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Development and Performance Evaluation of Engine-Operated Dual Animal Feed Chopping and Milling Machine

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ABSTRACT: 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 have always been a challenge in the livestock sector. This process is laborious and time takes more. To alleviate this problem, using maize and sorghum stalks is an important remedy. Therefore, the chopping and milling machine was developed and evaluated. The research was conducted at Jimma Agricultural Engineering Research Center, Dedo and Kersa districts to evaluate the machine performance in terms of chopping efficiency, throughput capacity, cutting efficiency, milling efficiency and fuel consumption at different speeds of cutter shaft. The output of the chopper was found to be a remarkable achievement. The performance of the machine was evaluated using sorghum stalk, maize stalk, and maize grains with treatments of the engine speed, and feed rate using factorial design with three replications. The highest mean chopping capacity of maize and sorghum stalk (511.33 kg hr^{-1}, 551.33 kg hr^{-1})respectively, the finest of (shortest) mean cut length maize and sorghum stalk(1.13cm, 1.01cm) respectively, the highest chopping efficiency of maize and sorghum stalk(97.54% , 98.68%) respectively, the highest milling efficiency and milling capacity of maize grains 93.8% and 234kg hr^{-1}respectively,and the mean lowest fuel consumption of maize and sorghum was 0.58 liter and 0.52 liter respectively were recorded. The operation speed was observed to be highly significant among the treatments, at a significance level of 0.05. Based on the result obtained, it is recommended to improve the capacity of the machine.

KEYWORDS: Feed, Throughput capacity, Efficiency, Capacity

INTRODUCTION

Ethiopia has a large livestock population in Africa[1]. This livestock sector has been contributing a considerable portion to the economy of the country, and still promising to the economic development of the country [2]. It also plays an important role in providing export commodities, such as live animals, hides, and skins to earn foreign exchanges to the country[3]. The estimate of cattle for the rural and pastoral sedentary areas at the country level is about 65.35 million[4]. Out of this total cattle population, female cattle constitute about 55.90% and the remaining 44.10% are male cattle [3]. It is indicated that 97.76% of the total cattle in the country are local breeds. The remaining hybrid and exotic breeds accounted for about 1.91% and 0.32%, respectively [3]. Between 2015 and 2050 demand for milk and beef is estimated to grow by about 5.5 million tons and 0.9 million tons or 145 and 257% increase, respectively, with similar or higher growth rates for the demand for other animal sources of foods[2].

Some of the challenging constraints in livestock production include (based on beef cattle production and marketing systems) a lack of feed resources, equipment, and input that would improve quality[1]. The available feed resources include natural pasture, crop residue, improved forage and agro-industrial byproducts of which, the first two contribute the largest share [5]. Currently, with the rapid increase of human population and increasing demand for food, grazing lands are steadily shrinking by being converted to arable lands. They are restricted to areas that have little value [5]. 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[5]. Feed quality and quantity, post-harvest handling, ecological deterioration, overgrazing, lack of seed and planting materials are among the major challenges [4].

Forage chopping is one of the common post-harvest management practices done by most local farmers. In most localities, farmers harvest forage grass from its stem, chop it into short lengths and mix it with the other constituents. Feeding dairy cattle un-chopped forages is associated with high feed wastage. Although majority of farmers still rely on the use of rudimentary hand tools implements, notably the machete and sickle for chopping forage[6]. The use of such implements is "time consuming" and is associated with drudgery and health hazards [7]. Physical treatment includes chopping, shredding, grinding or milling and pelleting[8]. The grinding or milling of the feed results in higher animal intake, up to 30% and more [9]. Considering all the above challenges generation of new technology processing animal feed is very important. To solve this problem this developing and evaluating of animal feed chopping and milling machine is important.

MATERIALS AND METHODS

Materials

The material required to construct the prototype were:

- Sheet metal
- Angle iron
- Flat iron
- Round bar
- Shaft
- Bolts and nuts, etc.

Laboratory equipment's

- 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

Methodology

Description of study areas

The dual feed chopper and miller machine was fabricated at Jimma Agricultural Engineering Research Center (JAERC) in the workshop by using locally available material. The experiment was carried out at Jimma zone Dedo district located at 7° 59'N & 36°42'E. Has an average maximum and minimum temperature of 31°C and 18°C, respectively with an annual average rainfall of 1143mm.

