Adaption of modified brush cutter for rice harvesting

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Abstract: An existing 1.5 kW brush cutter was modified and evaluated with the view to adapt a low-cost rice harvesting machine. The modifications included replacing existing blade with circular saw blade, incorporating a guider and a driver to lay down the harvested crop in swath and attachment of a harness belt for easy and comfortable operation. The machine was evaluated keeping in view major influencing factors i.e., crop establishment (conventional transplanting, system of rice intensification (SRI), and mechanical transplanting), blade type (B_1: 40 teeth, pitch 1.92 and B_2: 80 teeth, pitch 0.96) and straw moisture content (38%-42%, 33%-37% and 28%-32%, d.b). The results showed that the height of cut was significantly affected (p<0.05) by the crop establishment and blade type however straw moisture content did not have significant effect on height of cut. The height of cut for the machine with blade B_1 ranged from 21.40-31.95 mm for different crop establishment; which was much lower than existing reapers/combines. Fuel consumption increased with decrease in row to row spacing or increase in plant population per m^2 area giving rise to the trend: SRI < mechanical transplanting < conventional transplanting and decreased with decrease in straw moisture content. Cutting efficiency was higher under mechanical transplanting/SRI over conventional transplanting because of symmetrical transplanting of rice. With respect to straw moisture content, cutting efficiency was highest at moisture content of 33%-37%, because of desirable turgidity of the straw. The results showed that the field capacity of the machine ranged from 0.031-0.033 ha h^{-1} under different crop establishment. Resting cycle was found to be 10 minutes for every 30 minutes of work. The benefit-cost ratio, payback period and breakeven point were determined as 1.35, 74.91 h and 0.134 ha, respectively for the portable rice harvester. The developed harvesting machine was able to harvest the rice crop when fitted 40-teeth circular saw blade having carbide tip. A machine of this kind is a positive development in rice harvesting especially for small and marginal land holdings.

Key words: brush cutter, rice harvesting, crop establishment, straw moisture content, blade type, height of cut, fuel consumption, grain loss, cutting efficiency

Citation: Dixit, J., F. A. Hakak, and A. Saxena. 2022. Adaption of modified brush cutter for rice harvesting. Agricultural Engineering International: CIGR Journal, 24(1): 90-101.

1 Introduction

To ensure timeliness of farming operations and increase the income from a piece of land, farm mechanization of agricultural operation is essential, so that job may be done effectively and efficiently to improve productivity. With the introduction of high yielding varieties of paddy and wheat, the agricultural operations become more intensive requiring higher amount of labour. Also, due to increase in cropping intensity and crop production, the demand for labours during some of the agricultural operations has increased remarkably. Apart from this, crop characteristics require crop to be harvested in very short duration.

Rice (*Oryza sativa* L.) a major staple crop of Jammu and Kashmir is grown on an area of 3.05 lakh ha with an annual production of 646.6 MT (Anonymous, 2016). The use of mechanical harvesting device has been increased in the recent years particularly in northern India. The farmers are using reapers or combines to harvest their

Received date: 2020-10-12 **Accepted date:** 2021-05-28

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crops. A number of researchers have developed reapers and harvesting aids for small and marginal land holdings. Alizadeh (2001) compared power tiller and self-propelled reapers and found losses as 3.23% and 3.16%, respectively. Bora and Hansen (2007) developed a small engine powered harvesting aid for farmers cultivating rice over a small area of land. The original cutter blade of a bush cutter was replaced by a 25 cm circular saw blade and a metal plate and a rubber guard assembly was fitted behind the blade on the handle to guide the stalk and to segregate on one side. Handaka and Pitoyo (2011) modified grass cutter into rice harvester by replacing the cutter blade with a rotary blade, changing the dynamic balance of the harvest machine into a mower type, adding a guider, a propeller and adding an operator belt. Performance tests on 100 m^2 showed that the modified machine had a working capacity of 0.038 to 0.051 ha h^{-1}, fuel consumption of 15.0 l ha^{-1}, work efficiency of 95%, labour requirement of 19 to 26.30 h ha^{-1} at two different locations, respectively. Baneh et al. (2012) designed a cutting head for a portable brush cutter for harvesting rice. The cutting head consisted of a circular saw blade with 24 cm diameter and 2 mm thickness having 136 teeth with 0° rake angle, 30° clearance angle and 6 mm pitch. Results indicated that compared to local rice varieties maximum power consumption of about 1.132 kW was obtained. Results also showed that rice losses of the portable reaper were lower than manual harvesting and field capacity of machine was 4.20 times greater than manual harvesting. Chavan et al. (2015) modified and developed a manually operated reaper and found high labour saving equipment requiring only 20 man-h ha^{-1} and reduced cost of harvesting (17.14 \$ ha^{-1}) over traditional method (27.42 \$ ha^{-1}). Sarkar et al. (2016) while evaluating the performance of a hand held Crop Cutter observed 2.44 times higher field capacity in comparison to manual harvesting. Falana et al. (2020) determined the efficiency of a modified brush cutter for kenaf harvesting and found suitable for harvesting whole kenaf stalk when fitted with the 3-tooth and 40-tooth brush cutter blades.

