Performance Evaluation of Chinese Mini Combine Rice Mill cum Grind Machine

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Abstract- Rice is the most important food grain crop in Nepal along with maize and wheat. Post harvest handling is one of the important processes after harvesting rice. Milling and grinding are main post harvest operations for using rice as food. Traditional milling and grinding practices such as water mill (*PaaniGhatta*), and mortar and pestle(*Jhantos, Okhal and Dhikis*) are very slow, tedious, drudgerious, labour- intensive and time-consuming and low output practices. Therefore, there is a need of a low cost rice milling machine having multiple function (milling and grinding).Hence, a study was conducted to evaluate the performance of Chinese mini combine rice mill cum flour grind machine powered by a 3HP electric motor. Combine mill performance was evaluated in terms of percentage of broken rice, milling efficiency, head rice recovery, machine efficiency, machine capacity, unmilled grain, milling losses, grinding efficiency and grinding rate at moisture content of 13.5 %. Based on this study, result showed that the combine mill has a milling capacity of 87kg/hr rough rice or paddy at 13.4% moisture content. Similarly, it has a grain grinding capacity of 119.87 kg/hr. The milling efficiency or recovery of 69.63% was obtained for Khumal-4 paddy variety.The head rice recovery based on total milled rice, unmilled grain percentages, broken grain and grain in husk from the combine mill were 82.47%, 2.29%,15.24%, and 2.11%, respectively. Additionally, a grinding efficiency of 88.82% was achieved from the grinding compartment of combine mill.

Considering economic perspectives, the combine mill becomes profitable only after 393.5 h of annual machine use which is equivalent to 236.14 quintal of rice output at a machine output capacity of 59.67 kg/hr with respect to investment cost of NRs 40,000 andmilling charge at NRs 2 per kg. The benefit cost ratio (B/C ratio) was found out to be 1.18. The internal rate of return (IRR) turned out to be 46.2 percent. The Payback period (PBP) was calculated to be 1.85 years. As B/C ratio is greater than 1, IRR is greater than the rate of interest (15 percent) and PBP is of less duration, the investment in mini combine mill is economicallyviable. Overall, finding of this evaluation study can be used to compare any other rice mill in future. It can be concluded that combine mill has possibility of becoming a one of the suitable milling and grinding technology for hilly and mountainous areas of Nepal.

Keywords: *Combine mill, economical aspects, grinding compartment, milling compartment, post-harvest techniques, performance evaluation, paddy*

1. Introduction

Rice (Nepali name: Dhan; Scientic name: Oryza sativa L.) is the most important food grain crop in Nepal followed by maize and wheat. Rice is grown in wide range of agro ecological zones under varying climates, altitudes and topography ranging from 60 meters in Terai to 3050 meters above sea level in Chumchure, Jumla [1]. It contributes almost 20% in national agriculture gross domestic Product (AGDP). In 2016/17, it occupies total area of approximately 1.55 million ha cultivable land of Nepal with the average productivity of 3.36 t/ha producing 5.23 million tons of paddy rice[2, 3].On average, Nepalese consume about 122 kg milled (or 200 kg paddy) rice per year. Rice contributes about 20% of the agricultural GDP and one-third of the total calorie intake in Nepalese people.Cereals contribute about 90 percent of the total calorie intake, and 50 percent of this comes from rice [4].

Post-harvest handling is one of the important processes after harvesting rice. Milling and grinding arecrucial postharvestaction for using rice as food such as rice grain as cooked rice (*Bhat*), and rice flour as bread (*Roti),*ring shaped spongy doughnut *(sel-roti)*, noodles, snacks, sweets, and beverages. Rice husk is used as feed for animals, for paper making and as a source of fuel. Similarly, rice bran is used in feed for cattle and poultry, defatted bran, which is high in protein, can be used in biscuit preparation and as feed for cattle. Basically, rice grain consists of a husk and a grain of brown rice (consists of bran layer). Rice becomes edible after removal of husk and bran producing white rice kernel. A rice milling system involves single to multi stage process. In a single step process, milled or white rice is produced directly out of paddy by removal of husk and bran in one time. In a two-step process, rice milling involves two basic operations of removing husk to produce brown rice (dehusking) and removing bran layer from brown rice to produced polished /white rice (polishing or whitening)[5].

