorghum stems is 24o with an energy requirement of 22 J [5]. The smaller the bevel angle, the sharper the knife, and the lower the required cutting force. However, with ordinary carbon steel, the knife will break easily and quickly trumpet, so standard alloy steel JIS SKD 11 is used which is hardened to 59 HRC with a bevel angle of 28o.

The main part design parameters to determine the capacity of the forage chopping machine are blade width, amount of knife, round cylinder, feeding rate, thick heap and bulk density of forage, Gaps between sorghum stalks in piles, the force required to cut the sorghum stems, and characteristics of flat belt conveyors. Each parameter has a contribution to machine performance specifically dimension of slice and machine capacity. At the same machine shaft rotation, size of forage slice is influenced by number and distance between each blade and the feeding rate. The shorter of distance between knife, the smaller forage slice size [9].

The results of measurements of the cutting force of sorghum stems with an average moisture content of 50.07% indicate that the amount of force required to cut sorghum stalks with an average diameter of 21.3 mm reaches 235.3 N or an average shear stress of 70.57N (Table 2). With a large enough cutting force, it is necessary to have the blades in an alternating arrangement to minimize the power required and suppress machine vibration.

**Table 1.** The results of shear force measurements of sorghum stems using test rigs

| Sample No. | Sorghum stem diameter | Moisture content | Cutting force, Fc | Shear strength, Ō | Choping force,Fs |
|---|---|---|---|---|---|
| | (cm) | (%) | (N) | (N/cm$^2$) | (N) |
| 1 | 1.7 | 48.5 | 217.2 | 72.81 | 3631.43 |
| 2 | 1.7 | 50.1 | 108.6 | 47.87 | 2387.52 |
| 3 | 2 | 52.4 | 271.5 | 86.46 | 4312.45 |
| 4 | 2.3 | 47.9 | 325.8 | 78.45 | 3913.00 |
| 5 | 3.5 | 52.2 | 325.8 | 56.81 | 2833.38 |
| 6 | 1.6 | 49.3 | 162.9 | 81.06 | 4042.93 |
| Average | 2.13±0.69 | 50.07±1.72 | 235.3±88.2 | 70.57±15.02 | 3520.12±749 |
| | | | | | |

Based on literature study, field studies, and preliminary measurements, data/information was obtained as a design consideration for chopper as follows:

**Tabel 2.** Design consideration for chopper machine

| Description | Notation | Value | Unit | Information |
|---|---|---|---|---|
| Sorghum land area | Ac | 50 | ha | Requirement |
| Productivity | Pr | 4,000 | t/year | Yield potential |
| Working days | Hk | 60 | Day/year | Assumption |
| Working hours | Jk | 5 | Hour/day | Assumption |
| Design capacity | Ww | 7 | Ton/hour | Target |
| Chop length | lc | 5 | mm | Consumer requirement |
| Porosity between stem and leaves | Ɣ | 0.72 | % | Y Zhang et al (2012) |

The formula used to calculate the performance of the chopper is as follows:

a. Machine capacity

The design capacity ($W_w$) of the chopper is determined based on the biomass produced in 50 ha of sorghum crop area at the pilot location, the productivity of sorghum biomass and the production target of the biomass to be processed, calculated using the following formula:

$$W_w = \frac{A_c P_r T_p}{H_k J_k} \quad (1)$$

$W_w$ = Design capacity (t/h) (2)

$A_c$ = planting area ( ha )
$P_r$ = Productivity (t/ha)
$T_p$ = production target (%)
$H_k$ = day work per year (d/y)
$J_k$ = working hours per day (h/d)

Whereas actual machine capacity ($W_a$) is calculate using the following formula :

$$x\ f_p\ x\ N_c\ x\ 60 \quad (3)$$

$W_a$ = actual capacity of chopper (kg/h)
$L_t$ = total blade length (m)
t = thickness pile biomass on the conveyor (m)
$l_c$ = Length of chopped (m)
n = number of blade rows around chopper cylinder
ρ = bulk density of sorghum biomass ($t/m^3$)
fp = feeding factor