In Jammu and Kashmir, harvesting of rice is carried out manually using sickles which is considered a labour intensive and tedious operation. The labour cost involved in manual harvesting with sickle ranges from 329 to 356 $ per hectare in addition to meals provided to labourers three times a day (Din et al., 2018). Another shortcoming that crops up is the shortage of available labourers at the zenith of the harvesting season. The farmers are using reapers or combines to harvest their crops particularly in northern India. But, these means especially combine, are costly making it non-affordable to most of the small farmers. The marginalized and mediocre class of farmers cannot afford use of such machines due to their high costs as the economic condition of the farmers is derogatory (Dixit et al., 2014a). It is also notable that in J&K, farmers are marginal with 0.66 ha average land holdings, undulating topography, terraced farming and irregular field shapes (Dixit et al., 2014b). Particularly in Kashmir division of Jammu and Kashmir, rice straw is used as a cattle feed. The commercially available mechanical rice harvesters usually harvest the crop to a height of 30-40 cm or even more resulting in wastage of straw due to which farmers with small and marginal land holdings are reluctant in adopting mechanical harvesting. Also reapers and combines are not techno-economically viable for harvesting of paddy in the region due to undulating topography, terraced farming and irregular field shapes. These factors have made mechanization difficult with the available farm machines in commercial arena. Thus, a need was felt for a smaller and efficient harvesting machine, which would be more accessible and also considerably cheaper and light in weight.

The purpose of the modification of a powered brush cutter into a portable rice harvesting machine was to find innovative solutions for simple rice harvesting machinery that serves to small and marginal land holdings.

2 Materials and methods

A commercially available powered brush cutter having specifications given in Table 1; was modified into portable rice harvester.

2.1 Modification of the different components

To modify the brush cutter into portable rice harvester, the components viz. guider, driver and a harness belt were developed (Figure 1). The guider and driver were developed (Figure 2) based on the height of crop (60-80 cm) and mass of cutting material in one stroke (300-500 g) and assembled to transform the brush cutter into portable rice harvester (Figure 3). The specification of modified brush cutter is given in Table 2.

2.2 Guider

The guider was made up of galvanized iron sheet. It consisted of base and driver supporters. The main aim of guider is to provide support to driver and guide the operator while cutting the hills of paddy. The guider has been designed in such a way that it takes the hill into its ambit leaving some clearance area on each side and without deforming.

2.3 Driver

It consisted of crop collector and collector supports. The collector was made up of mild steel, while as, the supporters are made up of galvanized iron. The driver was designed in accordance with plant height (average height of rice straw taken as 400 mm) to provide support and is concave in shape so as to collect the cut hills. It supports sweeps and lays the harvested crop in swath.

Table 1 Powered brush cutter specifications

SI. No.	Parameter		Specification
1	Mass		8.4 kg
2	Volume of fuel tank		0.65 L
3	Power		1.27 kW
4	Fuel		Petrol mixed with 2T
5	Specific fuel consumption		573 g (kW h)$^{-1}$
6	Engine Speed		6500 rpm
7	Right Handle Vibration	Idling	0.8 m s^{-2}
		Racing	1.6 m s^{-2}
8	Left Handle Vibration	Idling	2.3 m s^{-2}
		Racing	1.3 m s^{-2}

2.4 Design of harness belt

Based on preliminary investigations existing belt was found ergonomically un-suitable for long use as it caused pain in shoulder, back and abrasion in thigh. The existing belt was replaced with a new one which was ergonomically more efficient. The harness belt is made of polyester webbing with cross section (width × thickness) as 45 mm× 10 mm. The new harness belt consisted of two straps which distribute the weight of the machine equally on the shoulders and back of the operator. The straps could be adjusted according to height and comfort level of the operator. A thigh pad was also put in place in order to protect the thigh of the operator while swinging the harvester during operation. The harness belt was fixed in such a way that it maintains the dynamic balance of the machine.

2.5 Selection of blades

Different types of cutter blades (star blade, eddy blade, and brush blade) used in powered brush cutter and available locally were studied thoroughly. Based on initial investigation, two different circular saw blades mainly used for pruning of trees and locally available were selected. These blades were selected on the basis of their ability to cut the paddy crops easily and smoothly. In the 1st, the cutting head consisted of a circular saw blade with 255 mm diameter and 2 mm thickness having 40 teeth with 0° rake angle and 1.92 mm pitch. Blade was made up of high carbon steel with carbide tip. The carbide tip provides additional strength to edge of blade during cutting and is not worn-out easily. In the 2nd, the cutting head consisted of a circular saw blade with 255 mm diameter and 2 mm thickness having 80 teeth with 0° rake angle and 0.96 mm pitch. The blade did not possess carbide tip but its teeth could be sharpened and could be used again once it wears out.

2.6 Dynamic balance of modified brush cutter

In order to maintain the balance of machine, the length of sleeve and weight of machine was taken into consideration (Figure 4). The main consideration in designing length of sleeve or rod was safety and comfort of the operator when swinging the harvester in a half circle movement.

Mass of blade = 400 grams

Mass of driver= 540 grams

Mass of guider = 460 grams

Mass of engine = 6 kg

Mass of rod between gear case and handle = 1.65 kg

Mass of rod between engine and handle = 0.35 kg

W_1= Engine mass including weight of rod between engine and handle (6.35 kg)

L_2= Length of rod between gear case and handle (1000 mm)

L_1= Length of rod between engine and handle (500 mm)

W_2= Maximum mass of attachments that can be added on gear case

W_2=?

$W_1L_1=W_2L_2$

$6.35\times500 = W_2\times1000$

W_2= 3.18 kg

Therefore max mass of attachments that can be added on gear case was 3.18 kg.

W= mass of blade + mass of driver + mass of guider + mass of rod between case and handle

W = (400 + 540 + 460 + 1650) grams = 3050 grams = 3.05 kg

As the mass of attachments which were added was less than the mass that could be added on the gear case; therefore, the design of the modified brush cutter was safe.

