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Design, development and performance evaluation of small-scale fodder chopping machine for farmers

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Abstract: A straw chopper is a mechanical device used to uniformly chop fodder into small pieces to mix it together with other grass and then feed it to livestock. The objective of this research was to design and develop an animal fodder chopping machine to be utilised by dairy farmers within their purchase range. The drawing of these machine parts was undertaken in AutoCAD software and the construction was performed in a local workshop. After development of this machine, performance tests were carried out on a farm. The chopping machine tests were carried out with commonly grown fodder (namely: straw, grass, and maize) in Bangladesh. The performance evaluation of the developed machine was carried out in terms of the chopping efficiency, machine productivity, and energy consumption. The economic analysis of the straw chopping machine was assessed by indicating the cost effectiveness to the poor farmers. Analysis of the data in regard to chopping efficiency and machine productivity varied from 93 to 96% and from 192 to 600 $kg\cdot h^{-1}$, respectively. The energy consumption during the chopping process ranged between 0.0025 and 0.01 kWh for the different types of fodder. The break-even point of the fodder chopping machine was 3 793 kg of cut straw and the payback period was within one year depending on the use.

Keywords: break-even; chopping efficiency; economic analysis; machine productivity; power consumption

With the consequence of agricultural mechanisation in Bangladesh, manual and time-consuming work have turned to machine work, especially domestic household and farm work, with the introduction of different machines, such as straw cutting machines. Rice is one of the oldest cultivated crops and ranks as the most widely grown food grain crop. Rice serves as a staple food for Bangladesh and about half of the world's population. The majority of rice comes from the northern part of Bangladesh and, at the same time, a huge amount of straw is generated from its harvesting. Normally, people use the straw as the main food for the cattle and its other uses include fuel for cooking, an agricultural compost fertiliser, roof covering for village houses, etc. (Nader and Robinson 2010). Straw choppers have developed gradually from a very simple tool to commercial standard machines that can be driven at various speeds so as to achieve various chaff sizes with respect to the animal's preference (Mohamed et al. 2001). In order to make the task faster and comfortable for the users, the straw is tied in bundles of about 80–100 mm in diameter, which is normally undertaken during the rice harvesting time by the farmers.

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To chop the straw, the bundles are then put into the machine directly to cut it into a uniform length of about 25.4 mm. The sizing of the straw is one of the riskiest, lengthy and labour-intensive tasks for dairy farmers. Hence, a suitable machine is required at the lowest possible price for performing the chopping operation smoothly, smartly without any undue toll on the body with quick action and with the efficient cutting of the paddy straw.

Numerous studies have been conducted to design and evaluate the performance of straw chopping machines. These studies cover a wide range of topics including the design of the chopping machine, the cutting method, the power requirement for the cutting, the rotational speed of the cutting bar, the feed rate, the cutting size and the depth of the cut. A straw chopping machine was developed by Lal et al. (2018) to chop mushrooms. The main focus of their study was the construction of the machine and detailed drawings of the chopping machine were shown in their study. Ghaly et al. (2013) carried out another study to evaluate the performance of a straw chopping machine with considerations to the rotational speed, feed rate, depth of cut, length of cut and energy required to chop the straw. Their study reported that the power consumption ranged from 1.31 to 5.79 kW and the straw length ranged from 14.49 to 18.85 mm, depending upon the depth of the cut and the cutting speed during the experiment. In another study by Khairy et al. (2015), they developed a straw chopping machine by considering the physical properties of the rice straw. It was concluded, from their analysis, that the maximum productivity was 6.03 kg·h^{-1} and the optimum specific energy requirement was 52.08 kWh at a drum speed of 1 600 rpm.

It should be noted from the earlier studies that the development and performance evaluation of the straw cutting machines were conducted by considering just one fodder and that there are very few studies in general. Therefore, the goal of the present study was to design and develop a chopping machine for the multiple fodders that are used by cattle farmers. In addition, the study was also aimed at the performance evaluation of the developed chopping machine.

