Development and Performance Testing of Rice Thresher for Fogera Hub Farmers in Ethiopia

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Abstract. Traditional paddy threshing is still carried out by man-power, and animal trampling in the rural village of Fogera district in the Amhara region of north-west Ethiopia. This paper was aimed to reduce paddy losses, minimize drudgery activities, and avail the technology in this area. The developed rice thresher also protects the paddy from mud mixing for further prevention of fast wearing and damaging of rubber roll during rice milling. The 3D modeling and working drawing are prepared by using CATIA software for fabrication and testing purposes. The paddy thresher is designed to separate paddy from panicles without damaging the stalk of rice. The research seeks to develop a power-operated rice thresher that can be manufactured by local manufacturers, and accessed by all small-holder rice producing farmers in Ethiopia. Components of the thresher were designed, fabricated, and assembled from the available materials in the local market. The experimental test in this study indicated that the threshing capacity of the designed paddy thresher is approximately 128 kg/h using two labor participation. Considering the unthreshed loss, drum loss, and broken grains, the average efficiency of the machine noted 96.6%.

Keywords: Prototype development · Rice thresher · Threshing capacity · Threshing efficiency · Threshing loss

Nomenclature

DL	Drum loss
SL	Separation loss
TE	Threshing efficiency
TC	Threshing capacity

1 Introduction

Rice (Oryza Sativa Linu) is the major food for 70% of the world's population, and it is consumed by 3.5 billion people or more [1]. Rice was initially announced in Ethiopia in the 1970s at a place of Fogera district, which has a wetland of south Gonder [2]. It is

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also a productive crop next to maize in the country [2] and is considered as the major cereal which is expected to contribute to food security in Ethiopia [3]. Rice is now suitably cultivated in different parts of the country. The predominant potential areas are West central high lands of Amhara region (Fogera, Gonder Zuria, Dembia, Takusa, and Achefer), North West low land areas of Amhara, and Benshangul Regions (Jawi, Pawi, Metema, and Dangur), Gambella regional state (Abobo, and Etang Woredas), South, and south-west low lands of SNNPR (Berklee, Weyito, Omorate, Gura Ferda, and Menit), Somali Region (Gode), and South Western high lands of Oromia Region (Illuababora, East and West Wellega, and Jimma Zones) [4]. 58% of the regional rice production and 28% of the national rice production is found in Fogera district, Ethiopia. About 72% of the households produced rice and about 50% of the farmers benefited from rice by using it as a cash crop [5]. This indicates that rice has both food and economic importance for small household farmers in the area [5]. According to CSA 2015 report, in the Amhara region, there are 79,683 small household farmers with a total area of 38,322 hectares of land covered by rice with a production volume of 1.13 million quintals that is 85.6% of that national production [6]. Since 1998 the first rice variety was released in the country, and till that time around 20 improved varieties are released. Among those varieties, only Gumara, Kokit, Tigabe, Andasa, Nercia 4, and Ediget are popularized in Fogera plain. Other than these the most popular and productive local varieties in Fogera are X-Jigna [6]. Investigators' efforts concentrated on the testing or introduction of highland varieties. Research data indicated that most farmers have used the X-Jigna variety to grow rice into the highland system, probably because of better yield potential, especially at times, and locations when/where water availability was not scarce [7]. However rice productivity is encouraging in the Fogera district, post-harvesting processes like harvesting and threshing are performed traditionally and cause undesirable loss of paddy.

Threshing is commonly accomplished by trampling several oxen, cows, and sometimes donkeys, some-times; beating panicles on the ground by using human power. In Fogera rice hub, threshing is done on the small fields prepared with a straw without using tarpaulins, plastic, or canvasses which intern is causing a mixture of sand, rocks, and other dirt. Threshing is followed by winnowing, cleaning, and destoning in the same field. Cleaning threshed paddy rice by tossing it into the air blowing off most of the light chaffs, and other impurities. However, this doesn't separate stones, soil, and weeds mixed in the paddy, and it is also a tedious time taking process. The major causes of rice losses during traditional threshing are grain remains in the bundles, and require repeated threshing, grain scattering, grain sticking to mud, wasting grains by birds, and domestic fowls. The panicles of rice should be well organized in the bundle to reduce losses during threshing with beaters. When threshing might be late, the harvested paddy stalk bundles also wait in a dry and shady place, which facilitates the air circulation, and prevents excessive heating. The undesirable loss of paddy during the threshing process can be predicted using the formula [8]:

$$\text{Threshing losses} = [\text{Weight of leftover grains}/\text{Total weight of collected grains}] \times 100\% \quad (1)$$