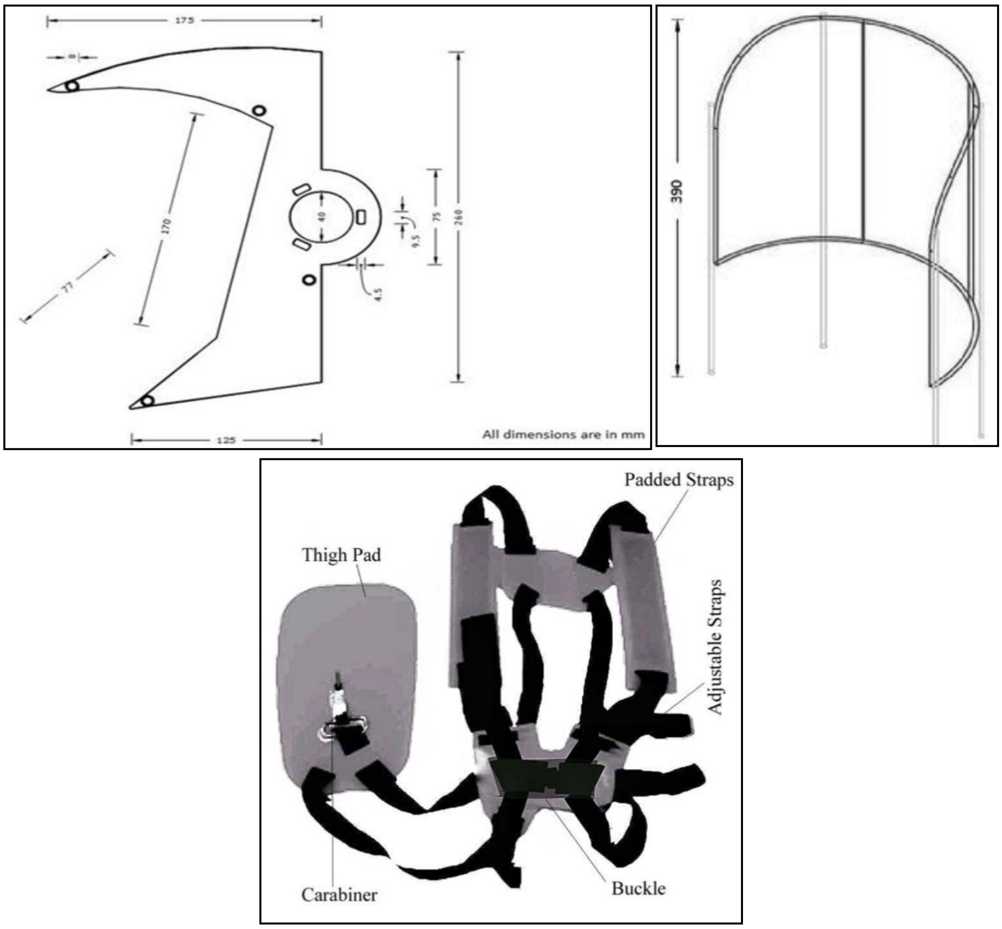

Figure 1 Conceptual view of guider, driver and harness belt

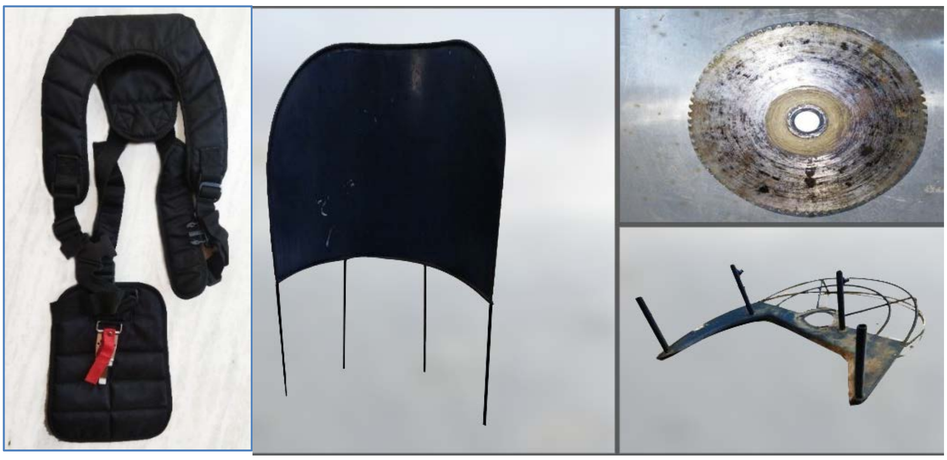

Figure 2 Different modified attachments for brush cutter

Table 2 Specifications of modified brush cutter

SI. No.	Feature	Specification
1	Weight	9.40 kg
2.	Fuel tank capacity	1100 mL
3.	Engine Type and Power	Air cooled, 2-stroke petrol engine 1.27 kW
4.	Fuel	Petrol mixed with 2 T oil
5.	Engine speed	6500 rpm
6.	Maximum speed	9000 rpm
7.	Effective field capacity	0.031-0.033 ha h^{-1}
8.	Height of cut	21.40-31.95 mm
9.	Grain loss	< 2%
10.	Cutting efficiency	98%-99%
11.	Fuel consumption	9.71 l ha^{-1}
12	B.C. ratio	1.35
13.	Cost of operation	3.19 \$ h^{-1}
14.	Pay back period	74.91 h
15.	Total cost of machine	438.66 $

