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DEVELOPMENT AND PERFORMANCE EVALUATION OF A SMALL SCALE MOTORIZED FORAGE CHOPPING MACHINE

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ABSTRACT :

Forage chopper is a mechanical device used to chop forage grass or fodder into small pieces and fed to the livestock. Traditionally, livestock farmers chop forage grass or fodder using sharp edge knives or any crude implements into small pieces. This method is tedious, time consuming, unsafe to the operator with low output. The mechanized forage choppers are mostly imported devices which are sophisticated, costly and required operational and maintenance skills. The locally fabricated forage choppers are normally manufactured with little or no scientific and engineering background. It is therefore, important to develop a forage chopping machine as an intervention to the above envisaged problems. This report presents the development, fabrication and performance evaluation of a chopping machine for chopping capacity, chopping efficiency and length of cut at various pulley diameters 100, 120 and 140 mm and different feed rates and sharpening angle of the blades. The taguchi method was used to design the experiment, and the results were evaluated using the same method. The result showed that the maximum chopping capacity was 15.73 g/s, the maximum chopping efficiency was 96 % and the shortest mean length of cut was 36 mm. The optimum parameters for the process parameters of the machine were obtained. The analysis of variance carried out showed that the pulley diameter and feed rate have significant effects on the dependent variables (chopping capacity, chopping efficiency and chopping length). So the result reveals that pulley diameter has the statistical significance on the dependent variables at 5% level of significance.

Keywords: Forge Chopper, Chopping capacity, Length of cut, Maize stalk, Taguchi Method

1.0 Introduction

Forage choppers are machines used for cutting forages or fodders into small pieces in farms and small sized livestock units (Jamshidpouya *et al.,* 2018).Feeding animals with un-chopped forage or crop residue are associated with selective feed consumption and high feed wastage (Muhammad *et al.,* 2018). Although majority of farmers still rely on the use of rudimentary implements for chopping forages, such as axes and cutlasses, the use of such implements is time consuming and also is associated with drudgery and health hazards.

Forage chopping is very important for animal consumption. Consuming unchopped forage can be detrimental to nutrition because of its bulkiness. Reducing the size of bulky feed's particles, primarily forage resources, is one way to make it less bulky. Because the appropriate forage particle size promotes rumination, enhances secretion of saliva, counteracts ruminal volatile fatty acids, raises milk fat, and helps avoid digestive problems like acidosis, it is crucial to take into account the physical characteristics of forage particles in dynamic-rumen livestock. (Pratiwi *et al.,*2023). Livestock feed preparation is a great problem faced by livestock farmers nowadays. Livestock production, productivity and its sustained development depend on the advancement of science and technology that will enhance production, processing, handling, storing of livestock feed (Abayineh, 2020). Supply of animal feed is volatile as a result of the seasonality of the inputs, and the factors affecting the supply of animal feeds includes; inefficient marketing system, low availability and poor quality of raw materials, processing method used, handling and storage condition (Kassalir *et al,* 2020).

Feeding account for up to 60 % of the cost of livestock production in Nigeria (Adesogan, 20011). Nigeria has about 18.4 million cattle, 43.4 million sheep and 76 million goats produced annually (FMARD, 2017). Limited access to quality feed is a major challenge across all production systems in Nigeria (Shiawoya and Tsado, 2011).

In Nigeria the main feed resource for livestock in traditional production system is crop residues, which is low quality, high fibre content and low digestibility of roughages. The bulky and fibrous nature of coarse feeds results in poor nutrient supply and reduce feed intake. It common for animals to lose weight and condition, produce less and even have difficulty breeding when feed on these low quality roughages. Because such feeds have to remain in the rumen for extended periods before they are sufficiently digested to move out of the rumen and allow more feed consumption (Feyissa *et al*, 2014 and Jabo and Gado, 2017). The mixed farming system of livestock is limited by many factors: declining availability of grazing lands due to human population growth and increasing crop cultivation area, poor production and reproductive performance of animals and lack or inadequate access to technologies. Lack of access to capital for equipment is another problem (Duressa *etal,* 2014).