The maximum loss of rice is observed during threshing, and milling, this indicates that it needs interventions by using appropriate post-harvesting technology [9]. The rate of losses of rice starting from harvesting to milling process is depicted below in Fig. 1.

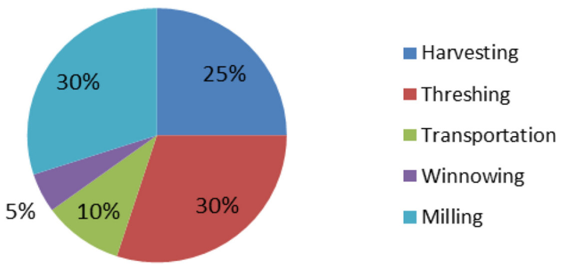

Fig. 1. Stages where post-harvest losses occur (adapted from Tilahun et al. 2012).

The appropriate wetness of rice before harvesting can be checked using a resistance-type moisture meter with small samples. The costly capacitive moisture meter is also important for a more sample but is more precise than resistance type units [9]. The preferred wetness of rice for threshing operation should be 20 to 25% for mechanical threshing and should be less than 20% for hand threshing [9]. The main impacts because of the inappropriateness of moisture content are incomplete threshing, grain damage, and cracking/breakage [9].

2 Materials and Methods

2.1 Materials

Fabrication Materials. The designed rice thresher was fabricated from the available materials in the local market of Bahir Dar city, Ethiopia. Different types of structural steel are used for the fabrication of different parts of the rice thresher; such materials are square hollow steel, black sheet iron, low carbon steel round bar, and aluminum pulley. The fabrication process was performed by applying cutting, bending, welding, and machining operations in the workshop of mechanical and industrial engineering faculty at Bahir Dar Institute of Technology.

Standard Items. The main standard accessories used for the fabrication of rice threshers in this study are the electric motor, v-belt, bearings, and hexagonal bolts and nuts. A single-phase electric motor, which has a 3 KW power rate, is selected. It is used to drive the threshing drum with the assembly of the pulley, and v-belt. The tension of the belt is adjusted by sliding the electric motor on its stand slot to get the appropriate rotation of the threshing drum. The bearings, which are used for the developed thresher machine, are identified by a number P206. It means that it has a 30 mm inner diameter to support the shaft at two ends. Bolts and nuts are used to assemble parts of the body of the machine for easy maintenance and transportation purpose.

Testing Instruments and Tools. The following testing instruments shown in Fig. 2 are used to conduct a basic experimental study for the performance evaluation of the newly developed rice thresher.

2a. Analog balance (0.5g sensitivity)

2b. Digital grain moisture meter

2c. Contact type Digital tachometer

2d. Sensitive digital Weighing Scale (Sensitivity: 0.1 g)

Fig. 2. Testing instruments and tools used for the experimental study (2a–2d).

The main testing tools used in this study shown above in Fig. 2 are described shortly as follows.

Analog Balance. 0.5 g sensitivity analog balance is used to measure the weight of samples of un-threshed rice straw and threshed rice during the experimental test.

Digital Grain Moisture Meter. A digital grain moisture meter is used to determine the moisture content of rice grain before the threshing operation. The average of three trials is taken for checking of moisture content of rice paddy was found to be 11.23%. This data indicated that the rice is much more dried compare to the allowed moisture content of 20%.

Tachometer. The digital tachometer was used to measure the speed of the threshing drum, and other driven components with or without load expressed in RPM.

Weighing Scale. The sensitive digital weighing scale (sensitivity: 0.1 g) is used to measure the weight of samples of clean paddy grain, and loss amounts to determine the production capacity and efficiency of the machine during testing.

