Development and performance evaluation of a battery operated small-scale reaper

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Abstract: In absence of appropriate mechanization, harvesting of both rice and wheat crop is a major production problem in Bangladesh. Acute labor shortages at harvest time cause delays in clearing fields leading to high grain and straw losses. This work is to help small-scale farmers to meet their technological support, by developing a battery operated reaper to harvest rice and wheat crops more efficiently. The research work is on ease of harvesting operation to the small land holders for harvesting rice and wheat crops in less time and at low cost by considering different factors as power requirement, cost of equipment, ease of operation, field condition, and time of operation. The performance was evaluated considering the technical parameters: cutting speed, operating speed, effective field capacity, cutting efficiency, power requirement, cost economics and percentage of grain losses. In this study, the cutting width of the reaper was 0.6 m and the average cutting efficiency and effective field capacity were 98.24% and 0.13 ha hr^{-1}, respectively. Average forward speed of the reaper was 2.17 km hr^{-1}. Labor requirements for developed reaper and manual harvesting were 7.69 man-hr ha^{-1} and 160 man-hr ha^{-1}, respectively. That’s why the harvesting cost of battery operated developed reaper was 85% less as compared with manual harvesting. The cost of this reaper is BDT 59,500 which is also affordable for the small-scale farmers.

Keywords: reaper, battery operated, harvesting, performance, ease of operation, efficiency, power

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1 Introduction

Bangladesh is basically an agricultural country. About 80% of the total population lives in rural areas and 95% of them are involved with agricultural activities. Bangladesh forms the largest delta in the world and is situated between 88°01' and 92°41' East longitudes and between 20°34' and 26°38' North latitudes (BBS, 2014). As it is deltaic, the land is very fertile and the climate is favourable for the production of cereal crops like paddy, wheat. Time between harvesting of one crop and sowing of the next one is very short in the present intensive agriculture. Optimum period for harvesting a crop depends on its biological maturity. So timely harvesting of the crop is very important. Crops are susceptible to shattering if harvesting is delayed. Acute labour shortage is felt during the harvesting season because time available for harvesting is limited and the operation is generally manual. In Bangladesh, most of the cereal crops are generally harvested by sickle which is quite tedious and labour intensive. During peak harvesting period there is scarcity of labour and harvesting is normally delayed resulting in greater losses of crops on the field.

In general, the harvesting operations take place 10 or 15 days after grain has reached physiological maturity. Samson and Duff (1973) reported that 5, 7 and 10 days delayed harvest resulted in 3, 6 and 11% decrease in rice yield, respectively.

Total area under Aman crop in Bangladesh was 55, 30, 014 hectares in 2015 and production of Financial Year 2014-15 was 1, 31, 90, 163 metric tons (BBS, 2014). During the season, farmers faced a loss of 3, 95, 705

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metric tons, 7, 91, 410 metric tons and 14, 50, 918 metric tons due to 5, 7 and 10 days delayed harvesting whose market price is about BDT 395.705 Crores, 791.41 Crores and 1,450.918 Crores, respectively. To resolve this huge amount of loss it is therefore necessary to introduce harvesting machinery.

Nowadays, self-propelled reapers are being used in many developing and least developed countries with small scale. Combine harvesters are being used mostly in developed countries. But in developing countries including Bangladesh, farmers are not being encouraged for using of it, because of its high cost, complexity, land fragmentation, unavailability of suitable road networks, lack of skilled labour, spare parts facilities for repairing etc. According to the annual (2014) report of Bangladesh Agricultural Research Council, total amount of reaper and combine harvester used in Bangladesh is only 500 and 130, respectively.