Therefore, developing forage chopping machine will helps to save and preserve feed for the time of scarcity during dry season. However, there is lack of choppers to prepare animal feed efficiently, effectively and economically. Unavailability of mechanical livestock feed chopper, within the economic reach of small and medium-scale livestock holders, majority of livestock producers in Nigeria, still rely on the use of traditional hand tools, which is time consuming, labour intensive, less efficient and associated with drudgery and health hazards. The aim of this study to develop and evaluate the performance of a motorize forage chopping and also to find the optimal combination of feeding rate, sharpening angle of the blade and pulley diameter that results in optimum chopping capacity, chopping efficiency, and minimal cut length is the goal of this work.

2.0 Materials and Methods

2.1Materials

The materials and instruments that were used in evaluating the performance of the machine includes: (a) forage chopping machine, (b) weighing balance, (c) stop watch, (d) meter rule, (e) oven, (f) bags.

2.2 Method

2.2.1Material selection

The forage chopping machine was fabricated and constructed at Saj Tech Bauchi. The development of the machine was based on related information gathered from journals, books and internet having almost the same concept, along with data on the test materials that were used. The development of the machine was based on the following criteria: (a) availability of the materials (b) durability of the materials (c) cost of the materials (d) machinability of the materials.

2.2.2 Machine Description

The forage chopping machine consists of the following eight (8) major components. (Figure 1) as follows: (1) Hopper (feeding tray), (2) Driving shaft, (3) Feed rollers, (4) Bearings, (5) Cutter-Head, (6) Prime mover seat, (7) Top cover, (8) Outlet unit as shown in Figure 1 below.

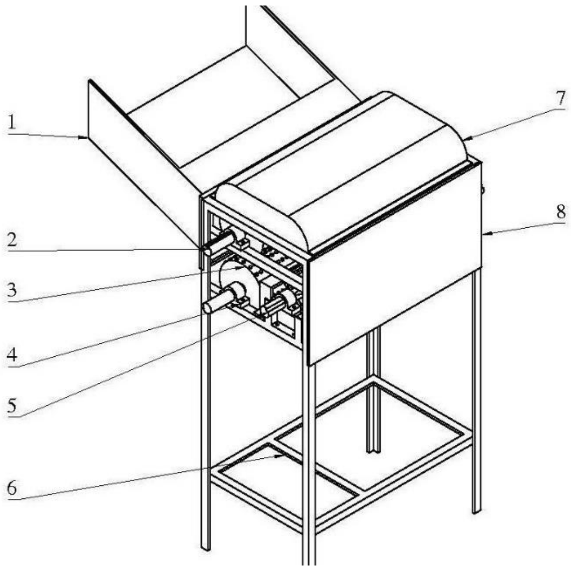

Figure 1: Forage chopping machine.

Feeding tray

Feeding tray is use as a feeding unit is part of the forage chopping machine that serves material cutting into the blade housing. The feeding tray houses the materials and delivers the materials to the feed roller at regulated feed rate. Trapezoidal shape was used in the construction of the feeding tray. The lengths of the two parallel sides are 400 and 370 mm, height 280 mm and width 145 mm as shown in Figure 2.

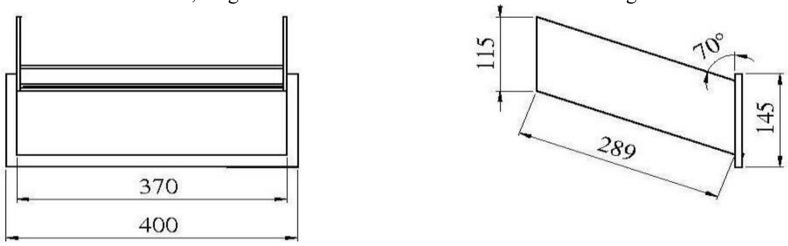

Figure 2: Feeding tray

Cutting Blade

These blades are made up of High carbon steel or alloy steel. The function of the blade is to cut the forage material that can be chopped into smaller pieces suitable for animal feed. There are four cutting blades used in this machine with the following dimensions, length 217 mm, breath 75 mm and thickness 4mm as shown in Figure 3.