Figure 3 Modified brush cutter as rice harvester

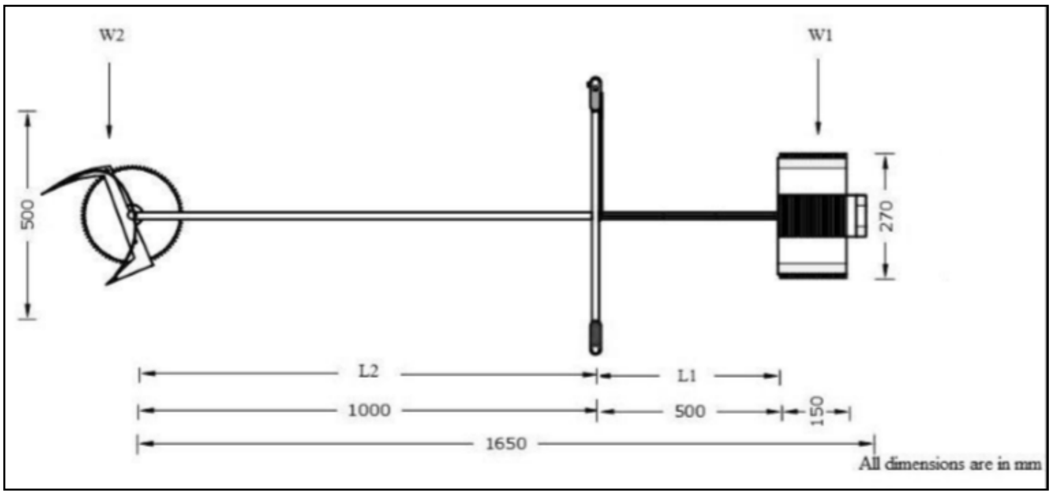

Figure 4 Sketch depicting dynamic balance of portable rice harvester

2.7 Evaluation of modified brush cutter for rice harvesting

The modified brush cutter was evaluated in experimental fields of SKUAST-K, Shalimar campus during 2017-2018 (Figure 5).

2.8 Experimental design

The range of operating factors affecting losses and performance of modified brush cutter for rice harvesting were the Crop Establishment (E), Type of blades (B) and Straw moisture content (M). Experimental trials were conducted with three replications. For every replication, 100 m^2 area was used. The crop was harvested within an interval of 10 days to maintain the desired straw moisture content of 38%-42%, 33%-37% and 28%-32% (db). The grain moisture content was 20% to 27% (db) at the time of harvest. A factorial experimental design (Table 3) was used for the study.

Table 3 Treatment combination of the experiment

SI. No.	Variables	Levels		
1	Crop Establishment	Conventional Transplanting (E1)	System of Rice Intensification (E2)	Mechanical Transplanting (E3)
2	Type of Blade	B_1 (No of teeth : 40, Circular pitch:1.92)	B_2 (No of teeth: 80, Circular pitch: 0.96)	-
3	Straw moisture content (db)	M_1 (38%-42%)	M_2 (33%-37%)	M_3 (28%-32%)

Figure 5 An overview of modified brush cutter for rice harvesting

2.9 Determination of dependent parameters

The modified machine was evaluated with respect to four different parameters as fuel consumption, actual field capacity, cutting efficiency, grain loss and height of cut. At the end of experiment, actual field capacity and cutting efficiency were accepted as positive results. On the other hand, fuel consumption, grain loss and height of cut as negative results. These results were determined (Hunt, 1995) using following formulae

2.10 Fuel consumption

Fuel consumption, in litres per hour is the amount of refuelling for the test. In this method, before the start of each test trial, the fuel tank was filled to its capacity and after each test trial, the tank was refilled using graduated cylinder (Oyelade and Oni, 2011)

$$F=\frac{Q}{T} \quad (1)$$

Where, F= Fuel consumption, Lh^{-1}; Q = Quantity of fuel consumed, L,

T = Consumption time, h.

2.11 Effective field capacity

The effective field capacity (FC_a) is the actual rate of coverage by the machine, based upon the total field time. The machine was operated with almost fixed speed for continuous field work for a fixed time and the area covered during the period was measured to determine the average output per hour (Oyelade and Oni, 2011)

$$FC_a=\frac{A}{To} \quad (2)$$

Where, A=Area Covered, ha; T_O=Total Operating time, h; FC_a= Effective field capacity, ha h^{-1}

2.12 Cutting efficiency

Cutting efficiency (C_e) was calculated based on the number of rice plants in 1 m^2 area before and after operation.

$$C_e=\frac{W1-W2}{W1}\times 100 \quad (3)$$

Where, W_1 = No. of plants before operation per m^2 area; W_2 = No. of plants after operation per m^2 area; C_e= Cutting efficiency, %

2.13 Grain loss

It is attributed to the loss of grains due to ear heads left on the ground as a result of the harvesting operation. The losses were determined based on samples drawn from each treatment and the data was converted from g m^{-2} to kg ha^{-1}. The results were then expressed in the form of percentage of grain loss (P_g).

$$P_g=\frac{Gy-Wg}{Gy}\times 100 \quad (4)$$

Where, G_y = mass of grain yield, kg; Wg = mass of output grain, kg; P_g =Grain loss, %

2.14 Height of cut

To determine the stubble height, height of cut from the ground of 05 randomly selected hills from each treatment were measured with the help of a measuring tape.

2.15 Ergonomic evaluation

2.15.1 Heart rate

Heart rate (beats min^{-1}) was recorded with the help of polar heart rate wrist watch before work at rest and during the work. For this purpose, polar FT series of heart rate monitor was used. Before measuring the heart rate of the workers, the operators were warmed up for 15 min followed by a rest of 30 min. After that the heart rate monitor was fixed on the worker. Data during working was taken for 30 min period (Singh, 2012).