In Bangladesh paddy is harvested manually by sickle and is left in the field for drying if weather is favourable. Harvesting losses occurs due to the shattering and handling. Duff and Toquero (1975) reported that depending upon the number of times the harvested stalks are handled from the field to the threshing yard, shattering loss was up to 7%. On the other hand, harvesting is a labour intensive operation. It is observed that wage rate of labour is different in different regions and is increasing day by day. As a result, the overall production cost of crops as well as harvesting is increasing. But average farmers want to reduce the production cost. Hence, there is an urgent need to mechanize this operation fully or partially to cut down man-hour and to reduce operational cost. Besides, the small-scale farmers do not have the capability of purchasing a combine harvester and even some cases the reaper also. In these circumstances, any kind of low cost small-scale harvesting device could help to minimize these problems. The socio-economic and agro-climatic conditions of Bangladesh have prevented the adoption of western type combines for harvesting of grain crops. For this reason, the small scale farmers desire low cost small-scale reaper. Keeping these in view, an attempt was taken to develop a small-scale battery operated reaper.

2 Materials and method

2.1 Development of the reaper

Three basic changes compared with the reapers available in market were done to develop the reaper that includes reaping unit, power source and power transmission system. The cutter bar, cutting blade, ground wheel, shaft, frame, reaping unit and other necessary parts of the reaper were made of MS angles, MS rod, MS flat bar, MS pipe and square bar. The cutting width of the reaper was reduced to 2 ft from 4 ft.

2.1.1 Reaping unit

Reaping unit is consisted of cutter bar, cutting blade, crop divider, star wheel and pair of lugged conveyor chain. Ten knives of triangular shape and two star wheels were used in the reaping unit. Cutter bar cuts the crop by impact and shear action between knives and finger guard. The reciprocation of cutter bar is achieved by the motion from pitman arm. Pitman arm converts the rotary motion into reciprocating motion. Per revolution of the crank gives two strokes and the stroke length is 6 cm.

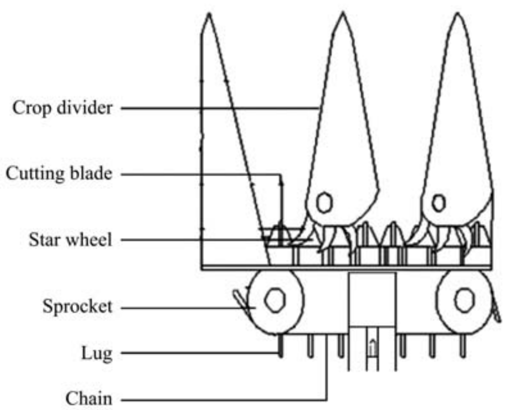

Figure 1 Reaping unit

During harvesting, the crop divider enters into the standing crop, guides it towards the cutter bar. Lugged chain is powered from motor by chain and sprocket. Total length of chain is 140 cm and lug pitch is 12.5 cm with 11 lugs. The cut crop is conveyed to one side by the lugged conveyor chain and star wheels vertically.

2.1.2 Power source

To make the reaper environment friendly and to reduce the harvesting cost, brushless DC Motor and battery were used as power source. Motor having a rated power of 1100 W, DC48v rated voltage, 260A current was used whose rated speed was 450 rpm. Four rechargeable batteries of 12 volt were used to operate the motor. The batteries need to be changed after every two years.

Figure 2 Brushless DC motor and battery

2.1.3 Power transmission system

The power transmission system consists of main axle, chain and sprocket, bevel gear and pinion, crankshaft and pitman. The knife of cutter bar is powered through a long pitman attached to the knife head. The overall power transmission system is as follows.