Canva Sheet. It is used to hold the threshed paddy grains temporarily during threshing, and sample measurements. It also prevents impurities and scattering losses of paddy grain.

Timer (Stopwatch). It is used to control the required operation time for threshing activities. The conditions of the crop, such as grain-straw ratio, and moisture content of the grain to be used in each test trial shall be taken using representative samples, which represent the different conditions of the test lot. This can be done by taking samples, each at the top, middle, and bottom of the pile. Samples representing the materials for each test trial shall be placed in appropriate containers for laboratory analysis.

Paddy Rice. Many varieties of rice are grown in Fogera farming lands which are developed in Woreta rice research center, Ethiopia. Among those varieties, X-Jigna, Gumara, Kokit, Tigabe, Andasa, Ediget, and NERICA are popularized in Fogera plain. Most of the names of the varieties of rice are given by the research center considering their cultivation area. X-Jigna variety was used in this study to evaluate the performance of developed rice threshers.

Grain-Straw Ratio (R). It is the ratio of the weight of the grains present in the panicles, to the total weight of the grain, and straw in the same sample [10].

$$\text{Grain - straw ratio(R)} = \text{Wg/Ws} \tag{2}$$

Where: Wg is the weight of grain, gram, and Ws is the weight of the sample (grain, and straw), gram. Harvested rice was collected from the test lot, to determine the grain-straw ratio, moisture content of the grain, straw length, and grain quality as the basic characteristics of the paddy are measured and presented in Table 1.

Table 1. Sample characteristics of threshed paddy

No.	Characteristics	Measured value
	Variety: Locally cultivated in Fogera (X-jigna)	
1	Average Grain moisture content	11.23%
2	Average Straw length	800 mm
3	Grain – Straw Ratio	0.546

2.2 Methods

To conduct this study, the major procedures and techniques are applied to design, develop, and evaluate the performance of rice threshers for satisfying the demand of Fogera hub farmers. The detailed methodologies followed for this investigation are carried out on these approaches are given below.

Gap Identification. In Fogera hub, threshing is commonly performed by integrating animal, and manpower on the around small field called “Awudima”. In this scenario, the paddy will be mixed with stone, and mud during threshing which will result in the fast wearing of an expensive rubber roller mill during de-husking. This traditional threshing process also makes the final white and brown rice less competitive in the market because of its dirt, and breakage. As per our observation in the Fogera district, there was no experience of rice threshing with technology, except some testing from researchers. This indicates the high available demand for different types of threshers in the sector. While there are attempts in different parts of the country to adapt the threshing technology, the operation is practically seen dominated by the traditional methods in Fogera Hub. Hence, the authors were highly motivated to design, and develop an appropriate rice thresher that has a wire loop beater to separate the paddy from its panicles without breakage.

Literature Review. Selected scientific research works are assessed, and reviewed from journals, conference papers, bulletins, and books. There is an intermediate technology for rice threshing. This involves the use of mechanical; semi motorized, and completely motorized rice threshers. There is also the technology of threshing, which uses a pedal thresher. The pedals are attached to an overhead drum that is perforated to create fingers. As the machine is pedaled, and the straw placed on the drum the resulting centripetal forces loosens the grain from the straw. However, the thresher is also very laborious, has limited output, and is suited for only small farms. Crop moisture content and shattering ability influenced the threshing efficiency, threshing capacity, grain loss, broken grain, fuel, and physical energy requirement at rice threshing. The imported, as well as the modified rice threshers, were demonstrated for farmers in the area are not affordable in cost. Therefore, an affordable and convenient rice thresher should be designed, and fabricated for further application.

Design of Paddy Thresher. The paddy thresher is designed for Fogera farmers by considering important factors such as affordability within the capacity of the local farmers, the ergonomic, and safety requirements, ease of operation, the drudgery activities involved in the traditional methods of threshing, the cost to make the machine, the choice of materials, and manufacturing methods for the development of the machine, threshing capacity, and also threshing efficiency. The 3D drawing of the paddy thresher after conceptual design work is shown below in Fig. 3.