$N_c$ = rotation of chopper cylinder (rpm)

b. Total length of blade ($L_t$)

Blade designed by using hardened material with JIS DC 11 standard with scale HRC hardness 60-61. The knife consists of a short knife blade which is tied around the chopper cylinder alternately as many as 6 grooves. The total blade length ($L_t$) is calculated using the following formula:

$$L_t = \frac{W_a}{\text{t x lc x n x } \rho \; x \; f_p \; x \; N_c \text{x } 60} \quad (4)$$

$W_a$ = actual capacity of Chopper ( kg /h)
$L_t$ = total blade length (m)
t = thickness of pile (mm)
$l_c$ = length of forage chop (mm)
$l_b$ = Length of individual blade (cm)
ρ = average density of sorghum stems and leaves (kg/m $^3$ )
n = Number of knife rows around chopper cylinder
$r_n$ = Amount of knife along chopper cylinder

c. Feeding rate ( $V_f$ )

Feeding rate is calculated based on the amount and characteristics of the biomass to be chopped, the length of the knife and the feeding factor determined from the expert judgment as stated in table 2 using the following formula:

$$V_f = l_c \; x \; n \; x \; N_c = \frac{W_a}{L_t \; x \; t \; x \; 60 \; x \; f_p \; x \; \rho} \quad (5)$$

d. Power requirement for chopper ($P_c$)

Power requirement for chopper is 32.23 kW and calculated using formulas as following :

$$P_c = F_s \; x \; \text{ɣ} x \; R \; x \; \omega \quad (6)$$

$$P_c = F_s x \; \text{ɣ} \; x \; R \; x \; 2 \; \pi \; \frac{N}{60000} \quad (7)$$

$F_c$ = Chopping force (N)
ɣ = space between stemp and leave (%)
R = radius of the end of blade tip (m)
ω= Speed angle ( Rad/sec)
π= 3.14

e. Power requierement for feeding ( $P_f$)

The power required to feed the sorghum stalks to the chopping machine consists of the power of the conveyor to transport the biomass (Pc) and the power to clamp and feed the biomass (Pp).
The power required to feed the sorghum stalks is calculated by the following formula:

$$F_f = W_m \times H + 0.04 \; (2 \times W_b + W_m) \times L \quad (8)$$

Because sorghum biomass is transported at the same height, the lifting height of the biomass H=0, so:

$$F_f = 0.04\ (2 \times W_b + W_m) \times L \quad (9)$$

$$F_{max} = 1.4 \text{ x } Ff \quad (10)$$

$$Pc = \frac{Fmax}{Vc} \quad (11)$$

The power to clamp and feed the biomass (Pp) is calculated by the following formula:

$$Pp = Wb\ x\ g \quad (12)$$

Power requierement for feeding (Pf) is 2.07 kW calculated by the following formula:

$$Pf = Pc + Pp \quad (13)$$

$F_{max}$ = maximum tensile force, 1.4 is drive factor [10]

$F_f$ = Force requierement for feeding (N)

$W_m$ = weight of biomass ( kg/m)

$W_b$ = weight of belt conveyor (kg/m, see table 3)

L = length of belt conveyor (m)

g = gravitation, 9.8 m/s2

**Table 3**. Flat belt conveyor weight based on belt width

| Belt width | Wb | W3 | |
|---|---|---|---|
| (mm) | Belt wieght | Weight of rotating part of a roller (kg) | |
| | (kg/m) | carrying | Return |
| 500 | 8 | 2.3 | 4.6 |
| 600 | 9 | 2.5 | 5.2 |
| 750 | 13 | 3.6 | 8.5 |
| 900 | 16 | 4.1 | 9.7 |
| 1.050 | 23 | 6.1 | 14.5 |
| 1.200 | 26 | 6.6 | 16.1 |
| 1.400 | 33 | 10.2 | 23.4 |
| 1.600 | 38 | 11.2 | 26.0 |
| 1.800 | 46 | 12.5 | 29.8 |
| 2.000 | 51 | 13,5 | 32.3 |

Source : [10]

## 3 Material and method

From the formulas and table as shown in section 2 design approach, the technical data for the chopper machine design are compiled in Table 4.