Design Aspects

The main design aspects considered during chopper development were cost and complexity of fabrication, energy requirement, ergonomic factor, maintainability, material strength, kinematics, and style. Considering these design aspects tangential feed type chopper (hammer mill), without a conveyor, was selected for this project. The machine is based on the principles of a hammer mill by which size reduction is accomplished by the cutting effects of rotating knives against small stationary knife plates welded in the casing. Since the knives are swinging there is less likelihood of risk even if hard inert material accidentally gets into the chopping chamber. Feed enters into the chamber from the top of the chopper, and size reduction is done by the rotating knives. Finally, the output is discharged from the bottom of the machine. The knives cut the Stover and other residues until they become small enough to pass through the bottom screen.

Design Requirements

The development machine 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, (d) Small in size to transport from place to place (e) Less number of component (f) Low manufacturing cost (g) Easy to assemble and Maintainability and also power sources

Design calculations of parts of the machine

Determination of weight of feeding hopper

A trapezoidal shape was used in the construction of the animal feeding hopper. The weight was calculated as follows. The mass of the feeding hopper material was computed using the following equations.

$$M_F = A_F \times t \times \rho f \quad (1)$$

$M_F = 0.06m^2 \times 1.5\times10^{-3} m\times7850kgm^{-3}$

$M_F = 0.71$ kg

The weight of the feeding material was computed using the following equations.

$$W_F = M_F \times g \quad (2)$$

$=0.71kg \times 9.81m\ s^{-2}$

$=6.97$ N

Main frame

The main frame generally consists of four legs and made up of angle iron'

The whole machine was mounted over the legs.

Design of shaft

The shaft was subjected to a twisting moment .To find the diameter of the shaft when the shaft was subjecting moment (torque) only

$$\frac{T}{J} = \frac{\tau}{r} \quad (3)$$

- Where: T = Twisting moment or torque acting on the shaft.

J = Polar moment of inertia of the shaft about the axis of rotation

τ = Torsional shear stress and r = Diametric distance from the neutral axis to the outer most fiber

The allowable shear stress for the shaft material was calculated as

$$\tau = \frac{\sigma_u}{2fs} \quad (4)$$

=560Mpa/(2*3.5)

=560Mpa/7=80Mpa

Where, σ_u =560Mpa for carbon steel ,fs = factor of safety 3.5

From the equation $T=\pi/16\ \tau*d^3$ (5)

The diameter of the shaft by considering twisting the shaft

- $T=\pi/16\times\tau\times d^3 =50000Nmm=\pi/16*80*d^3$,

$d^3=(50000*16)/(80*\pi)$, d=14.27mm

Shaft subjected to bending moment

When the shaft is subjected to bending moment only, then the maximum stress was given by

$$\frac{M}{I} = \frac{\sigma b}{y} \quad (6)$$

Where M = bending moment, I = moment of inertia of cross-sectional shaft σb = bending stress, y = distance from the neutral axis to the outer most fiber

For round solid shaft, a moment of inertia is found by $I=\pi/64*d^4$ and y=d/2 substitution in equation (6)

$$M=\pi/32*\sigma_b * d^3 \quad (7)$$

The maximum bending moment of the carbon steel was,

M = 424320Nmm.

Substituting the above values to determine the diameter of the shaft

$$M=\pi/32*\sigma_b *d^3$$

$$424320Nmm=\pi/32*160Mpa*d^3$$

$$d^3=(424320*32)/(\pi*160)=27013.05,$$

$$d=27013.05=30mm$$

The mass of the shaft was calculated by the following equation

$$M = \rho \times v \quad (8)$$

The shaft is made up of carbon steel with a density of 7853kg/m^3.

$$V = A \times L = (\frac{\pi d^2}{4} \times L)$$

$=(\pi*(0.03)^2 *0.7)/4$

$=4.95\times10^{-4}m^3$

The mass of shaft material was computed using the following equations

$M_S = 4.95\times10^{-4}m^3 \times 7850kg/m^3 = 3.885$ kg .

The weight of the shaft was estimated using the following equations:-

$$W_s = M_s \times g \quad (9)$$

Blade holder: This is part of the machine to which the cutting blades are bolted, which also serves as a fly wheel to store rotational energy.

Selection of the drive belt

V-belt and pulley arrangements were used in this work to transmit power from the engine to the roller shaft. The main reasons for using the v-belt drive were its flexibility, simplicity, and low maintenance costs. Additionally, the v-belt has the ability to absorb shocks there by mitigating the effect of vibratory forces[10].