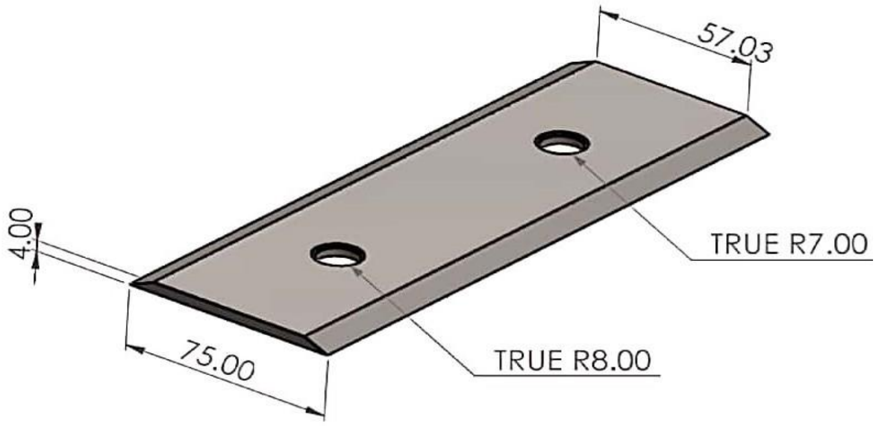

Figure 3: Cutting blade

Feed rollers

There are two feed rollers, upper feed roller and lower feed roller, present in the forage chopper. These rollers are made up of round pipe made from charker plate and have grooves on its periphery. The chopped material was first feed to the rollers, which in turn grip the material and then it move forward to the cutting blade. The lower feed roller was fix while the upper feed roller is spring loaded which can move up and down depending upon the quantity of forage being fed. The feed rollers were driven by a belt and pulleys, which obtained power from prime mover shaft. In light the specification for the blade, the length of the feed rollers was assumed to be 340 mm with outer diameter of 102 mm inside each roller a solid circular shaft was set as the roller axis as shown in Figure 4.

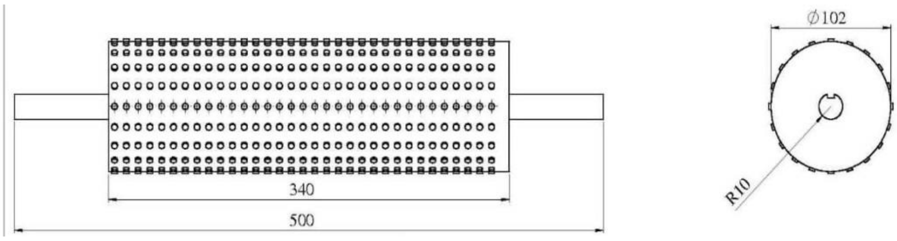

Figure 4: Feed roller

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. Main frame is generally consists of four legs and made up of angle iron .The whole machine was mounted over the legs. The minimum height of the stand is approximately 700 mm from the ground level for easy feeding of the crop in standing posture of the user as shown in Figure 5.

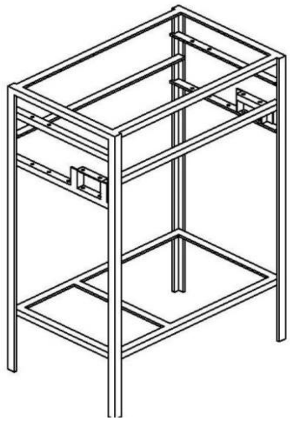

Figure 5: Main Frame

2.2.4 Machine Operation

A petrol engine (5.5hp) provides the power to the cutter-head shaft. The cutter-head shaft which rotates with the help of bearings provides drive to the shaft of the cutting chamber through belt and pulley, while the upper feed roller shaft is powered by the engine from the cutter-head shaft with the help of belt and pulley, which also help to rotate the lower feed roller by means of spur gears. As the material was being fed into the feeding tray, the lower feed roller is fix and the upper feed roller is spring loaded gathered, compressed and advanced the material into the cutting chamber for the cutting into the various lengths with blades attached to the cutter-head. The materials got out through the outlet as shown in Plate 1 below.