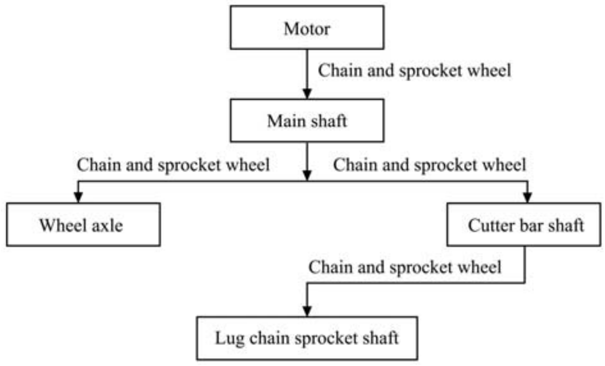

Figure 3 Flow diagram of power transmission system

2.1.4 Frame

The frame of the harvester was made of MS angles of size 50×50×5 mm, 12.5 mm MS rod, MS flat bar and square bar. The frame was made capable in order to bear the weight of a motor, battery and reaping unit. The overall length and width of the reaper were 2400 mm and 850 mm, respectively. The overall weight of the reaper was 78 kg.

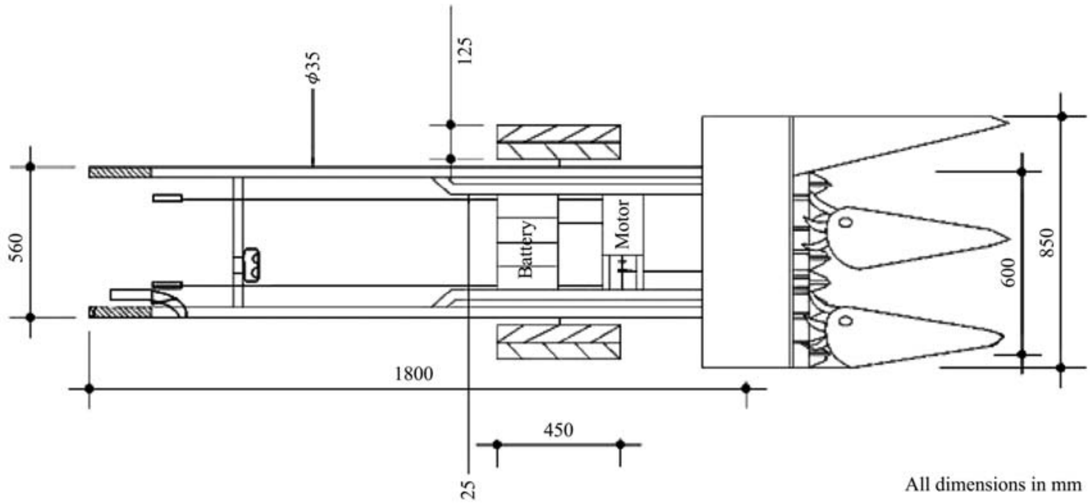

Figure 4 Top view of the developed reaper

Figure 5 Developed battery operated reaper

2.2 Laboratory testing of the reaper

Rated rpm of the motor was counted with the help of digital tachometer and cutter bar reciprocating speed was calculated by the cutter bar shaft rpm and stroke length.

2.3 Field Test and operation of the reaper

An area of 10 m × 10 m of paddy field was considered to conduct the experiment. Experimental areas were selected randomly. Cutting height from the ground was 88 mm. Five experimental replications were conducted during the field test.

The operating speed, cutting efficiency, field capacity, effective field capacity, and cost comparison were calculated as follows:

2.3.1 Operating speed

The operating speed was calculated using the following Equation.

$$So = 3.6D/T \quad (1)$$

where, So = Operating speed, km h^{-1}; D = Harvesting distance, m; T = Harvesting time, s.

2.3.2 Cutting speed

Cutting speed was calculated by the cutter bar shaft r/min and stroke length using the following formula.

$$\text{Cutting speed, m min}^{-1} = 2L \times n \quad (2)$$

where, L = Stroke length, m; n = Cutter bar shaft r/min.

2.3.3 Cutting efficiency

The cutting efficiency of the harvester was determined as the ratio of total number of cut plant to the total number of plant present before cutting operation of the plot. Then average cutting efficiency was calculated from five replications.

$$CE = \{(W1 - W2)/W1\} \times 100 \quad (3)$$

where, CE = Cutting Efficiency, %; $W1$ = Number of plants before cutting; $W2$ = Number of plants left after cutting.