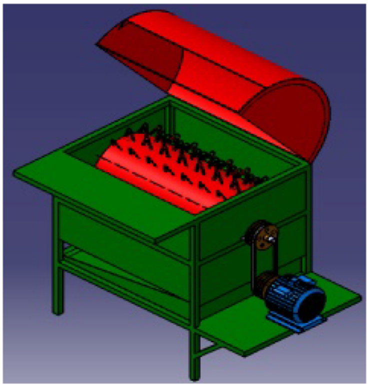

Fig. 3. 3D drawing of designed paddy thresher.

Design Analysis. The principal parameters of the threshing drum are the drum length, the drum diameter, the number of beaters on the drum, and the drum speed (http://www.knowledgebank.irri.org/). The drum length was obtained from the following equation [11].

$$f = f_p \times L \times n \tag{3}$$

Where: L = Drum length (m), f = Feed rate of thresher (kg/s), f_p = Permissible feed rate (kg/s), and n = Number of (rows of) beaters. Therefore, considering this equation, the drum length of the thresher is estimated at 700 mm, and the number of staggered wire loop beater is arranged 12 rows by 6 peripheral columns. The velocity of the threshing drum (V) is determined by using the following equation [12].

$$V = (\pi \times D \times N)/60 \tag{4}$$

Where: V = Velocity of threshing drum, D = Diameter of threshing drum, N = drum RPM. The speed of the driving motor and threshing drum can be correlated and computed using the equation below [13].

$$N_1 \times D_1 = N_2 \times D_2 \tag{5}$$

Where: N_1 speed of the driving pulley (rpm), D_1 diameter of a driving pulley (mm), N_2 speed of driven pulley (rpm), D_2 diameter of the driven pulley (mm). The nominal pitch length of the v-belt was calculated using Eq. (6) below to know the actual belt length required to transfer the speed from the electric motor to the threshing drum [14].

$$L = [(2 \times C) + (\pi/2 \times (D_1 + D_2)) + (D_2 - D_1) \times 2]/2 \times C \tag{6}$$

Where: D_1 and D_2 are the diameters of the driving, and driven pulley, respectively (mm), C is the distance between the centers of the driving, and driven pulley (mm). Generally, the major physical dimensions of a designed paddy thresher that was calculated for the better performance of the paddy thresher are presented in Table 2.

Working Principles. Hold on paddy threshers consist of a semi-closed rotating drum with a wire loop beater that can separate the paddy from its panicles. The designed paddy thresher machine can be worked using a single-phase electric motor or gasoline (petrol) engine. Initially, the power switch of the paddy thresher should be turned on to run the threshing drum. The operator grips the bundle of rice and holds the straw against the drum to be threshed by supporting it with the feeder table. The overall separation of the paddy is controlled by the operator by observing the situation there. When the wire loop beater hits the panicles the paddy and small size of dust will try to drop on the bottom tray. Two persons are enough to accomplish the tasks to get clean paddy without a winnowing process. The paddy thresher didn't damage the straw of the rice. Hence the farmers are using this straw for roof coverage, construction works, and animal feeds safely without significant wastes.

Fabrication of Paddy Thresher. The paddy thresher is manufactured from locally available structural steels and some standard items as it was presented under fabrication materials. The basic material used to fabricate the paddy thresher is square hollow steel, black sheet iron, electrode, bearing, pulley, belt, and motor. The basic parts of the paddy thresher machine are shortly described below.

Table 2. Physical dimensions of power-driven double loop beater paddy thresher.

No.	Item description	Manufacturer specifications
1	Overall dimensions of paddy thresher (L * W * H), mm	1300 * 600 * 1650
2	Stand height, mm	1000
3	Feeding table size (mm), L * W	845 * 240
4	Drum cover size (semicircular), mm	R = 380, L = 670
5	Overall weight without Engine, Kg	34
6	Threshing drum diameter, mm	D = 400
7	Threshing drum Length, mm	700
8	Threshing Drum shaft Diameter, mm	30
9	Threshing drum pulley diameter, mm	D = 290, W = 40
10	Double Wire loop beater size, mm	H = 65, W = 60
11	Number of a wire loop	63
12	Distance between wire loops beaters	120
13	Threshing Drum speed, RPM	370
14	Electric motor power rate	3 KW, 220 V
15	Motor pulley diameter, mm	75
16	Motor RPM	1400 RPM
17	Belt type, and size for the motor to drum drive	A56
18	Center to center distance (motor, and drum shaft), mm	502