Plate 1: Developed forage chopping machine

3.0 Data Collection Procedure

The following steps were carefully followed in collecting and gathering the data, which are as follows: (a) All the necessary material were sourced before testing the forage chopping machine, for example tools needed for adjustments to reduce down time during operation. (b) The moisture content of the material was determined using oven-dry method, (c) A specific amount of forage (sample) was fed into the feeding tray for chopping, (d) The time taken to chop each sample of the material was recorded for every operation, (e) Sample from each trial a sample were taken to the laboratory for the length of cut determination.

4.0 Experimental design

The experiment was design using Taguchi Method of Design of Experiment which uses an orthogonal array to study the entire parametric space with limited number of experiments. The three (3) parameters (independent variables) were taken at three (3) different levels, which gives an orthogonal array of L_9 (3^4) from the orthogonal selector as shown in Table 2.The independent variables were feed rate, sharpening angle of the blade and pulley diameter as shown in Table 1.

Table 1: process parameters and their levels

S/N	Parameters	Code	Level 1	Level 2	Level 3
1	Feeding rate (g/s)	A	1000	2000	3000
2	Sharpening angle of the blade (°)	B	24	26	28
3	Pulley diameter (mm)	C	100	120	140

Table 2: Orthogonal array of the experiment

Experiments	A	B	C
1	1000	24	100
2	1000	26	120
3	1000	28	140
4	2000	24	120
5	2000	26	140

6	2000	28	100
7	3000	24	140
8	3000	26	100
9	3000	28	120

5.0 Machine Performance Evaluation

Maize stalk was used for evaluating the performance of the machine (plate 2). Data were collected at each run and the dependent variables chopping capacity (CC), chopping efficiency (CE) and length of cut (LC) were determined. The average results of chopping capacity, chopping efficiency and length of cut from OA L9 replication were calculated as shown in Table 2. The character used for chopping capacity and chopping efficiency is "larger is better" and for length of cut is "smaller is better", the S/N ratios were determined using the equation (1) and (2) respectively.

$$\text{Larger-the-better (S/N)} = = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad \ldots (1)$$

$$\text{Small-the-better (S/N)} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \quad \ldots (2)$$

Where, n is the number of observation, y is the response, μ is the mean, σ is the variance.

(a) (b)

Plate 2: (a) Unchopped maize stalk (b) chopped maize stalk

5.1 Chopping capacity of the chopper (g/s)

The chopping capacity in (g/s) for the machine was determined using measurements of weight materials and time required. The times required for cutting the sample of forage were recorded (Adgidzi, 2007).

$$\text{CC} = \frac{Qa}{T}\ ,\text{(g/s)} \quad \ldots(3)$$

Where;
Qa = weight of the accepted material after chopping, (g)
T = time taken to chop the material, (s)

5.2 Chopping Efficiency

The chopping efficiency of the machine was measured by taking weight of material before chopping and weight of the material after chopping (Adgidzi, 2007 and Hassan, 2019)

$$\text{CE} = \frac{Qa}{Q^o} \times 100\ ,\ (\%) \quad \ldots(4)$$

Where;
Qa = weight of the accepted material after chopping, (g)
Q^o = weight of the material before chopping, (g)

5.3 Length of cut

After each chopping treatment, random samples were taken from the chopped material to the laboratory and separated to determine the actual means of the length of cut.

Table 3: Response table of values

EXP	A	B	C	Chopping capacity (g/s)	Chopping efficiency (%)	Length of cut (mm)	SN CC	SN CE	SN LC
1	1000	24	100	10.37	90	36	20.31558	39.08485	-31.1261
2	1000	26	120	10.43	90	44	20.29041	39.08485	-32.8691
3	1000	28	140	8.87	89	50	18.95847	38.9878	-33.9794
4	2000	24	120	10.29	94	40	20.24831	39.46256	-32.0412
5	2000	26	140	9.67	90	47	19.70853	39.08485	-33.442
6	2000	28	100	13.87	96	37	22.84153	39.64542	-31.364
7	3000	24	140	9.72	82	51	19.75333	38.27628	-34.1514
8	3000	26	100	15.73	92	36	23.93457	39.27576	-31.1261
9	3000	28	120	11.89	87	43	21.50364	38.79039	-32.6694