Determination of belt length

The length of the belt appropriate to drive the system was calculated using the equation given below (equation 10) by [11]. Assume the distance between the driver pulley and the driven pulley is 399.27mm according to the frame structure.

- The center distance (C) of driven pulleys was given by:

  C = 90/2 + 225 + 90/2 = 387 mm

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + (\frac{D_2 - D_1)^2}{4C} \quad (10)$$

$L=\pi/2(90mm+399.27mm)+2\times387mm+(399.27mm\_90mm)^2/(4\times387mm) =586.62mm+774mm+61.78mm =1422.4mm$

Where: L = belt length, m; C = center distance between pulleys, m; D2 = pitch diameter of driven pulley, m; D1 = Pitch diameter of driver pulley, m.

Since the calculated length of the v belt is equal to the closest standard belt the exact center distance is also correct.

Selection of Bearing

Bearings selection was made in accordance with the American Society of Mechanical Engineers (ASME) standard. The bearings will pillow block ball bearing (single row, deep groove radial bearing). Radial bearings, number 205 with internal bore diameter, outer diameter, and width of 30 mm, 52 mm, and 15 mm, respectively, were selected as recommended by[10].

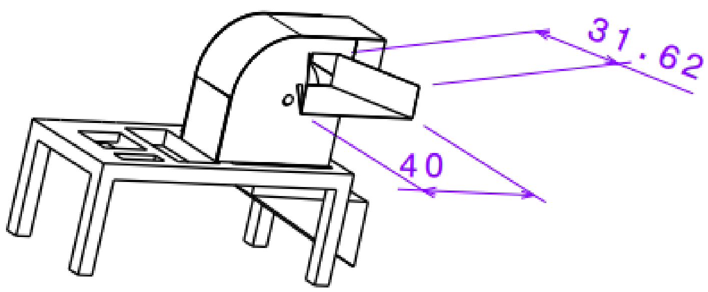
Chopper house: This is the unit that houses and supports all the functional units. It supports the shaft and bearing assembly and is bolted to the frame stand assembly at four different points.

Cutter blades: This is the main functional unit made up of treaded milled steel that performs the chopping action with a cutting depth of 3 cm and a cutting length of 10 cm and is made up of 6mm thickness and 5cm width developed to cut the feed to the recommended lengths with reasonable consistency.

Sieve: the milled material was screened during operation with 2mm open holes. It is recommended medium particle size of chicken feed is 0.74mm according to [12].

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

Isometric view of the machine



Isometric view

Figure 1 Manufactured Animal feed chopper and milling machine

Operating machine

The dual animal feed chopping and milling machine is a versatile agricultural equipment designed to process various animal feed materials efficiently through a comprehensive mechanism driven by a 5hp diesel engine. When operating in chopping mode, the machine utilizes a feeding table where feed materials like maize and sorghum stalks are introduced, and a rotating shaft equipped with cutting knives precisely cuts these materials into small pieces. The chopped materials are then collected through the dedicated chopped material outlet, ensuring uniform size and easy handling. For milling purposes, the machine transforms its functionality by inserting a sieve and using a different operational approach. In milling mode, feed materials are fed through a hopper into the hammer mill, which is mounted on a rotating shaft and applies impact force to break down the materials. The integrated sieve is crucial in controlling particle size, allowing only materials smaller than the sieve's aperture to pass through, and ensuring consistent and fine-milled output. The milled materials are then collected through the milled material outlet, providing farmers with a flexible and efficient solution for feed preparation. The power transmission system, comprising a pulley and belt mechanism, efficiently transfers the diesel engine's power to the rotating shafts, enabling smooth and controlled operation of both chopping and milling functions, making this machine an essential tool for agricultural feed processing.

Data collecting procedures

The following processes were carefully followed:

- 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.
- The machine was allowed to run for 10 min before feeding the desired feed to check the functionality of the machine and its parts.
- A specific amount of feed was supplied at the inlet for chopping.
- The time taken to chop each sample was taken for every operation
- Sample from each trial is taken for assessment.
- The amount of fuel consumed for each trial was measured using a graduated cylinder.

Performance evaluation of the machine

Maize and Sorghum stalks were used for evaluating the machine. The machine was evaluated in terms of capacity, work quality cutting-length and efficiency. During the test time taken, fuel consumption and chopped sample for each sample test was collected.