Stand. The stand of the paddy thresher is fabricated from SHS (30 × 30 × 1.5) mm pipe and black sheet iron which has 1 mm thickness. The stand is mainly used to support the threshing drum and powerful engine. It is also collecting the separated paddy at the bottom of the tray and slides through the paddy outlet. The feeding table is used to support the bundle of rice and creates a conducive situation for threshing.

Threshing Drum. The drum of the paddy thresher is fabricated from a flat iron, black sheet iron, and wire loop which have a 6 mm diameter, spoke, and hub. The drum is assembled with the rotating shaft, and supported by a pair of bearing designated by P206 at two ends of a shaft. The wire loop is welded on the rolled sheet metal with a staggered arrangement for better threshing performance.

Assembled Paddy Thresher. The assembling of parts of the paddy thresher is performed by using welding, and temporary fasteners like bolts, and screws. The top cover of the thresher is used to protect the losses of scattering paddy. The cover is assembled with a door hinge, and it can be open, and close on the specified position to feed the bundles of rice safely.

Performance Testing and Evaluation. Tests were conducted on the paddy thresher machine to ascertain its performance. The most efficient mode of threshing is the use of a motorized rice thresher. To determine the effect of drum speed of the designed machine, moisture content for threshing, the capacity of the thresher, and efficiency, there is the need to carry out field testing of paddy thresher. The fabricated paddy thresher machine was tested at the Woreta rice research center laboratory in the Fogera district by preparing the required experimental setup as shown in Fig. 4.

4a. a weight measurement of sample rice

4b. samples of measured rice for testing

4c. Drum speed measurement using tachometer

4d. Threshing process during testing

4e. Collected threshed paddy grain

4f. Sample weight measurement of cleaned grain for performance analysis

Fig. 4. Experimental setup for paddy thresher testing

The following criteria are used to evaluate the performance of the paddy thresher: Threshing capacity (TC), threshing efficiency (TE), and Separation efficiency (SE).

Threshing Capacity. The weight of grains (whole and damaged) threshed, and received per hour at the main grain outlet is called capacity. At the end of each test, the total threshed grain was collected from the main grain outlet. The capacity was calculated from the following expression [15, 16].

$$TC(kg/h) = (WG(kg)/\text{duration of test run}) * 60\ \text{min} \tag{7}$$

Where: TC, Threshing capacity (kg/h), WG, the weight of total output at the main outlet (kg).

Drum Loss. After threshing, the whole grain still attached to the straw of the rice stalk is called drum loss. The percent of cylinder loss was calculated as:

$$DL(\%) = [WDL(kg)/WG + WSL + WDL(kg)] \times 100 \tag{8}$$

Where: DL, Drum loss (%), WDL, Weight of drum loss grain (kg), WSL, Weight of separating loss grain (kg).

Separating Loss. The loose grain was collected from threshed straw. It is the ratio of the weight of grains that remained in the panicles of the plants fed into the threshing chamber, to the weight of total grain input of the thresher, expressed in percent. The percentage of separating loss was calculated as follows:

$$SL(\%) = [WSL(kg)/WG + WSL + WDL(kg)] \times 100 \tag{9}$$

Threshing Efficiency. The net threshed grain received at the main outlet concerning total grain input was expressed as percent by weight was termed as threshing efficiency. The threshing efficiency was calculated from the following expression:

$$TE(\%) = 100 - [\text{un - threshed grains at main outlet per unit time (kg)/total grain input}] \times 100 \tag{10}$$

3 Result and Discussion

The designed paddy thresher is used to separate the paddy from its panicles by removing the dust, and fine straws without significant damage to the stalk of the rice, and paddy. The developed prototype of rice thresher is shown in Fig. 5.