2.15.2 Energy expenditure rate

The equation used for calculation of energy expenditure rate (kJ min^{-1}) from heart rate equation (Varghese et al., 1994) as follows:

$$EER\ (kJ\ min^{-1}) = 20 + 0.52 \times (Working\ heart\ rate - 100) \quad (5)$$

Where *EER*= Energy expenditure rate, kJ min^{-1}

2.15.3 Resting cycle

It is the amount of rest required by the operator (Varghese et al., 1994) after working for a specific period of time and was calculated with the help of following equation:

$$R = \frac{T(k-s)}{k-6.3} \quad (6)$$

Where, *R*= Rest required in minutes; *T*= Total working time in minutes; *k*= Average kJ per minute of work; *s*= 21 kJ per minute (standard)

2.16 Data analysis

The randomized block design was followed in the study. The data collected was subjected to statistical analysis using statistical standard procedures. The critical difference at 5% level of significance was calculated for testing the significance of difference between parameters. The analysis of experimental data was done with the help of SAS (SAS Inc. USA) licensed to Division of Agricultural Statistics SKUAST-K.

3 Results and discussion

3.1 Effect of crop establishment, blade type and straw moisture content

3.1.1 Fuel consumption

The results of ANOVA of the operating parameters viz. crop establishment (E), blade type (B) and straw moisture content (M) of affecting fuel consumption as shown in Table 4 indicated that all the operating parameters had significant impact on fuel consumption. The interaction effect of E*B*M was also found statistically significant on fuel consumption. The minimum mean fuel consumption was 8.92 l ha^{-1} under SRI (E_2), blade B_1 and 28%-32% (M_3) straw moisture content (w.b.) while as the maximum mean fuel consumption was 51.14 l ha^{-1} under conventional transplanting (E_1), blade B_2 and 38%-42% straw moisture content (M_1). The high fuel consumption in conventional transplanting method was mainly due to non uniform paddy hills which involved high harvesting time as compared to other practices. The fuel consumption increased with decrease in row to row spacing or increase in plant population per m^2 area giving rise to the following trend: SRI < mechanical transplanting < conventional transplanting. The plant population per m^2 area in different crop establishment was 480, 600 and 450 for E_2, E_3, E_1, respectively. Fuel consumption was directly proportional to straw moisture content i.e. fuel consumption decreased with decrease straw moisture content. As moisture content decreases, force required to cut the plant also decreases resulting in decrease in fuel consumption. Fuel consumption was lesser in blade B_1 than B_2 due to presence of carbide tip in blade B_1that helped the blade to cut the crop smoothly. Shreen et al. (2014) also reported that fuel consumption decreased with decrease in moisture content of grain. Aung et al. (2014) reported fuel consumption of 7.87 l ha^{-1} in case of powered reaper.

Table 4 Effect of blade type, straw moisture content and crop establishment on fuel consumption (l ha^{-1})

Blade Type➔	B1 : Type I Blade				B2 : Type II Blade				Mean (E)	Factor Mean
Moisture content / Crop Estb.	M_1 38-42%	M_2 33-37%	M_3 28-33%	Sub Mean	M_1 38-42%	M_2 33-37%	M_3 28-33%	Sub Mean	Overall Mean	
E1: Conventional Transplanting	33.49	22.76	23.33	26.52	51.14	32.43	30.76	38.11	32.32	M_1= 26.60
E2: SRI	9.76	11.50	8.92	10.06	11.11	13.66	17.33	14.03	12.05	M_2= 22.40
E3:Mechanical Transplanting	24.58	25.13	20.47	23.39	29.52	28.92	31.88	30.01	26.75	M_3= 22.11
Mean	22.61	19.79	17.57	19.99	30.59	25.00	26.65	27.41		

Note: C.D ($p \leq 0.05$)
Crop Establishment (E): 2.47 Type of Blade (B): 2.01 Moisture Content (M): 2.46 E*B : 3.5 E*M: 4.27 B*M: NS E*B*M: 6.044

3.1.2 Effective field capacity

There was a significant combined effect of crop establishment, blade type and moisture content of straw on effective field capacity of the modified brush cutter for rice harvesting (Table 5). The minimum mean field capacity was 0.012 ha h^{-1} under conventional transplanting (E_1), blade B_2 and 38%-42% moisture content (M_1) while the maximum field capacity was 0.055 ha h^{-1} under SRI (E_2), blade B_2, and 38%-42% moisture content (M_1). The individual effect of blade and straw moisture content was found non-significant on effective field capacity. The effective field capacity was highest in SRI followed by mechanical transplanting and conventional transplanting. This trend could be attributed to the plant population which was least in conventional transplanting (450 m^{-2}) followed by SRI (480 m^{-2}) and mechanical transplanting (600 m^{-2}). Handaka and Pitoyo (2011) estimated actual field capacity of a power reaper as 0.038 ha.h^{-1}. Aung et al. (2014) reported actual field capacity of power reaper as 0.24 ha h^{-1}. The actual field capacity of portable rice harvester was in close proximity with the findings of Handaka and Pitoyo (2011) and Aung et al. (2014).

Table 5 Effect of blade type, straw moisture content and crop establishment on effective field capacity (ha h^{-1})

Blade Type➔	B_1 : Type I Blade				B_2 : Type II Blade				Mean (E)	Factor Mean
Moisture content / Crop Estb.	M_1 38-42%	M_2 33-37%	M_3 28-33%	Sub Mean	M_1 38-42%	M_2 33-37%	M_3 28-33%	Sub Mean	Overall Mean	
E_1: Conventional Transplanting	0.014	0.020	0.019	0.018	0.012	0.019	0.021	0.017	0.018	M_1= 0.032
E_2: SRI	0.047	0.040	0.052	0.046	0.055	0.047	0.037	0.046	0.046	M_2= 0.031
E_3:Mechanical Transplanting	0.028	0.028	0.033	0.029	0.032	0.032	0.029	0.031	0.032	M_3= 0.033
Mean	0.030	0.029	0.035	0.031	0.033	0.033	0.029	0.031		

Note: C.D ($p\leq 0.05$). Crop Establishment (E): 0.003. Type of Blade (B): NS. Moisture Content (M): NS. E*B: NS. E*M: 0.004 . B*M: 0.004. E*B*M: 0.006.