6.0 Result and discussion

6.1 Influences of the feed rate, sharpening angle of the blade and pulley diameter on chopping capacity (CC)

Taguchi method used the signal-to-noise (S/N) ratio to measure the value of the quality characteristics of the choice (Pratiwi *et al.,* 2024) as shown in Table (3). The character of S/N ratio used for chopping capacity is the larger the better as showed in Table 4. Therefore, the greater the delta value of a parameter is the better. The optimum setting of process parameters on this approach are obtained by sorting the delta in an order of significance affecting the chopping process. The higher the delta value signifies the more effect their parameters contribute. The highest plots of each parameter were chosen as shown in Figures 2, below. The optimum process parameters obtained by this approach for chopping capacity are A3 (3000 g), B2 (26 degrees) and C1 (100 mm). The result revealed that feed rate and pulley diameter are the most important process parameters influencing chopping capacity. Abagissa and Bose (2024) conducted a study that revealed that feed rate and operational speed had a significant effect on chopping capacity of the machine.

Table 4: Response for S/N ratio large is better for chopping capacity CC

Level	Feed rate	Sharpening angle of the blade	Pulley diameter
1	19.85	20.11	22.36
2	20.93	21.31	20.68
3	21.73	21.10	19.47
Delta	1.88	1.21	2.89
Rank	2	3	1

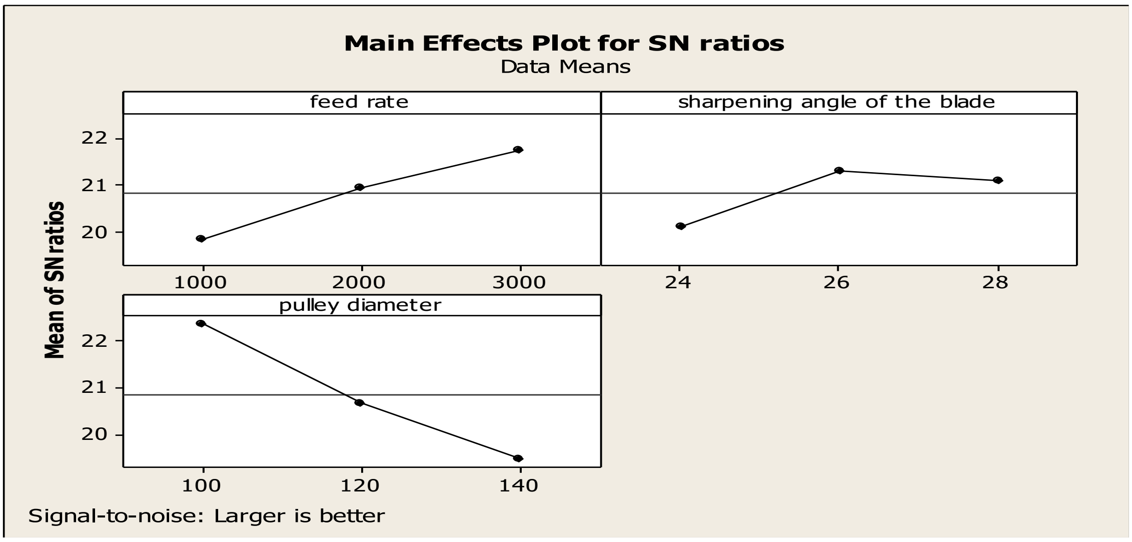

Figure 2: main effects plot for SN ratio for chopping capacity (CC)

6.2 Influences of the feed rate, sharpening angle of the blade and pulley diameter on Chopping efficiency (CE)

The character of S/N ratio used for chopping efficiency is the larger is better as shown in Table 6. Therefore, the greater the delta value of a parameter, the better. The optimum setting of process parameters on this approach are obtained by sorting the delta in an order of significance affecting the chopping process. The higher the delta value the more effective the parameter contribute. The highest plots of each parameter were chosen as shown in Figure 3. The optimum process parameters obtained by this approach for chopping efficiency are A2 (2000 g), B2 (26 degrees) and C1 (100 mm). the result match the study conducted by Abagissa and Bose (2024). Saanoding *et al.* (2019) also determined that the faster the speed the higher the chopping efficiency.