Fig. 5. Developed prototype at Bahir Dar Institute of Technology-Bahir Dar University (photo captured in BiT-BDU, June 2020)

The developed rice thresher has a threshing cylinder wherein wires of the same arc and size are attached on the periphery of the cylinder in tandem arrangement with the threshing drum cover to protect scattering of grains and operators from accidents.

Testing Result. The developed prototype of rice thresher was tested following PNS/PAES 205:2015 agriculture machinery testing standards. The experimental tests were conducted by applying three trials. During each test trial, samples were collected from the outlet of the rice thresher to evaluate the losses and grain quality. For testing purposes, scattered grains were gathered since these grains are part of the total grain input. A spread canvas sheet was placed around the threshing floor area to catch these grains after each test trial. The collected scattered grains were labeled in appropriate containers for further analysis. Provisions had provided for the collection of scattered grains with a maximum distance of 1 m away from the base of the machine. The threshing losses were affected directly by different operating parameters such as feed rate, threshing drum speed, paddy moisture content, and others. The production capacity, efficiency of the machine, and other threshing testing parameters are summarized in the following Table 3.

Table 3. The performance evaluation result of thresher (Sample of un-threshed rice 2 kg).

No.	Parameters	Test result			
		Trial 1	Trial 2	Trial 3	Average
1	Threshing drum speed (RPM)	370	370	370	370
2	Net Threshed grains (g)	1070	964	1130	1054.67
3	Threshing time (min)	1:48	1:15	1:33	1:32
4	Unthreshed loss (g)	22	15	21	19.33
5	Drum loss (g)	16	17	15	16
6	Broken grains (g/100 g sample)	2	1.8	2.2	2

The experimental data shown in Table 3 is also depicted graphically in Fig. 6, and 7 as shown below.

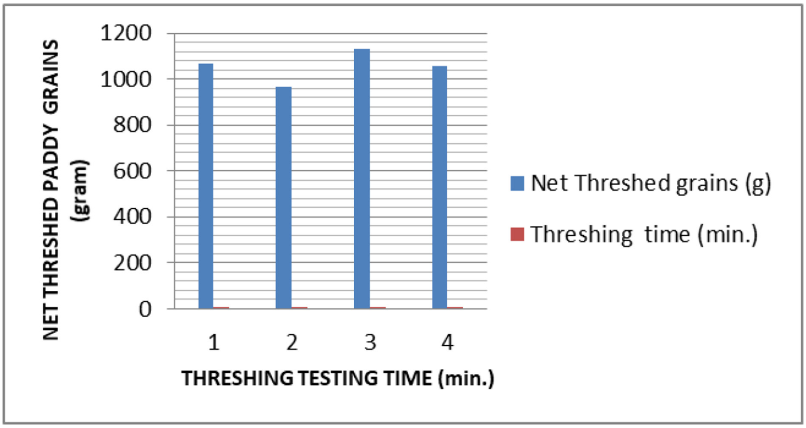

Fig. 6. Net threshed grains versus time during rice thresher testing.

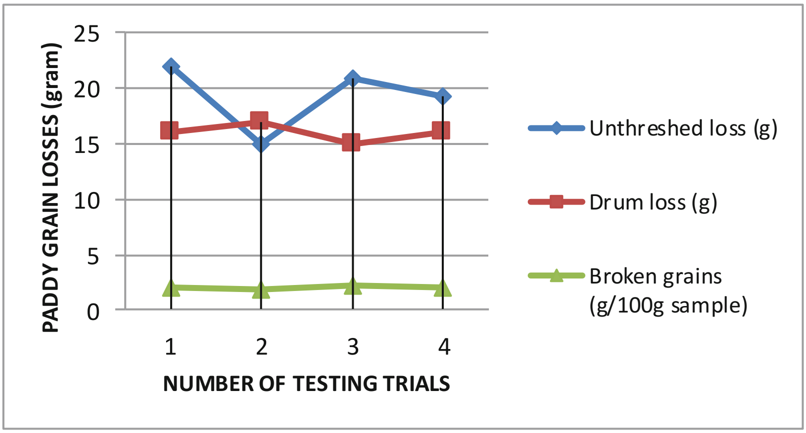

Fig. 7. Rice grain losses versus time during rice thresher testing.