The length of the cut(cm)

Cutting length of the machine was calculated by equation given by [13]

$$L_{th} = \frac{60000Vf}{\lambda knc} \qquad (10)$$

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

Cutting efficiency(%)

The cutting efficiency was calculated by equation given by[14] as follows:

$$\eta c = \frac{Lac - Lth}{Lac} \times 100 \quad (11)$$

Where: ηc = Cutting efficiency; Lac = Actual length (mm), and Lth = Theoretical length (mm).

Determination of throughput capacity (kg min^{-1})

Throughput capacity of the machine was calculated by equation given by Harry and John, 2007.

$$\text{Throughtput} = \frac{\text{mass}}{\text{time}} \quad (12)$$

Determination of milling efficiency (%)

$$\text{Milling efficiency}(\%) = \frac{\text{mass of product}}{\text{mass of feed}} \times 100 \quad (13)$$

Experimental Design and Statistical Analysis

These experiments were performed using a factorial design (3^2) with two main factors three feeding rates (3, 4 and 5 stalks) for chopping and (2, 3 and 4 kg) for milling and three engine speeds (650, 750 and 850 rpm) with three replications. All experimental data were analyzed using the analysis of variance (ANOVA). Analysis was done using Stata 8.0. The treatment means that were different at a 5% level of significance were separated by using LSD.

RESULTS AND DISCUSSION

Each sample was weighed and measured (mass before chopped or milled) and passed to the inlet into the cutting unit, which was coming into contact with the cutter blade. The chopped and milled materials were collected through the outlet. The time taken to chop and the mill was the sample recorded. The collected materials were weighed as mass after being chopped and milled. Each test was replicated three times. The specific chopping resistance increases with the increase of the stalks fed through the chute. The prototype was tested using maize grains, maize stalk, and sorghum stalk and the results were presented in table 1 to 8. Tables 1 to 3 show the results obtained from the analysis of the data collected after the evaluation of the machine on maize stalk and tables 4 to 6 on sorghum stalk and also table 7 to8on feed milled performance. These comprised the mean values of the performance parameters and the analysis of variance (ANOVA) tables which describe the significance of the treatments in affecting the performance of the machine

Table 1 Effect of feed rate and operation speed on the cutting length (cm) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of maize stalk.

Feed rate *speed							
Feed rate(stalk-number)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
3	3.98^{a}	2.91^{c}	1.99^{e}	3	2.96^{a}	650	3.66^{a}
4	3.65^{ab}	2.45^{d}	1.45^{f}	4	2.52^{b}	750	2.54^{b}
5	3.36^{b}	2.26^{de}	1.13^{f}	5	2.25^{c}	850	1.52^{c}
SE	0.20				0.12		0.12
LSD	0.43				0.23		0.23
CV							9.56

Where, CV = coefficient of variation, LSD = least significance difference, SE=standard error.

Table 1 shows the mean values of cutting lengths (cm) .The machine was evaluated using maize stalk with the same sizes of thickness at three different feed rates of 3,4 and 5 numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the operation speed has a significant effect ($p<0.05$) on the cutting length of a machine. Neither the feed rate nor the interaction has a significant effect. The finest (shortest) mean cut length (1.13 cm) was obtained when the machine was fed by 5 stalk number of maize stalk with the same thickness of diameter chopped at an operation speed of 850 rpm.

The mean chop length produced by the prototype was within the acceptable range of between 1to 4 cm. However, the cutting length of the machine in this study were comparable with the values (1.2 cm to 1.3) reported by [4] and with the 3.2cm to 3.9cm reported by [15].

Table 2 Effect of feed rate and operation speed on the Cutting efficiency (%) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of maize stalk.

Feed rate *speed							
Feed rate(stalk-number)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
3	89.187^{e}	94.107^{c}	97.540^{a}	3	93.611a	650	88.062^{c}
4	88.000^{f}	93.037^{d}	96.010^{b}	4	92.349^{b}	750	93.072^{b}
5	87.000^{f}	92.073^{d}	94.793^{c}	5	91.289^{c}	850	96.114^{a}
SE	0.4950				0.2858		0.2858
LSD	1.0494				0.6058		0.6058
CV							0.66

Where, CV = coefficient of variation, LSD = least significance difference, SE=standard error.

Table 2 shows the mean values of cutting efficiency (%).The machine was evaluated using maize stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the cutting efficiency of a machine. The highest chopping efficiency was97.540% obtained when the machine was fed by 3 stalk- number of maize stalk with the same thickness of diameter chopped at operation speed of 850 rpm. However, the recorded cutting efficiencies of the machine in this study were comparable with the values (88% to 97%) reported by [4] and with the 95.8% to 97.6% reported by[15].