3.1.3 Cutting efficiency

The results of ANOVA of the operating parameters affecting cutting efficiency (Table 6) indicated that all operating parameters viz. crop establishment (E), blade type (B) and straw moisture content (M) had significant impact on cutting efficiency. The interaction effect of B*M and E*B was not significant on cutting efficiency similarly interaction effect of E*B*M was also non-significant. The maximum cutting efficiency was under mechanical transplanting (99.64%) followed by SRI (99.54%) and Conventional transplanting (98.34%). This trend could be due to symmetrical transplanting of rice in case of mechanical transplanting with rice transplanter. Cutting efficiency was higher (99.41%) with blade B_1 as compared to blade B_2 (98.44%) mainly because of presence of carbide tip which provides additional strength to blade and hence cuts the plant smoothly. With respect to straw moisture content, cutting efficiency was highest at moisture content of 33%-37% (M_2); because of desirable turgidity of the straw cells at this moisture content. At 28%-32% straw moisture content, the cells of the straw were not enough turgid to be cut smoothly while at 38%-42% moisture content, turgidity of the cells of the straw increased to an extent that it offers resistance to smooth cutting. Similar trends were observed by Aung et al. (2014) who found cutting efficiency of 98% while evaluating the performance of the powered reaper for harvesting paddy. Shreen et al. (2014) reported that the cutting efficiency tended to increase with the increase in moisture content of grain. These findings were in close agreement with the results of portable rice harvester.

Table 6 Effect of blade type, straw moisture content and crop establishment on cutting efficiency (%)

Blade Type➔	B_1 : Type I Blade				B_2 : Type II Blade				Mean (E)	Factor Mean
Moisture content / Crop Estb.	M_1 38%-42%	M_2 33%-37%	M_3 28%-33%	Sub Mean	M_1 38%-42%	M_2 33%-37%	M_3 28%-33%	Sub Mean	Overall Mean	
E_1: Conventional Transplanting	96.91	99.37	99.02	98.43	96.91	99.02	98.84	98.25	98.34	M_1= 98.68
E_2: SRI	99.93	99.65	99.93	99.83	99.02	99.37	99.37	99.25	99.54	M_2= 99.46
E_3:Mechanical Transplanting	99.93	100	99.94	99.95	99.38	99.36	99.22	99.32	99.64	M_3= 99.39
Mean	98.92	99.67	99.63	99.41	98.43	99.25	99.14	98.94		

Note: C.D ($p \leq 0.05$). Crop Establishment (E): 0.34. Type of Blade (B): 0.27. Moisture Content (M): 0.34. E*B: NS. E*M: 0.58. B*M: NS. E*B*M: NS.

3.1.4 Grain loss

The results of ANOVA of the operating parameters affecting grain loss (Table 7) indicated that all operating parameters viz. crop establishment (E), blade type (B) and straw moisture content (M) had significant impact on grain loss. The interaction effect of E*B, B*M and E*B*M was found non-significant. Percentage of grain loss was significantly lesser (1.21%) with blade B_1 as compared to blade B_2 (1.40%) which could be due to carbide tip on blade B_1 that provides additional strength to the edge of blade for proper and smooth harvesting. With respect to crop establishment, grain loss was lowest in mechanical transplanting (1.15%), followed by SRI (1.19%) and conventional transplanting (1.59%) which could be due to symmetric crop standing in mechanical transplanting of rice. The grain loss was found lowest at straw moisture content of M_2 (1.22%) because of smoothly crop cutting at this moisture content followed by M_3 (1.25%) and M_1(1.45%). The observed results related to the work of Garg et al. (1984) where they reported about 1.0% grain loss while harvesting with vertical conveyer reaper. Similar results were obtained by Aung et al. (2014) where 0.4% grain loss was estimated using the powered reaper. Shreen et al. (2014) reported that percentage of grain loss tends to increase with the increase in moisture content of grain due to increase in cutting losses.

Table 7 Effect of blade type, straw moisture content and crop establishment on grain loss (%)

Blade Type➔	B1 : Type I Blade				B2 : Type II Blade				Mean (E)	Factor Mean
Moisture content / Crop Estb.	M_1 38%-42%	M_2 33%-37%	M_3 28%-33%	Sub Mean	M_1 38%-42%	M_2 33%-37%	M_3 28%-33%	Sub Mean	Overall Mean	
E_1: Conventional Transplanting	3.086 (1.996)	0.622 (1.270)	0.978 (1.400)	1.562 (1.555)	3.080 (2.010)	0.977 (1.390)	1.150 (1.450)	1.736 (1.617)	1.65 (1.59)	M_1= 1.31 (1.45)
E_2: SRI	0.069 (1.033)	0.347 (1.150)	0.069 (1.033)	0.162 (1.072)	0.972 (1.395)	0.625 (1.263)	0.625 (1.270)	0.741 (1.309)	0.45 (1.19)	M_2=0.534 (1.22)
E_3:Mechanical Transplanting	0.0616 (1.02)	0.0 (1.000)	0.0513 (1.020)	0.038 (1.013)	0.617 (1.260)	0.634 (1.270)	0.771 (1.320)	0.674 (1.283)	0.356 (1.15)	M_3=0.608 (1.25)
Mean	1.0722 (1.349)	0.323 (1.140)	0.366 (1.151)	0.580 (1.213)	1.556 (1.555)	0.745 (1.307)	0.848 (1.346)	1.050 (1.403)		

Note: C.D ($p \leq 0.05$) *Values under parenthesis are Square root transformation value

Crop Establishment (E): 0.34 (0.105). Type of Blade (B): 0.28 (0.086). Moisture Content (M): 0.34 (0.105). E*B: NS. E*M: 0.59 (0.182). B*M: NS. E*B*M: NS.