MATERIAL AND METHODS

A small-scale fodder chopping machine was designed for dairy farmers who have a home business in rural areas for milk and meat production. The developed machine was fabricated in a local workshop and experiments were carried out on a farm in the Thakurgaon district, Bangladesh. The activities for the research work included setting an estimated budget to make the fodder chopping machine so that it remains within the purchase capabilities of the farmers. According to the budget, different parts were designed, such as an electric motor for the power source, a V-belt drive, a cutting wheel, a feed roller and cashing, a hopper and a supporting frame. After assembling the machine, performance tests on the cutting efficiency, machine productivity, energy requirements were carried out and some economic analysis on the fixed costs, variable costs and the break-even point were also performed. The whole method is described in the following step by step processes.

Description of the major components of the fodder chopping machine

Supporting frame. The various parts of this machine are mounted on this frame. The complete frame is made up of mild steel angle.

Cutter wheel and cutter blade. It is a circular wheel made from cast iron that holds the cutting blade. During operation, the cutter wheel rotates at a uniform speed and the attached blade cuts the fodder.

Inlet hopper. This is made from a cast iron plate and this is where the raw fodder is kept prior to chopping.

Feed roller. The feed roller is a device used to pull the fodder from the horizontal hopper and feed it to the cutting blades. The roller is driven by a helical gear mechanism which is connected to the belt drive.

V-belt drive. The V-belt drive is used to transmit the power from the motor to the cutting wheel. The V-belt drive provides several advantages including that it requires no lubrication, it is highly efficient, it has a low noise generation level, has a long service life, it is easy to install, and acts as a "safety fuse" refusing to transmit power during overload.

Electric motor power source. An electric motor is used to convert electrical energy into mechanical energy. To construct this machine, a 1.49 kW motor was purchased from a local market.

Assembled fodder chopping machine

The fabrication of the straw chopper machine was accomplished in a local workshop. A standard frame of (760 × 540 mm) was built by mild steel angle to rigidly support the whole assembly of the

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chopping machine. The diameter of the cutting wheel is 650 mm which is attached to a pulley (100 mm in diameter) of the motor through the V-belt. This machine was designed with two simple feed roller shafts whose diameters were 120 mm, while the inlet side was 215 mm and the outlet side was 165 mm. Figure 1 illustrates the details of the assembly.

Working procedure of the designed and developed machine

The first step to start working this machine is connecting the machine to a single-phase power supply source. After switching on the power transmission through the V-belt, the motor will start, which will, in turn, rotate the cutter wheel. The raw fodder needs to put into the hopper; through the feed rollers, the machine will automatically start pushing the fodder into the cutting blade for chopping. The task of the operator is only to put the fodder into the hopper in the direction of the feed rollers. The light weight particles of the chopped fodder are thrown outward towards the outlet by the centrifugal force of the cutting blade. So, it is advantageous to use a container to collect the chopped fodder.

Experimental set-up

For this study, dried and stored Sharna rice straw, Napier grass and seasonal maize leaves were used as the fodders to test the different performance parameters. The straw height was about 0.9–1.2 m, the Napier grass height was about 1.5–1.8 m and the maize leaves height was around 0.9–1.2 m. The straw was fully dry and lightweight, the grass and maize leaves were collected directly from the field. For the performance testing of each type of chopped fodder, 20 kg was used in each experiment. The full set-up is shown in Figure 2.

Figure 2. Used samples before and after chopping of (A) Napier grass, (B) dried straw and (C) maize plant