Table 5: Response for S/N ratio large is better for chopping efficiency (CE)

Level	Feed rate	Sharpening angle of the blade	Pulley diameter
1	39.05	38.94	39.34
2	39.40	39.15	39.11
3	38.78	39.14	38.78
Delta	0.62	0.21	0.55
Rank	1	3	2

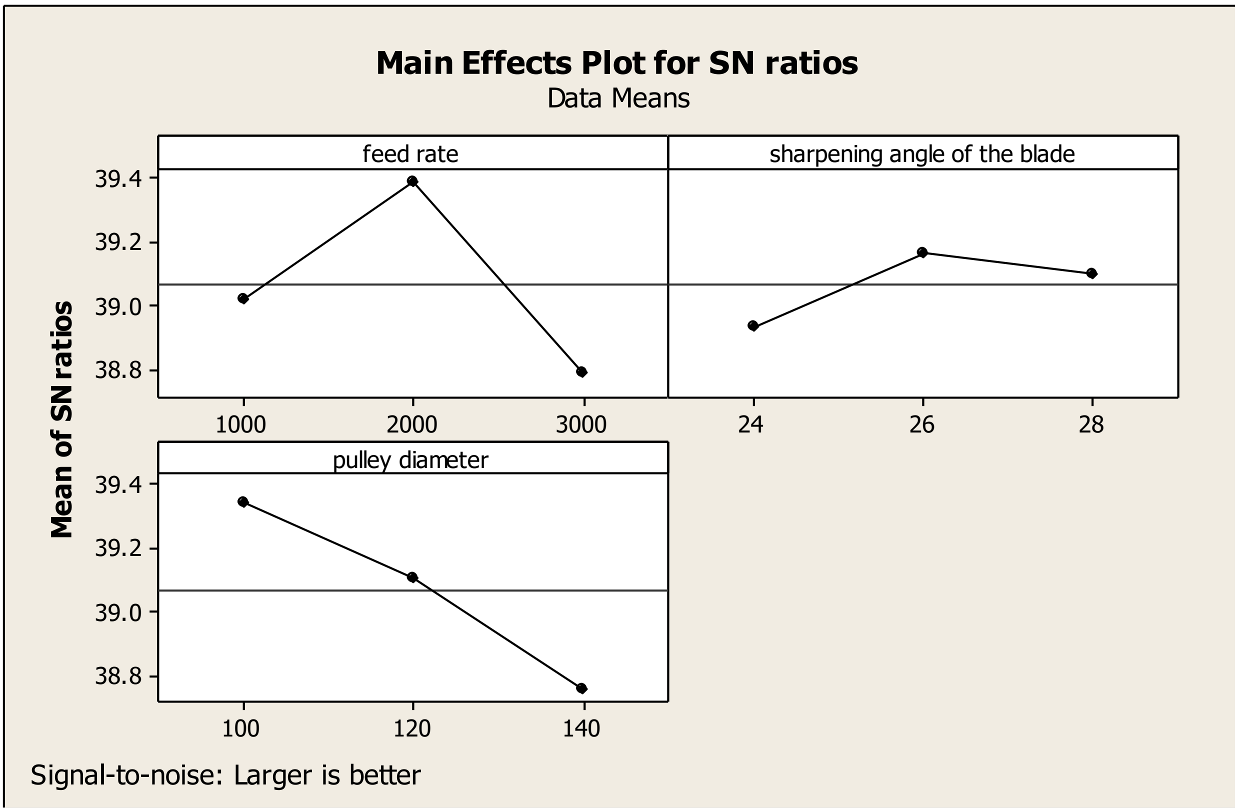

Figure 3: main effects plot for SN ratio for chopping efficiency (CE)

6.3 Influences of the feed rate, sharpening angle of the blade and pulley diameter on length of cut (LC)

The character of S/N ratio used for length of cut is the smaller the better as showed in the Table 3: below. Therefore, the greater the delta value of a parameter is the better. The higher the delta value signifies the more effect its parameter contributes. The highest plots of each parameter were chosen as showed in Figure 4: below. The optimum parameters obtained by this approach for length of cut are as follows: A2 (2000 g), B1 (24 degrees) and C1 (100 mm). Abayineh (2020) and Yonas (2021) reported that the faster the operational speed the finer (smaller) the feed the length of cut, and the slower the operational speed the longer (bigger) the feed length of cut of the machine.