**Table 4.** Chopper machine design technical data

| Description | Notation | Value | Unit | Information |
|---|---|---|---|---|
| Stem density | ρ | 127 | Kg/m3 | Y Zhang et al (2012) |
| Design capacity | Ww | 7,000 | Kg/h | Determined |
| | Wc | 55.12 | m3/h | Calculated |
| | | 0.92 | m3/min | |
| Rotation of chopper shaft | Nc | 1,500 | rpm | Determined |
| Number of blade | η | 6 | rows | Determined |
| Forage pile thickness | t | 0.1 | m | Determined |
| Chop length | lc | 0.005 | m | Technical requirement |
| Chopping rate per rotation | w | 0.20574 | Kg/rotation | Calculated |
| Feeding factor correction | fp | 40 | % | Expert judgment |
| Output capacity | W | 7406.64 | Kg/h | Recalculated |
| Length of total blade = length of chopper cylinder = width of conveyor belt | Lt | 0.51 | mm | Calculated |
| corrected blade total length | L | 0.54 | mm | Determined |
| Length of single blade | lb | 0.18 | mm | Calculated |

Design of Cross-Flow Type Sorghum Chopper shown in Figure 5 (Main Assembly), and Figure 6 (Sub Assembly).

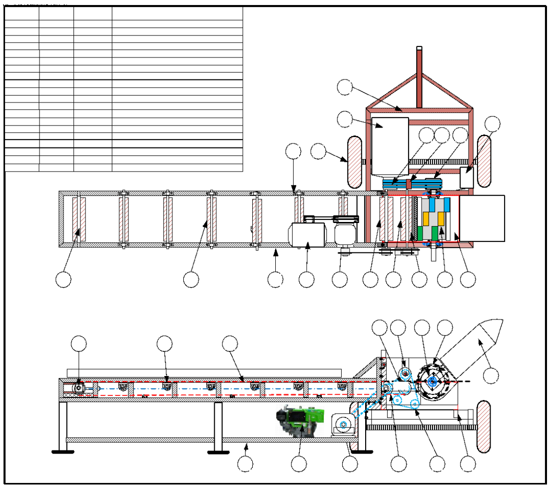


**Fig. 5.** The main assembly of a Cross Flow type Sorghum Chopper with a capacity of 7 t/h

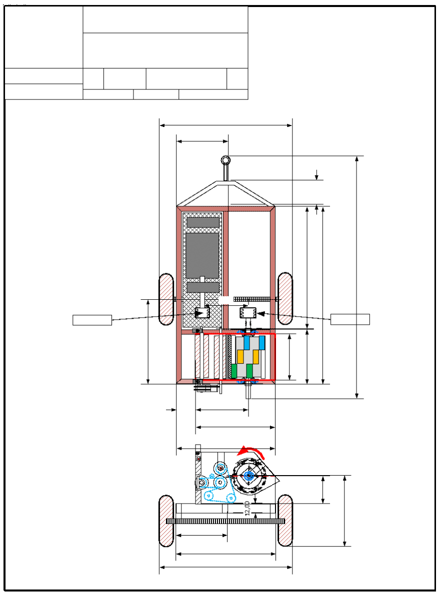


**Fig. 6.** Assembled part of chopper and engine

Performance Test of Cross Flow type Sorghum Chopper

The performance test of the chopper was carried out at the location of the Berdikari 2 group, in the village of Klatakan, Kendit District, Situbondo Regency, shown in Figure 7. The test material used was sweet sorghum of the Bioguma variety which is harvested at 70 days of age. The performance test used 3 repetitions with a weight of 500 kg for each repetition.