3.1.5 Height of cut

The results of ANOVA of the operating parameters viz. crop establishment (E), blade type (B) and straw moisture content (M) of affecting height of cut as shown in Table 8 indicated that the operating parameters crop establishment and blade type had significant impact on height of cut however straw moisture content had no significant effect on height of cut. The interaction effect of E*B was also found statistically significant on height of cut, whereas E*M and B*M did not have a significant impact on height of cut. Height of cut was minimum in mechanical transplanting (29.18 mm) followed by SRI (35.00 mm) and conventional transplanting (37.78 mm). Because of symmetrical transplanting of crop in mechanical transplanting, minimum height of cut could be achieved with modified brush cutter. Height of cut was significantly lesser with blade B_1 (26.02 mm) as compared to blade B_2 (41.92 mm) which might be due to presence of carbide tip on blade B_1 that helped in smooth harvesting. Murthy (1989) reported 70-80 mm height of cut in case of a tractor mounted vertical conveyer reaper. Pradhan et al. (1998) while working on various paddy harvesting methods i.e. sickle, power tiller operated vertical conveyer reaper and tractor operated vertical conveyer reaper; reported average height of cut as 50, 100 and 150 mm, respectively.

Table 8 Effect of blade type, straw moisture content and crop establishment on height of cut (mm)

Blade Type➔	B_1 : Type I Blade				B_2 : Type II Blade				Mean (E)	Factor Mean
Moisture content / Crop Estb.	M_1 38%-42%	M_2 33%-37%	M_3 28%-33%	Sub Mean	M_1 38%-42%	M_2 33%-37%	M_3 28%-33%	Sub Mean	Overall Mean	
E_1: Conventional Transplanting	35.83	30.83	29.17	31.95	42.50	45.83	42.50	43.60	37.78	M_1= 33.90
E_2: SRI	19.17	20.83	24.17	21.40	46.67	48.33	50.82	48.60	35.00	M_2= 33.05
E_3:Mechanical Transplanting	25.83	22.5	25.83	24.73	33.32	30.00	37.50	33.60	29.18	M_3= 35.00
Mean	26.94	24.72	26.39	26.02	40.83	41.38	43.60	41.92		

Note: C.D ($p \leq 0.05$). Crop Establishment (E): 3.05. Type of Blade (B): 2.06. Moisture Content (M): NS. E*B: 4.50. E*M: NS. B*M: NS. E*B*M: NS.

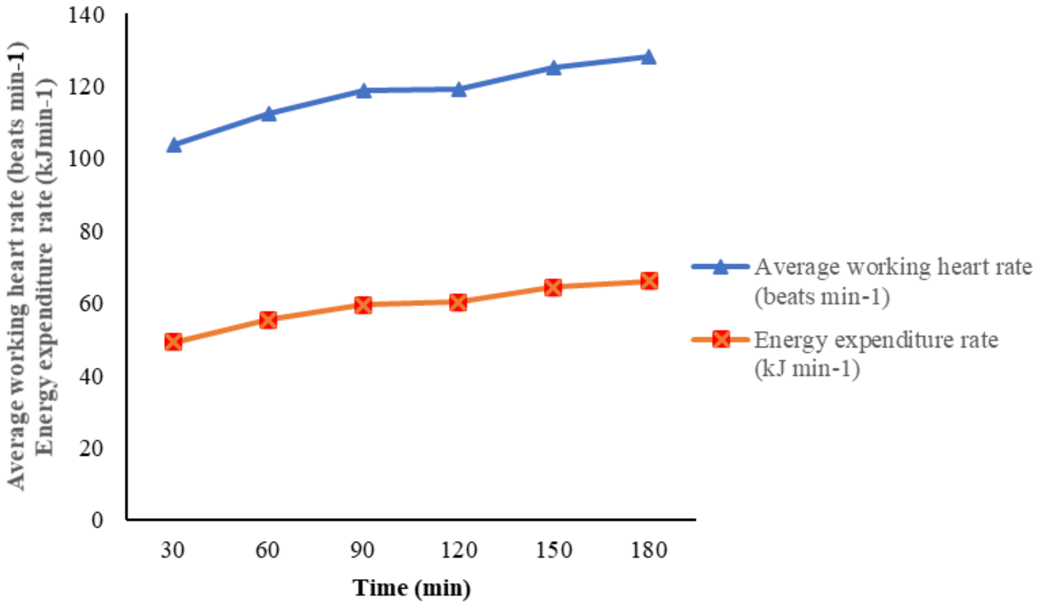

Figure 6 Average heart rate and energy expenditure rate during operation of developed harvester

3.2 Ergonomic evaluation and economic analysis

The analysis of various ergonomic parameters i.e. energy expenditure rate, resting cycle, working heart rate evaluated on three different subjects revealed that the portable rice harvester was ergonomically feasible to operate (Figure 6). The maximum working heart rate of three subjects were 131, 126 and 128 beats per minute while as the minimum working heart rate were found to be 105, 102 and 105 beats per minute, respectively. The maximum energy expenditure rate of three subjects was

36.12, 33.52 and 34.56 kJ min^{-1}, respectively. The resting cycle was 10 minutes for every 30 minutes of work. The benefit cost ratio was 1.35 which revealed that machine is beneficial and economical. The payback period of developed rice harvester was 74.91 h and break-even point of 0.134 was obtained indicating that it can be used by farmers with smaller and marginal land holdings (Table 2).