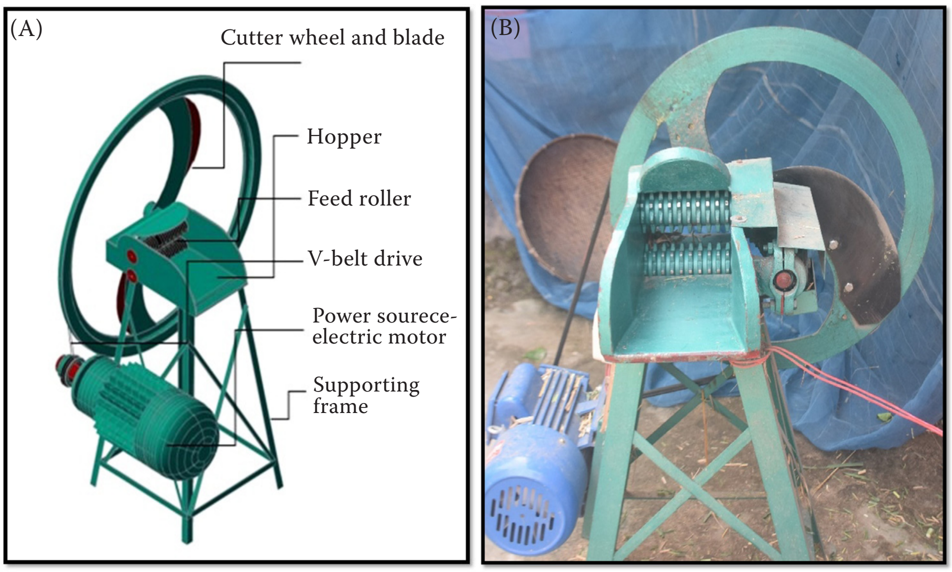

Figure 1. (A) Designed and (B) developed machine

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Performance testing

The machine performance tests were performed to evaluate the machine's capabilities while under operation. The major performance test parameters that were tested: (*i*) chopping efficiency; (*ii*) machine productivity; and (*iii*) energy requirement. The performance test was conducted based on the standard test of Chopper Machine of Organic Fertilizer Raw Material – Quality Requirement and Test Method as modified by Srivastava (1993). Testing was performed with 5 repetitions for each experiment with each kind of fodder.

Performance evaluation

The performance evaluation of the machine is an important criterion. There are several indices (efficiency, productivity, and energy consumption) to assess the performance of a machine. Therefore, the chopping efficiency, machine productivity and energy requirement during the fodder chopping process was determined for the developed fodder chopping machine.

Chopping efficiency. The chopping efficiency (%) was calculated following Equation (1) as stated by Mady et al. (2015).

$$\text{Chopping efficiency} = \frac{(W_{out} - W_{uncut})}{W_{in}} \times 100 \quad (1)$$

where: W_{in} – the inlet mass of the fodder (kg); W_{out} – the outlet mass of the fodder (kg); W_{uncut} – amount of non-chopped fodder (kg).

Machine productivity. The machine productivity (P) (kg·h^{-1}) of the fodder chopping machine was determined by Equation (2) according to procedure noted by Mady et al. (2015).

$$P = \frac{W}{T} \times 60 \quad (2)$$

where: W – the weight of the sample (kg); T – the machine operating time (min).

Energy consumption. The energy consumption (kWh) for the chopping of fodder was calculated by dividing the rated power of the motor by the machine productivity as shown by Equation (3).

$$\text{Energy consumption} = \frac{\text{Rated power}}{\text{Machine productivity}} \quad (3)$$

Economic Analysis. The economic analysis of the straw chopping machine includes: the fixed costs, variable cost and break-even point.

Fixed cost. The fixed costs (FC) (BDT – Bangladesh taka) were calculated by the following mathematical expression.

$$FC = D + H + M + I + L \quad (4)$$

where: D – the depreciation; H – place or building; M – repair or maintenance; I – tax; L – capital cost.

Variable cost. The variable cost (VC) was calculated by adding the terms, operator fee and cost of electricity (Sugandi et al. 2019).

$$VC = BOP + BI \quad (5)$$

where: BOP – the operator fee (BDT·h^{-1}); BI – the cost of electricity (BDT·h^{-1}).

Break-even point. The break-even point (BEP) (kg) was calculated following the procedure stated by (Sugandi et al. 2019) which is shown in the following equation.

$$BEP = \frac{FC}{HP - BV} \quad (6)$$

where: HP – the product price (BDT); BV – variable cost.