**Fig. 7.** The performance test of the Cross Flow type Sorghum Chopper

The results of the performance tests showed that the average capacity of the Prototype Shredder was 7.22 tons/hour. The chopped results varied between 0.3 to 10 mm. The results showed that the chopping results were affected by the rotation of the chopping blade shaft, an increase in the shaft rotation caused a decrease in the amount of chopping less than 5 mm [11]. Likewise, the results of the study [12] showed that the rotation of the chopping blade shaft had an effect on the size of the chopped results. Fuel consumption of 4.24 l/h. The speed of feeding can still be increased but because the workforce is limited, namely only 5 people, the workforce is unable to feed more sorghum stalks to the machine, however, the capacity of this machine has exceeded the planned capacity of 7 tons/hour. Results The results of the performance test can be seen in Table 5.

**Table 5 .** Performance test results of Cross Flow type Sorghum Chopper

| Num. | Sampl e | RPM of chopper engine | RPM of chopper cylinder | RPM of conveyor engine | Fuel consu | Length of chopped stalk | Chopping capacity |
|---|---|---|---|---|---|---|---|

| | weigh t | | | | | | | mptio n | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | no load | loade d | no load | loaded | no load | loaded | | | |
| | (kg) | (rpm ) | (rpm) | (rpm) | (rpm) | (rpm) | (rpm) | (l/h) | (mm) | (t/h) |
| 1 | 500 | 1450 | 1447 | 1449 | 1445 | 2100 | 2098 | 3.56 | 3-10 | 7.164 |
| 2 | 500 | 1450 | 1445 | 1448 | 1444 | 2100 | 2097 | 3.58 | 3-9 | 7.278 |
| 3 | 500 | 1450 | 1448 | 1449 | 1446 | 2100 | 2097 | 3.66 | 3-9 | 7.150 |
| 4 | 500 | 1450 | 1446 | 1449 | 1446 | 2100 | 2098 | 3.60 | 3-8 | 7393 |
| 5 | 500 | 1450 | 1447 | 1448 | 1447 | 2100 | 2099 | 3.62 | 3-10 | 7.279 |
| 6 | 500 | 1450 | 1445 | 1449 | 1445 | 2100 | 2096 | 3.58 | 3-9 | 7.065 |
| avera ge | 500 | 1450 | 1446.3 | 1448.7 | 1445.5 | 2100 | 2097.5 | 3.6+0.0 3 | 3-9 ± 0.5 | 7.221±0.1 |

## 4 Final Analysis

One of the important factors in developing a feed mill is the machines operating cost. Financial analysis uses the BC Ratio calculation, with a chopping machine price of IDR 300,000,000; using 5 operators, the fuel consumption is 3.6 l/h, the engine capacity is 7.22 tons/hour, the machine working hours is 6 hours/day; 60 working days/year and the economic life of the machine is 7 years, the operational costs are 58,784 Rp/ton, while the custom rate is Rp 160,000 Rp/ton, so the BCR is 3.04; so that the business of developing a feed mill using a sorghum chopping machine is financially feasible.

## 5 Conclusion

The design of a Cross - Flow Type Sorghum Chopper with a capacity of 7 t/h to process 60% of sorghum biomass production in an area of 50 ha has been successfully carried out according to design onsiderations, the power required for the chopper is 32.23 kW, the power required for the conveyor is 2.07 kW , chopped length is 3-9 mm and the machine capacity is 7.22 t/h. The application of chopper machines to produce feed is business-sustainable because it is financially feasible, and also from a technical point of view it is able to produce chopped forage that meets the standard requirements, namely the size of the chopped is less than 10 mm, and reaches the design capacity of 7 t/h. With these results, the application of chopper machines is technically and financially feasible, thus providing positive support for livestock sustainability.

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