Table 3 Effect of feed rate and operation speed on the throughput capacity (kg/h) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of maize stalk

Feed rate *speed							
Feed rate(stalk-number)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
3	320.00^{h}	347.67^{g}	366.67^{f}	3	344.78^{c}	650	391.78^{c}
4	395.00^{e}	439.33^{d}	481.00^{b}	4	438.44^{b}	750	422.33^{b}
5	460.33^{c}	480.00^{b}	511.33^{a}	5	483.89^{a}	850	453.00^{a}
SE	5.5907				3.2278		3.2278
LSD	11.852				6.8426		6.8426
CV							1.62

Where, CV = coefficient of variation, LSD = least significance difference, SE=standard error.

Table 3 shows the mean values of throughput capacity (kg hr^{-1}).The machine was evaluated using maize stalks with the same sizes of thickness at three different feed rates of 3, 4, and 5 numbers with three different machine operation speeds of 650,750, and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the throughput capacity of a machine. The highest mean chopping capacity was 511.33kg/hr obtained when the machine was fed by 5stalks, several maize stalks with the same thickness of diameter chopped at an operation speed of 850 rpm. However, the recorded throughput capacity of the machine in this study was comparable with the values (569.32kg/hr) reported by [4] and with the 756kg/hr reported by [15].

Table 4 Effect of feed rate and operation speed on the cutting length (cm) of a machine that selected the same feed

Feed rate *speed							
Feed rate(stalk-number)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
3	3.7600^{a}	2.7100^{cd}	1.8600^{e}	3	2.7767^{a}	650	3.4611^{a}
4	3.4567^{ab}	2.2500^{de}	1.2500^{f}	4	2.3189^{b}	750	2.3422^{b}
5	3.1667^{bc}	2.0667^{e}	1.0133^{f}	5	2.0822^{b}	850	1.3744^{c}
SE	0.2269				0.1310		0.1310
LSD	0.4811				0.2777		0.2777
CV							11.62

Where, CV = coefficient of variation, LSD = least significance difference, SE=standard error.

Table 4 shows the mean values of cutting lengths (cm) .The machine was evaluated using sorghum stalks with the same sizes of thickness at three different feed rates of 3,4, and 5 numbers with three different machine operation speeds of 650,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the operation speed has a significant effect ($p<0.05$) on the cutting length of a machine. Neither the feed rate nor the interaction has a significant effect. The finest (shortest) mean cut length (1.0133 cm) was obtained when the machine was fed by 5 stalk-number sorghum stalk with the same thickness of diameter chopped at operating speed of 850 rpm. The mean chop length produced by the prototype was within the acceptable range of between 1 to 4 cm However, the cutting length of the machine in this study were comparable with the values (2.1cm to 3cm) reported by[15].

Table 5 Effect of feed rate and operation speed on the Cutting efficiency (%) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of sorghum stalk.

Feed rate *speed							
Feed rate(stalk-number)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
3	90.080^{f}	95.010^{cd}	98.680^{a}	3	94.590^{a}	650	89.037^{c}
4	89.030^{fg}	94.040^{de}	97.110^{b}	4	93.393^{b}	750	94.063^{b}
5	88.000^{g}	93.140^{e}	95.773^{c}	5	92.304^{c}	850	97.188^{a}
SE	0.5578				0.3220		0.3220
LSD	1.1825				0.6827		0.6827
CV							0.73

Where, CV = coefficient of variation, LSD = least significance difference, SE=standard error.

Table 5 shows the mean values of cutting efficiency (%).The machine was evaluated using sorghum stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 stalk-numbers with three different machine operation speeds of 650,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the cutting efficiency of a machine. The highest chopping efficiency was 98.680%obtained when the machine was fed by 3 stalk-number of sorghum stalk with the same thickness of diameter chopped at operation speed of 850 rpm. However, the recorded cutting efficiencies of the machine in this study were comparable with the values (96.8% to 98.6%) reported by [15].

Table 6 Effect of feed rate and operation speed on the chopping Capacity (kg/h) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of sorghum stalk.

Feed rate *speed							
Feed rate(stalk-number)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
3	343.33^{h}	367.67^{g}	386.67^{f}	3	365.89^{c}	650	412.89^{c}
4	415.00^{e}	459.33^{d}	501.00^{b}	4	458.44^{b}	750	442.33^{b}
5	480.33^{c}	500.00^{b}	551.33^{a}	5	510.56^{a}	850	479.67^{a}
SE	4.52				2.61		2.61
LSD	9.58				5.53		5.53
CV							1.24

Where, CV = coefficient of variation, LSD = least significance difference, SE=standard error.