2.3.4 Field Capacity

Field capacity of a machine is the actual rate of land preparation/harvested or crop processing in a given time, based on total field time. Field capacity was calculated using the following formula.

$$\text{Field capacity, } C = A/T \quad (4)$$

where, C = Field capacity (ha hr^{-1}); A = Area of land reaped at specified time (ha); T = Total time for the reaping operation (hr).

2.3.5 Harvesting losses

The harvester has only two types of losses; cutter bar loss and shattering loss. These two types of losses were computed from the data obtained according to the following formulae.

$$\text{Cutter bar loss, \%} = \frac{\text{Total number of unreaped crop} - m^{-2}}{\text{Before reaping total number of crop} - m^{-2}} \quad (5)$$

$$\text{Shattering loss, \%} = \frac{\text{Topingtal earhead fallen on the ground during rea} - m^{-2}}{\text{Total number of earhead on the ground} - m^{-2}} \quad (6)$$

2.4 Power requirement

Power required to operate the reaper was calculated by using the forward speed, cutting speed, throwing speed, width of cut, and weight of the reaper.

Power calculation

Assumptions:

Maximum crop yield = 5 ton ha^{-1}

Straw/paddy ratio = 1.4:1

Over all power transmission efficiency of an engine = 85%

Calculation

Forward speed, Vs = 2.17 km hr^{-1} = 2170 m hr^{-1}

Weight of whole unit = 78 kg

Weight of cutterbar = 20 kg

Width of cut = 0.6 m

Cutting speed, Vc = 1.3 × Vs = 1.3 × 2.17 = 2.821 km hr^{-1} = 47.02 m min^{-1}

Lug speed or throwing speed, VL = 1.5 × Vc = 1.5 × 47.02 = 70.53 m min^{-1}

Power required moving whole reaper at a speed of

$$2.17 \text{ km hr}^{-1} = \frac{78 \text{ kg} \times 2170 \text{ m} \times 1 \text{ hr} \times 1 \text{ min} \times 1 \text{ hp}}{1 \text{ hr} \times 60 \text{ min} \times 60 \text{ sec} \times 75 \text{ kg m secs}^{-1}}$$

= 0.627 hp

1. Crop to be thrown per minute

$$= \frac{0.6 \text{ m} \times 2170 \text{ m} \times 1 \text{ hr} \times 5000 \text{ kg (paddy)} \times \text{ha}}{1 \text{ hr} \times 60 \text{ min} \times 10000 \text{ m}^2 \times 1 \text{ kg paddy} \times \text{ha}}$$

×2.4 kg (Straw+Paddy)=26.04 kg min^{-1} (Straw+Paddy)

Power required to throw this (Paddy + Straw)

$$= \frac{26.04 \text{ kg} \times 1 \text{ min}}{60 \text{ sec}} \times \frac{70.53 \text{ m}}{\text{min}} \frac{1 \text{ hp}}{75 \text{ kg m sec}^{-1}} = 0.408 \text{ hp}$$

2. Power required to operate the cutter bar

$$= 20\ \text{kg} \times \frac{47.02\ \text{m}}{\text{min}} \times \frac{1\ \text{min}}{60\ \text{sec}} \times \frac{1\ \text{hp}}{75\ \text{kg m sec}^{-1}} = 0.209\ \text{hp}$$

Total power required = 0.627 + 0.408 + 0.209 = 1.244 hp

Assuming over all power transmission efficiency = 85%

Engine Power = 1.244/0.85 = 1.464 hp

Therefore, a 1.5 hp power source is needed to operate the reaper.

2.5 Harvesting cost

The costs of harvesting with the developed reaper were classified into two categories: fixed cost and variable cost. Fixed cost included depreciation cost, interest, shelter and taxes and is a function of purchase value, useful life and interest rate. Annual interest was calculated on average investment on the machine over its full life. Depreciation was determined by straight-line method by the following Equation:

$$\text{Depreciation, } D = (P - S)/L \quad (7)$$

where, D = Mean yearly depreciation (Tk. year^{-1}); P = Purchase value (Tk.); S = Salvage value (Tk.); L = Useful life (year).