Since primitive age, most of the rural villages of Nepal were dependent on traditional milling and grinding practices such as water mill (*PaaniGhatta*), mortar and pestle*(Dhikis* and *Okhal*), and *Jhantos* as shown in Figure 1.Generally, wooden *Dhiki* consists of fulcrum having two short poles and long thick plank of wood with a small vertical extension that goes into a hole made on ground.One person press and release the plank at regular interval, while other person near the *Okha l*(hole) keep grain in the hole[6]. Similarly, rice milling is performed by pounding the rough rice in a wooden mortar with pestle (*Okhal*) and then winnowed to remove the chaff from the grain. These practices make local production of rice very low with poor quality and required human muscle power[5, 7].Major disadvantages of traditional practices includes labour intensive, very slow, tedious, drudgerious, time consuming (*Dhikis and Jhantos*), and work interruptions during flood time and low water discharge during dry seasons (water mill). The grinding capacity of a traditional water mill ranges from 10-20 kg per hour while its frequency of repair and maintenance is substantially high. Most of the water mill has function of grinding cereals grains only (maize, millet, wheat, rice, etc.). Improved water mills can be used to dehusk and partially polish paddy (50-70kg/hr) and grind cereals grains also capacity ranging 20-50 kg/hr[8].

Presently, with the advancement of technologies, different types of modern automated rice milling machines such as rice sheller, huller, disk mill, and polisher are being used in the country.Increasing trend of machine milling has gradually replacing the traditional method of rice processing. Most of the bigger mills are established in terai regions and the investment cost is also very high. Bigger capacity mills are not appropriate in hills and mountains due to geographical and economic constraints. Considering this aspect, currently different types of smaller hulling or milling machine powered by electricity or gasoline engine are being used for milling purposes. Most of the machines only shell the rice and further processing such as whitening and grinding need another kind of machines. This demerits results additional increment in machine investment, operational cost and occupies larger space which ultimately affect the milling charge per kg. Focusing this, mini combine rice mill cumgrind machine having function of two in one (milling and grinding) could be one of the affordable postharvest mechanizationoptionin the rural areasof mountainous and hilly regions. Different kind of subsides by government bodies are being started to provide in this kind of machines.Despite these possibilities, no meaningful initiative has been taken on performance evaluation study of the milling machine in Nepalese context. The performance evaluation of the machine is therefore important to know its ability to mill and grind rice or grains along with economic feasibility.

Thus, the objective of this study was to evaluate the performance of Chinese mini combine rice mill cum grindmachine. Evaluation on both milling and grinding operationwas done on the basis ofmilling or grindingefficiency, milling recovery, milling capacity, grinding capacity, head rice yield, machine efficiency, milling losses and product quality of the machine. Furthermore, economic evaluations, constraints and comparative evaluations of machine with other previous studies on traditional practices were also integrated in this study. The finding of the evaluation study will be useful for farmers, small scale mill entrepreneurs, community and consumers.

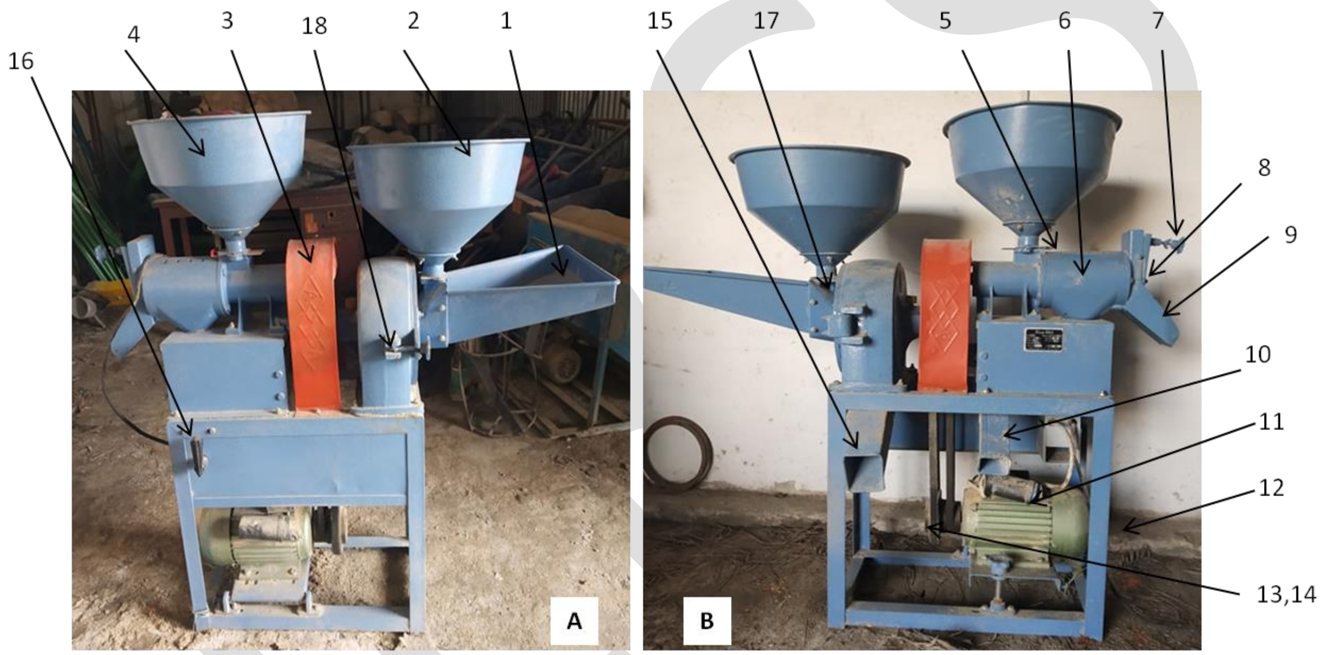
Figure 1: Traditional practices of milling and grinding, A: *Dhiki*[6], B: Water mill and C: Rotary Quern (*Jhantos*)