4 Conclusion

The modified brush cutter was found suitable for rice harvesting when fitted with blade B_1 (cutting head fitted with a circular saw blade of diameter 255 mm, thickness 2 mm, 40 teeth with 0° rake angle and 1.92 mm pitch). The machine worked well under crop establishment as mechanical transplanting/SRI at straw moisture content of 33%-37% (w.b.). The average stubble height of rice stem left on the field after harvesting was 21.40-31.95 mm while commercially available reaper/combines can only achieve a minimum height of about 50-60 mm. The straw moisture content significantly affected the fuel consumption, cutting efficiency and grain loss. Fuel consumption increased with decrease in row to row spacing or increase in plant population per m^2 area giving rise to the trend: SRI < mechanical transplanting < conventional transplanting and decreased with decrease in straw moisture content. The resting cycle for the machine was found to be 10 minutes for every 30 minutes of work. The developed harvester was found techno-economically feasible for rice harvesting with time saving of 128.75 h ha^{-1} and a net saving of 11394 Rs ha^{-1} over manual harvesting with sickle. It can be used on undulating and plain terrain. Little knowledge is required to operate the machine hence, it can be easily adapted by local rice growing farmers as this will eliminate the drudgery involved in manual rice harvesting.

Acknowledgements

The authors are grateful to Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India for master’s research support.

References

Alizadeh, M. R. 2001. Investigation and comparison of losses in different harvesting method of paddy. Technical Report. Rasht, Iran: Rice Research Institute.

Anonymous.2016. Government of Jammu & Kashmir, Directorate of Economics and Statistics, Department of Planning, Development and Monitoring. *Digest of Statistics* 2015-16, pp. 166.

Aung, N. N., P. P. Myo, and H. Z. Moe. 2014. Field performance evaluation of a power reaper for rice harvesting. *International Journal of Scientific Engineering and Technical Research*, 12(3): 2631-2636.

Baneh, N. M, H. Navid, M. R. Alizadeh, and H. R. Ghasem Zadeh. 2012. Design and development of a cutting head for portable reaper used in rice harvesting operations. *Journal of Appied Biological Science*, 6(3): 69-75.

Bora, G. C., and G. K. Hansen. 2007. Low cost mechanical aid for rice harvesting. *Journal of Applied Science*, 7(23): 3815-3818.

Chavan, P. B., D. K. Patil, and D. S. Dhondge. 2015. Design and development of manually operated reaper. *Journal of Mechanical and Civil Engineering*, 12(1): 15-22.

Din, T. M. U., L. A. Mir, and T. A. Bhat. 2018. Cost benefit analyses of rabi and Kharif crops in Kashmir Valley: A case study of district Anantnag. *Growth*, 5(1): 1-5.

Dixit, J., D. Namgial, S. Sharma, S. K. Lohan, and D. Kumar. 2014a. Anthropometric survey of farm workers of Ladakh region of India and its application in equipment design. *CIGR Journal*, 16(2): 80-88.

Dixit, J., S. Sharma, and M. Ali. 2014b. Present status potential and future needs for mechanization of agricultural operations in Jammu and Kashmir state of India. *CIGR Journal*, 16(3): 87-96.

Falana, O. B., O. B. Aluko, D. A. Adetan, and J. A. Osunbitan. 2020. Determining the efficiency of a modified brush cutter for kenaf (*Hibiscus cannabinus*) harvesting. *CIGR Journal*, 22(2): 59-67.

Garg, I. K., V. K. Sharma, and S. Singh. 1984. A power tiller-operated vertical conveyer reaper-windrower. *Agricultual Mechanization in Asia, Africa and Latin America*, 15(3): 40-44.

Handaka and J. Pitoyo. 2011. Modification of a grass cutter into small rice harvester. *Indonesian Journal of Agriculture*, 4(1): 40-45.

Hunt, D. 1995. *Farm Power and Machinery Management*. 9 th ed. Ames, IA, USA: Iowa State University Press.

Murthy, C. N. N. 1989. Tractor-mounted reaper for efficient wheat harvesting. *Farmers Journal*, 9(9): 32-33.

Oyelade, O. A., and K. C. Oni. 2011. Farm tractor testing and evaluation for Nigeria's economic transformation: A case study of TAK tractors. In *Proceedings of 11th International Conference of Nigerian Institution of Agricultural Engineers*, 123-132. Ilorin, 17-20 October.

Pradhan, S. C., R. Biswajit, D. K. Das, and M. Mahapatra. 1998. Evaluation of various paddy harvesting methods in Orissa, India. *Agricultual Mechanization in Asia, Africa and Latin America*, 29(2): 35-38.

Sarkar, B., U. Kumar, N. Chandra, J. S. Mishra, and B. P. Bhatt. 2016. Performance evaluation of hand held crop cutter used in wheat and rice harvesting. *International Journal of Agriculture Sciences*, 8(20): 1364-1365

Shreen, F. A. M., M. E. Badawy, and M. H. M. Abo El-Naga. 2014. Comparison between the most common mechanical methods and rice combine modified for harvesting wheat crop in the Egyptian fields. *Egypt Journal of Agricultural Research*, 92(2): 675-692.

Singh, S. P. 2012. Physiological workload of farm women while evaluating sickles for paddy harvesting. *CIGR Journal*, 14(1): 82-88.

Varghese, M. A., P. N. Saha, and N. Atreya. 1994. A rapid appraisal of occupational workload from a modified scale of perceived exertion. *Ergonomics*, 37(3): 485-491.