Useful life for the reaper was considered 10 years. The purchase price of the developed reaper was considered as BDT 59,500. The machine salvage value was considered to be 10% of purchase value. Interest is an actual cost in agricultural machinery and was determined by straight line method by the following equation considering an interest rate of 9%:

$$\text{Interest, } I = \{(P+S)/2\} \times I \quad (8)$$

where, I = Mean interest (Tk. yr^{-1}); P = Purchase value (Tk.); S = Salvage value (Tk.); I = interest rate (%).

The tax, insurance and shelter costs were 2% of purchase value.

Variable costs include power, lubricant, repair and operational costs and are directly related to the amount of work done by the machine. Repair cost for the harvester was considered 0.025% of purchase value. The fuel cost (electricity) was assumed as BDT 6 per unit (Kilowatt-Hour) as it varies in different sectors.

The wages of labour in manual method of harvesting using sickle was also calculated and it was BDT 400 per day (eight hours of working day).

Total cost was calculated as:

Fixed cost, FC = Depreciation + Interest on investment + Tax, insurance and shelter

Variable cost = Repair & maintenance + power + Lubricants + Labour

Total cost = Fixed cost + Variable cost

3 Results and discussion

The performance evaluation of the reaper was done in Jamalpur district, Bangladesh. The cutting efficiency and field capacity of the reaper were calculated. The cost comparison for the developed reaper and manual harvesting was also done in BDT per hectare. Table 1 shows the overall field performance of the reaper.

Table 1 Filed Performance

Sl. No.		
1	Time of start	10:00:00 am
2	Time of finish	10:04:37 am
3	Actual field operation	4.61 min
4	Length of the field	10 m
5	Width of the field	10 m
6	Area covered	100 sq. m
7	Effective working width	600 mm
8	Effective field capacity	0.13 ha hr^{-1}
9	Cutting efficiency	98.24%
10	Forward speed	2.17 km hr^{-1}
11	Height of cut	88 mm
12	Labor required	1

Figure 6 shows that cutting efficiency does not depend on forward speed of the harvester. So, there is no significant relationship between cutting efficiency and machine forward speed. But, in this case, machine forward speed must be lower than or equal to the cutting speed. Again cutting efficiency depends on the number of plants which is gone out of reach of the cutterbar, due to lodging of plants.

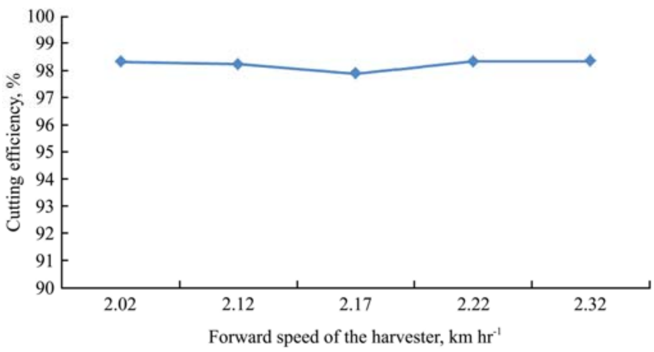

Figure 6 Forward speed versus Cutting efficiency of the reaper

Figure 7 represents that cutting efficiency increases with the increase of cutterbar reciprocating speed up to 48 m min^{-1}. When cutterbar reciprocating speed exceeds 48 m min^{-1} then cutting efficiency will be independent of cutterbar reciprocating speed. Therefore, it may be recommended that the device should be operated at a cutterbar reciprocating speed of about 48 m min^{-1}. So it is obvious that cutting efficiency will be increased up to a certain cutterbar reciprocating speed. After this, it will be independent of the cutterbar reciprocating speed. For normal cutting of plants, cutterbar reciprocating speed should be at least 45m min^{-1}. If cutting edge of the cutterbar blade is sharp enough then cutting efficiency will be increased and power requirement will be decreased otherwise cutting efficiency will be decreased and power requirement will be increased. The cutterbar reciprocating speed was calculated by the cutter bar shaft rpm and stroke length.