2. Materials and methods

2.1. Structure, characteristics and major parts of mini combine rice mill cum grind machine

The multi-functional combined mill is composed of two compartment named rice mill compartment (Rice Sheller) and flour grinding compartment (disc mill). Rice Mill consists of onealloy steel rice roller&one stainless steel rice screen, matched with air blower device. It can remove outer skin of rice, remove the sheet, whiteness the rice and separate the whole rice from the broken at once.The machine performs two operations at the same time (husking and whitening).

Similarly a disc mill (grind) compartment hasone rotating disc and fixed casing. It can be used to grind or crush the milled rice into flour.The different parts and basic technical features of machine are shown in Figure 2 and Table 1. Alphabet A representsback part and B represents front part of machine. Major parts includes feed hopper A, feed hopper B, protective cover, rice feed hopper, feed adjuster plate, roller, screw adjust nut, adjustable handle, rice discharge port, discharge port for broken rice and husk, electric motor, frame, rice huller belt, belt for grinder, flour discharge port, on/off knob for milling and grinding option, feed adjustable plate, adjustable handle, blower port. On/off knob is used to transmit motor power in needed compartment. Leftturn of knob transmit power to milling compartment while right turn of knob transmit it to grinding compartment. Vertical position is for disengage of power.



1.Feed hopper A	2. Feed hopper B	3. Protective cover	4. Rice feed hopper	5.Feed adjusting plate
5. Feed adjusting plate	6. Roller	7. Screw adjust nut	8. Adjustable handle	9. Rice discharge port
10. Discharge port for broken rice and husk	11. Electric motor	12.Frame	13.Rice huller belt	14. Belt for grinder
15. Flour discharge port	16.On/Off knob for milling and grinding option	17. Feed adjustable plate	18. Adjustable handle	

Figure 2: Photographic view of machine (A-back view and B-front view)

2.2. Working Principle of Machine:

Rice milling machine consists of feed hopper, propeller, rice milling, rice sieve, roller, discharge port etc. Paddy feed into the milling chamber through the feed hopper manually, after then grinding process occurs inside under the joint action of the knife, sieve and rice roll, and then rice discharge by the discharging outlet. In another side, grinding compartment consists of feed hopper, rotor, crushing chamber, the fixed fluted disc, powder sieve, machine casing, machine frame etc. Firstly, material (in experiment rice) is feed into the crushing/grinding chamber slowly from the feed hopper. Immediately after rice reached chamber, grinding process started under the action of high speed blow and strong bump rub from the tooth claw and grains sheared between the rotating disk and fixed casing.

This results quick breakage into fine powder and then fine powder will come out through the discharging outlet under the action of centrifugal force and air flow.

Table 1: Characteristics of combine mill.