Table 6 shows the mean values of throughput capacity (kg hr^{-1}).The machine was evaluated using sorghum stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 stalk numbers with three different machine operation speeds of 650,750, and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operating speed had a significant effect ($p<0.05$) on the chopping capacity of a machine. The highest mean chopping capacity was 551.33kg hr^{-1}obtained when the machine was fed by 5stalk-number sorghum stalk with the same thickness of diameter chopped at operation speed of 850 rpm. However, the recorded throughput capacity of the machine in this study were comparable with the values 870kg hr^{-1}reported by [15].

Table 7 Effect of feed rate and operation speed on milling efficiency (%) of the machine on maize grain.

Feed rate *speed							
Feed rate(kg)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
2	82.490^{f}	84.070^{de}	89.127^{b}	2	85.229^{c}	650	83.25^{c}
3	83.220^{ef}	85.307^{d}	90.150^{b}	3	86.226^{b}	750	85.589^{b}
4	84.063^{de}	87.390^{c}	93.800^{a}	4	88.418^{a}	850	91.026^{a}
SE	0.6991				0.4036		0.4036
LSD	1.4821				0.8557		0.8557
CV							0.99

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 7 shows the mean values of milling efficiency (%).The machine was evaluated using maize grains at three different feed rates of 2, 3 and 4kg with three different machine operation speeds of 650,750, and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the milling efficiency of the machine. The highest milling efficiency was 93.8% obtained when the machine was fed by 4kg of maize grain an operation speed of 850 rpm. The mean milled produced by the prototype was within the acceptable range of between 0.1 to 0.9mm particle size depending on the 2mm sieve size required to maintain proper rumination and salivation It is recommended medium particle size of chickenfeed is 0.74mm according to [12].

Table 8 Effect of feed rate and operation speed on the milling capacity (kg/h) of the machine on maize grains

Feed rate *speed							
Feed rate(kg)	Operation speed(rpm)			Feed rate	Mean	Operation speed(rpm)	Mean
	650	750	850				
2	151.33^{g}	160.33^{ef}	166.33^{e}	2	159.33^{c}	650	160.22^{c}

3	154.33^{fg}	184.67^{c}	208.00^{b}	3	182.33^{b}	750	184.78^{b}
4	175.00^{d}	209.33^{b}	234.00^{a}	4	206.11^{a}	850	202.78^{a}
SE	3.4677				2.0021		2.0021
LSD	7.3511				4.2442		4.2442
CV							2.33

Where, CV = coefficient of variation, LSD = least significance difference, SE=standard error.

Table 8 shows the mean values of milling capacity (kg/hr).The machine was evaluated using maize grains at three different feed rates of 2,3, and 4kg with three different machine operation speeds of 650,750, and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the milling capacity of the machine. The highest mean milling capacity was 234kg hr^{-1}obtained when the machine was feed 4kg of maize grains at an operating speed of 850 rpm.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

It concluded, as observed in the performance evaluation result, that the machine can attain its highest capacity for chopping and milling based on the operation speed and feeding rate. As the machine operates at a higher speed the capacity increases to its highest possible performance. The speed of the machine also affects the length of cut of the feed, cutting efficiency, milling efficiency, and fuel consumption. The faster the operation speed, the shorter the feed cut length; the slower the speed, the longer the cut length. The faster the machine's operation speed, the higher its efficiency and fuel consumption. The machine's performance was evaluated using sorghum stalk, maize stalk, and maize grains with treatments of the engine speed, and feed rate using factorial design with three replications. The highest mean chopping capacity of maize and sorghum stalk (511.33 kg hr^{-1} and 551.33kg hr^{-1}) respectively, the finest of (shortest) mean cut length maize and sorghum stalk(1.13cm, 1.0133cm) respectively, the highest chopping efficiency of maize and sorghum stalk(97.54%, 98.68%) respectively, the highest milling efficiency and milling capacity of maize grains(93.8%,234kg)respectively, and the mean lowest fuel consumption of maize and sorghum (0.58,0.52) were recorded.

RECOMMENDATIONS

The following recommendation should be carried on:-

- The machine should be recommended to demonstrate for small to medium farmers.
- The machine should be recommended to operate at 850rpm of speed.

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