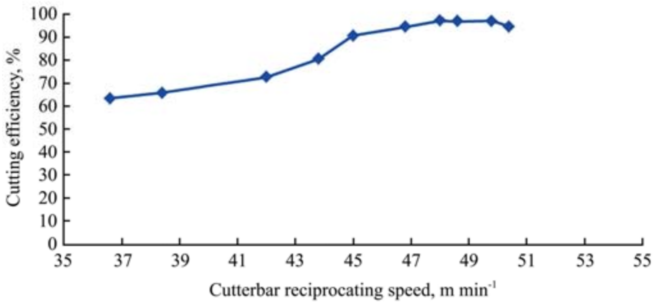

Figure 7 Cutterbar reciprocating speed versus cutting efficiency

Table 2 presents the comparative performance characteristics of the developed battery operated reaper with manual harvesting of rice. From the table it can be said that the use of developed reaper is much more economic in all sides.

Table 2 Comparative performance characteristics of battery operated reaper with manual harvesting in paddy filed

Sl. No.	Parameter	Harvesting Methods	
		Developed reaper	Manual
1	Power source	1.5 HP DC motor	Man power
2	Rice variety	BRRI dhan49	BRRI dhan49
3	Date of harvesting	23-11-2015	23-11-2015
4	Study area (ha)	0.01	0.01
5	Speed of operation (km hr^{-1})	2.17	NA
6	Width of operation (cm)	60	NA
7	Time required (hr ha^{-1})	7.69	160
8	Actual field capacity (ha hr^{-1})	0.13	0.0062
9	Cutting efficiency (%)	98.24	97
10	Labour requirement (man ha^{-1})	1	20
11	Fuel (electricity) cost (BDT hr^{-1})	4	NA
12	Cost of operation (BDT ha^{-1})	924	8000
13	Harvesting loss (%)	3.93	6.36

Note: NA = Not Applicable, BDT = Bangladesh Taka.
(3 unit of electricity is required for fully charged of the batteries which gives about 4.5 hour service in the field. BDT 5.5 is needed to pay for one unit.)

4 Drawbacks

Based on analysis of results following drawbacks seen during operation:

1. It is not suitable for lodged crops and wet field condition.

2. Overlapping occurs as cutting width (60 cm) is below the average height (88 cm) of the paddy plant.

5 Conclusions

The overall performance of the developed battery operated reaper is fairly satisfactory. The average cutting efficiency of this reaper was 98.24%. Cutting efficiency decreases due to the lodging of plants to the ground. Cutting efficiency will be increased up to a certain cutterbar reciprocating speed (48 m min^{-1}). After this, cutting efficiency does not depend on the cutterbar reciprocating speed. For normal cutting of plants, cutterbar reciprocating speed should be at least 45 m min^{-1}. The field capacity was 0.13 ha hr^{-1}. Field capacity increases with the increase of machine forward speed when machine width was constant at 0.60 m. The average forward speed of the machine was 2.17 km hr^{-1}. Cutting speed and the throwing speed were 2.821 km hr^{-1} and 4.232 km hr^{-1}. For optimum effective field capacity, machine forward speed should be equal to the cutting speed. The cost of the reaper was BDT 59,500 which is affordable to the small-scale farmers. Costs of operation for the developed reaper and manual harvesting were BDT 924 ha^{-1} and BDT 8000 ha^{-1}, respectively. The operation was smooth, environment friendly and created less tiredness to the operator. Thus the use of the developed battery operated reaper is much more economic than manual harvesting.

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