Table 6: Response for S/N ratio smaller is better length of cut (LC)

Level	Feed rate	Sharpening angle of the blade	Pulley diameter
1	-32.66	-32.44	-31.21
2	-32.28	-32.48	-32.53
3	-32.65	-32.67	-33.86
Delta	0.38	0.23	2.65
Rank	2	3	1

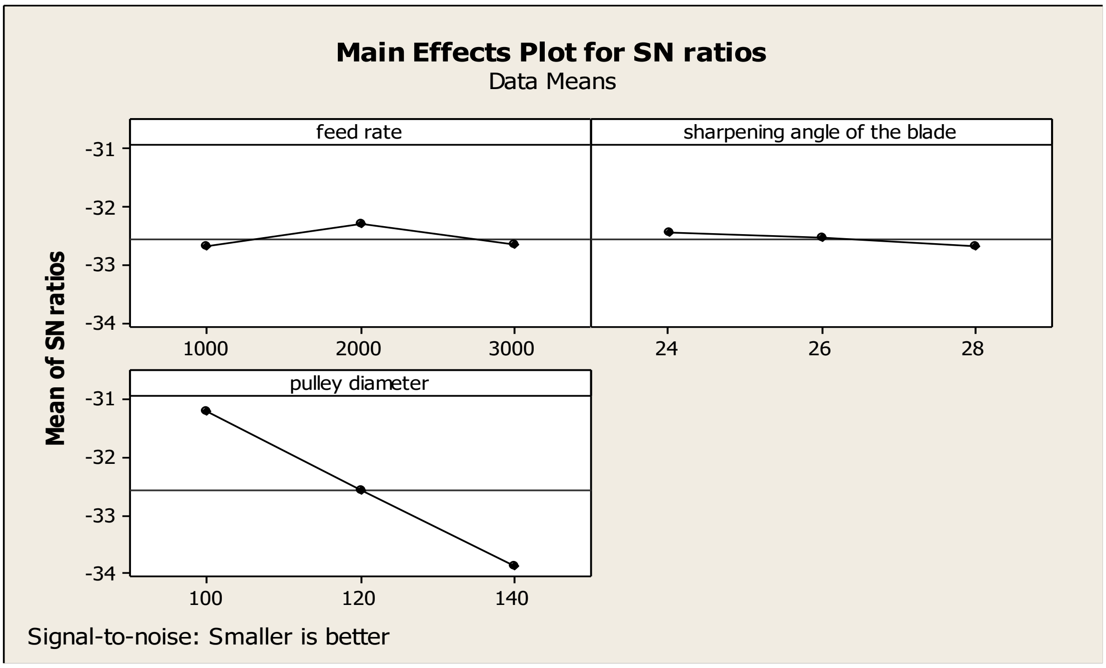

Figure 4: Main effects plot for SN ratio for length of cut (LC)

Analysis of variance of signal-to-ratio of the performance parameters

Analysis of variance was used to understand the percentage contribution of each process parameter in the chopping process. Table 7, showed the analysis of variance of S/N ratio for chopping capacity, it revealed that pulley diameter is the most significant parameter at 5% level of significance and has the highest percentage contribution of (60.4 %), feed rate (25.4 %) and sharpening angle of the blade (11.9 %). It indicates that pulley diameter and feed rate have the most significant effect in the chopping process as reported by Abagissa and Bona (2024).