Statistical analysis

A statistical analysis was carried out using a single factor experiment in a completely randomised design (CRD). The only factor was the feeding of the different fodder. The values of the chopping efficiency, machine productivity, and energy consumption were calculated and reported as the mean values with a mean SE. The statistical software package SPSS (version 22) was used for the ANOVA. Duncan's multiple range test was applied to compare the mean values of the chopping efficiency, machine productivity, and energy consumption among the different fodder feeding at a 5% level of significance.

RESULT AND DISCUSSION

A major part of this research was to design a fodder chopping machine for farmers within their purchase price range. After individually designing the machine parts using AutoCAD software (version 2016), the complete machine construction was successfully undertaken in a local workshop. Further analysis related to its performance and economic feasibility is scientifically discussed in the following points.

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Performance evaluation

Chopping efficiency. Figure 3 shows the chopping efficiency of the developed fodder chopping machine during the cutting of the straw, grass, and maize. It can noticed from the figure that the chopping efficiency significantly differed for each fodder. The highest chopping efficiency was noticed for the grass fodder and the lowest chopping efficiency was observed for the straw and maize fodder. The highest efficiency obtained for the grass fodder was achieved due to the wet condition of the grass that caused a higher weight. The dry weight and higher bulk volume of the straw yielded the lowest chopping efficiency. The results of this study, in terms of the chopping efficiency, match that of the previous investigation of Madi et al. (2015). It was documented, from their observation, that the chopping efficiency varied from 92–97% while experiment was conducted with a variable cutting blade speed. The results also match the study conducted by Sultan Mahmood et al. (2016). The results found by them conclude that the field efficiency of all machines was less than 65% for cutting both oats and berseem. They found that only the Agritec rotary fodder cutter exhibited the highest field efficiency (64.8%).

Machine productivity. Figure 4 shows the machine productivity for the different fodders. For the straw, the productivity was 192 $kg \cdot h^{-1}$ because the straw was fully dry. The statistical analysis indicates that type of fodder had a significant effect on machine productivity. For the grass, the productivity was 600 $kg \cdot h^{-1}$ because of the weight. For the maize, the productivity was 348 $kg \cdot h^{-1}$. Mady et al. (2015) determined that the machine productivity increases with an increased number of knives and rotational speed.

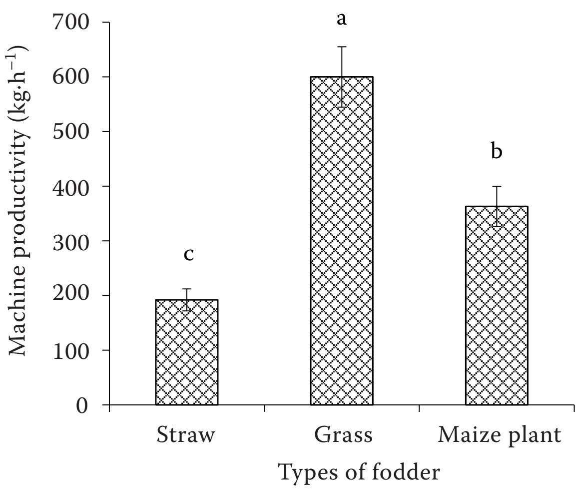

Figure 4. Machine productivity for the different fodder

Values followed by the same lower case letter are not significantly different at $P < 0.05$

Power consumption. Figure 5 shows the energy consumption in the units used for the electrical power, particularly kWh for the utility bills, for cutting the different fodder. The consumed energy for cutting the straw was 0.486 kWh, for the grass 0.56 kWh, 0.73 kWh for the maize leaves and 0.025 kWh for the maize plant. For the maize leaves, the required power is the highest because it takes more time to load them which results in a higher power requirement. The lowest power requirement comes for the maize plant because the root is attached to the maize leaves which carries more weight. Mady et al. (2015)