During sample testing, the minimum, and maximum threshing capacity is presented on the second and third trials as shown in Fig. 7. The average net threshed grains in three trials were approximately 1.055 kg per 1:32 min using a 2 kg unthreshed rice sample with the one-person operation. Besides, the major grain losses which were observed in the test are graphically shown below in Fig. 7.

The main grain losses observed during testing of rice threshers are unthreshed grain loss, drum grain loss, and broken grain loss. The maximum unthreshed grain loss is depicted on the test as is shown in Fig. 7. The causes of unthreshed losses may be operators handling skills, and arrangement of wire loop beater. The broken grain losses are low because of the good profiles of wire beater, drum speed, and moisture content. According to the test result, the average actual threshing capacity of the machine is calculated at approximately 128 kg/h using two labor interventions. Hence, there is a possibility to get 1024 kg net paddy grain output at an eight-hour operation of a day. As it was observed, the threshing practice in Fogera Woreda, animal trampling is widely used on large scale in this area. Animal trampling on average takes three human labors, and more than 5 oxen for 10 h to produce 1500 kg output of fairly dried rice for three days operation. The absence of sufficient livestock for trampling forces also resulted in a prolonged threshing period thereby increasing loss due to shattering, pests, and rotting of grains. Therefore the wire loop beater paddy thresher can give an output paddy grain of 3072 kg within three days of operation which is operated at a similar time by the animal trampling method. This indicates that the designed, and developed paddy thresher can double the threshing capacity of the farmers by saving time, saving labor cost, and also avoids impurities that will harm the paddy milling process. In this experimental test, the weight of broken grains per 100-g sample is averagely 2%. Considering the unthreshed loss, drum loss, and broken grains, the performance efficiency of the machine is evaluated to be 96.6%. Therefore, the performance evaluation indicated that the rice thresher will benefit the targeted farmers by reducing unwanted losses, and drudgery activities.

4 Conclusion and Future Work

In time threshing is essential to reduce post-harvest losses, and to spare power sources for carrying out other farm operations. Threshing is time taking, drudgeries operation, so that suitable technology is required to reduce postharvest losses, and to increase the quality of paddy in the Fogera rice farm area. Government and other private sectors should consider spending on appropriate threshers to improve productivity, quality, and facilitate national self-sufficiency in rice production by Fogera marginal farmers. From the above development, and experimental study of rice thresher, the following conclusions are drawn:

- The paddy thresher is designed to be operated by exchanging either an electric motor or petrol engine as per its requirement. It is used to separate the paddy from panicles without feeding the overall stalk of rice. It means that the operator feeds the panicles part to the threshing drum to separate the paddy by hitting with wire loop beater. The machine is designed to reduce scattering loss and to increase the quality of paddy by preventing mud mixing during animal trampling.
- However, the moisture content of the sample is 11.23% and is below the recommended level, the breakage loss is an averagely of 2%. This indicates that the selected wire loop beater for the thresher design gives the advantage to reduce breakage loss.
- The developed paddy thresher can give an output paddy grain of 1024 kg per eight hours operation with three labor engagements. This experimental test and analysis show that the machine can save working time by a minimum of 50% compared to the animal trampling method. It also increases quality by avoiding mixture paddy with mud, and unwanted soil.
- The experimental test on the developed paddy thresher showed that the threshing capacity of the machine is about 128 kg/h using three labor engagements, and considering the unthreshed loss, drum loss, and broken grains. The performance efficiency of the machine is evaluated at approximately 96.6%. Also, the selling price of the paddy thresher is estimated at approximately 31170.50 ETB (954 dollars). This cost can be affordable by associated farmers in Fogera hub for their peer purposes. Generally, the paddy thresher is designed as simple to operate, and affordable for small-hold farmers for better improvement of productivity, and quality of paddy for Fogera hub farmers in Ethiopia.
- This research was focused on the development of affordable rice thresher to reduce drudgery activities for Fogera hub farmers in Ethiopia. In future research works, the rice thresher should include a modified blower to get clean paddy, and also have a sieve or grader of paddy to make the farmers competitive in the global market in this area.

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