Table 7: Analysis of variance for S/N ratio large is better chopping capacity (CC)

Sources	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Feed rate	2	5.3166	5.3166	2.6583	10.60	0.086	25.4
Sharpening angle of the blade	2	2.4881	2.4881	1.2441	4.96	0.168	11.9
Pulley diameter	2	12.6452	12.6452	6.3226	25.22	0.038	60.4
Residual error	2	0.5014	0.5014	0.2507			2.4
Total	8	20.9513					

Table 8 showed the analysis of variance of S/N ratio for chopping efficiency, it revealed that feed rate has the highest percentage contribution of (46.1 %), pulley diameter (37.3 %) and sharpening angle of the blade (6.7 %). But it revealed that all the process parameters do not have significant effects on the chopping efficiency at 5% level of significance. Adigdzi (2007) reported that the specific cutting resistance of the material increases with the increase of the stalks fed through the feeding tray. Therefore, the quantity of maize stalk fed into the machine through the feeding tray at any particular time affects the cutting of the material.

Table 8: Analysis of variance for S/N ratio large is better chopping efficiency (CE)

Sources	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Feed rate	2	0.57337	0.57337	0.28668	4.66	0.177	46.1
Sharpening angle of the blade	2	0.08300	0.08300	0.04150	0.67	0.597	6.7
Pulley diameter	2	0.46338	0.46338	0.23169	3.77	0.210	37.3
Residual error	2	0.12297	0.12297	0.06148			9.9
Total	8	1.24271					

The analysis of variance of S/N ratio for length of cut as showed in the Table 9. It reveals that pulley diameter is the most significant parameter at 5% level of significance and has the highest percentage contribution of (93.9 %), feed rate (2.5 %) and sharpening angle of the blade (0.8 %). It indicate that pulley diameter has the most significant effect on length of cut as reported by saanoding *et al.*(2019).

Table 9: Analysis of variance for S/N ratio length of cut

Sources	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Feed rate	2	0.2756	0.2756	0.13782	0.87	0.535	2.5
Sharpening angle of the blade	2	0.0919	0.0919	0.04596	0.29	0.775	0.8
Pulley diameter	2	10.5514	10.5514	5.27568	33.25	0.029	93.9
Residual error	2	0.3174	0.3174	0.15869			2.8
Total	8	11.2363					

6.4 Validation test

Table 10: Presents the optimal settings for chopping capacity, chopping efficiency and length of cut. It also gives the predicted optimum value of the response variables. The verification tests were conducted with the optimal settings for chopping capacity, chopping efficiency and length of cut. The deviation of actual SN ratio value from the predicted is within one percent. It means that the percentage deviations of the predicted values from the confirmed values are quite small and insignificant.

Table 10: Optimum parameter settings for chopping capacity, chopping efficiency and length of cut

Parameters	Chopping capacity (g/s)	Chopping efficiency (%)	Length of cut (mm)
A: feed rate (g)	3000	2000	2000
B: sharpening angle of the blade (degrees)	26	26	24
C: pulley diameter (mm)	100	100	100
Predicted optimal value	23.7229	39.7676	-30.8521
Confirmation run	23.93500	39.64520	-31.1261
Percentage deviation	0.89 %	0.31 %	0.88 %

7.0 Conclusion

The influences of the process parameters, feed rate, sharpening angle of the blade and pulley diameter on the chopping capacity, chopping efficiency and length of cut of a developed forage chopping machine were investigated. The significance of these process parameters on the response variables was identified using the Taguchi Method of Design of Experiments. Analysis of variance method was used to quantify their level of significance in the form of percentage contribution to the total variation of the response variables.

The following conclusions were made about the behavior of the developed forage chopping machine:

1. The optimum settings of the process parameters are determined as follows:
   Chopping capacity
   A3 (3000 g), B2 (26 degrees) and C1 (100 mm)
   Chopping efficiency
   A2 (2000 g), B2 (26 degrees) and C1 (100 mm)
   Length of cut
   A2 (2000 g), B1 (24 degrees) and C1 (100 mm)
   (A1, A2 and A3 are levels of feed rate, B1, B2 and B3 are levels of sharpening angle of the blade and C1, C2 and C3 are levels of pulley diameter)

2. Among the three (3) process parameters the pulley diameter has greater influence on almost all the response variables.
3. The results from the test runs are very close to the predicted range of optimum settings and the deviations are less than one percent, which means that the deviation between the predicted and confirmed values is infinitesimal.

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