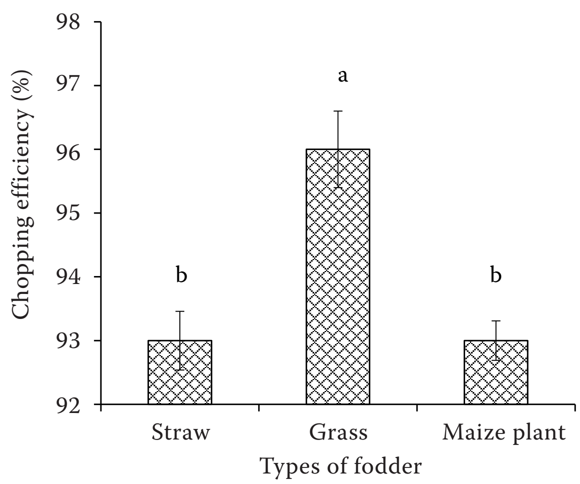

Figure 3. Chopping efficiency for the different fodder

Values followed by the same lower case letter are not significantly different at $P < 0.05$

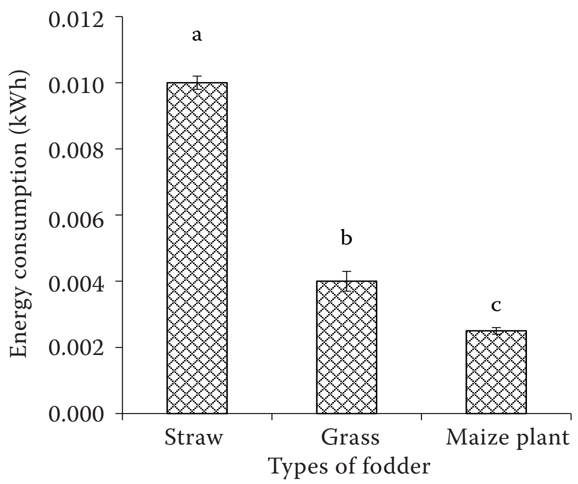

Figure 5. Energy consumption of the different fodder

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Table 1. Economic analysis of the straw chopping machine

Analysis parameter	Analysis result	Remarks
Fixed cost	BDT 8 800 (year^{-1})	considering a machine life of 5 years
Variable cost	BDT 41.68	operator fee per day BDT 300
Break-even point	3 793 kg	calculated based on rice straw

BDT – Bangladesh taka

Table 2. Statistical analysis of the tested parameters

Performance test parameters	Type of fodder	Results
Chopping efficiency (%)	straw	93.00
	grass	96.00
	maize plant	93.00
Machine productivity (kg·h^{-1})	straw	192
	grass	600
	maize plant	363
Power consumption (kWh)	straw	0.0111
	grass	0.0041
	maize plant	0.0025

found that the energy requirement decreases with an increasing number of knives.

The results of the above basic parameters summary are shown in Table 2. It shows that the machine has very good results for chopping the straw, grass and maize plants for the livestock of small sized farms and the possibility to use the machines for medium size dairy farms as well. In that case, the life of the machine will be reduced, but the best thing is that there is zero straw wastage.

Economic analysis

Since the design of this machine was made for Bangladeshi farmers who live below the poverty line, the initial purchase and installation cost and operating cost must be kept as low as possible. Some simple calculations for economic analysis have been performed and are shown in Table 1.

The fixed cost of the machine amounts to BDT 8 800 per year which is very low. The variable cost of this machine is very low, only the electricity cost and labour cost, which is only BDT 41.68·h^{-1}. The breakeven point comes at chopping 3 793 kg of rice straw. The payback period is also less than one year, which is also a good situation for farmers.

CONCLUSION

A small-scale fodder chopping machine was designed, developed and its performance was successfully tested. The whole undertaking was performed with a comprehensive approach with the necessary calculations. The findings of this study include the chopping efficiency and machine productivity, which varied from 93 to 96% and from 192 to 600 kg·h^{-1}, respectively. The energy consumption ranged between 0.0025 and 0.01 kWh during the chopping process for the different fodders. This machine provides the flexibility of using two blades to cut different lengths of fodder. Further analyses can be conducted to use this machine for other purposes like making compost fertilisers.

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