S.N	Features	Technical parameters	
		Rice mill compartment	**Disc Grind compartment**
	Matched Power	3 HP (2.2-3 kw)	1.5-2.2 kw
	Operation	Manual feeding and motor drive	Manual feeding and motor drive
	Material	Metallic steel (MS)	Metallic steel (MS)
	Weight	Approx 65 kg with motor	
	Power source	3 HP single phase electric motor	
	Voltage	220±10 V	
	Frequency	50 Hz	
	Overall dimensions (mm)	1250×530×1125	
	Rotor speed (r/min)	1400-1600	5500
	Rotor diameter (mm)	40	210
	Rice sieve (mm)	Size 166 *72 Thickness:1.2 Aperture:1.2	Aperture : 1.2

2.3. Experimental set-up

Experiment was performed in Agricultural Engineering Division, Nepal Agricultural Research Council Khumaltar, Lalitpur, Nepal in January-February 2019. Currently, Division is newly named as National Agricultural Engineering Research Centre. Paddy required for experiment was taken from Agronomy Division, Khumaltar, Lalitpur. The rice variety was Khumal-4 which is one of the popular varieties in Nepal. Pre-cleaning was performed to remove straw and chaff.Grain moisture meter (Wile 78 Crusher) was used to measure moisture content of paddy. Initial moisture content of paddy was about13.5% (wet basis). Vernier caliper (accuracy of ± 0.05 mm) was used to measure the diameter of sieve holes and dimensions of paddy rice grains. Physical dimensions (length, width and thickness) of paddy and whole rice kernel grain were determined by randomly choosing 15 whole grains using magnifying lens to read values in scale. Length to width ratio (L/W) was determined using formula 1 [9]. Dry milling process was adopted in our study as the machine can be used for domestic and commercial level. Two digital balances were used during the experimental period. Electronic Weighing Balance (made in India, ModelGTP, measuring range of 0-300 kg) was used to measure total mass of rough paddy before milling and grinding process. Weight of kernel, paddy husk, and whole grain and flour was measured on a digital balance having minimum accuracy of 0.01g. Electric motor was operated by electricity during experiment. Time takenwas noted using Stop watch.A schematic view of the experimental set up designed for this study is shown in Figure 3.

$$\text{Lenght to width ratio (L/W)} = \frac{\text{Average length of paddy, mm}}{\text{Average width of paddy, mm}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

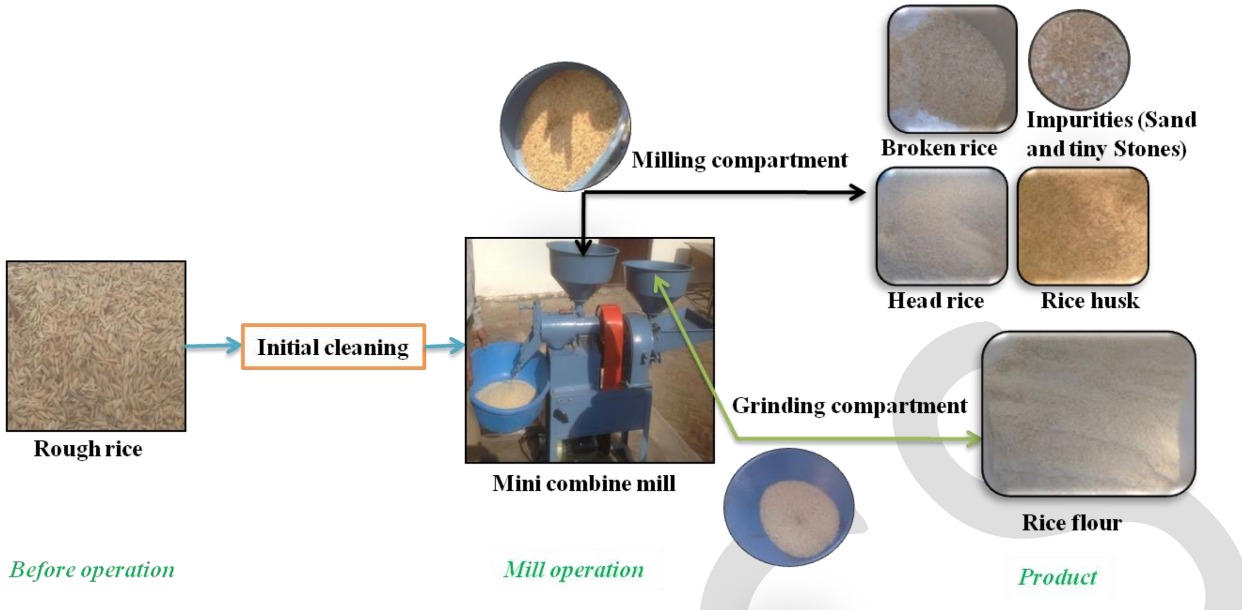


Figure 3: Schematic diagram of experimental set up in this study

2.4. Determination of milling and grinding quality of rice

Test were conducted to obtain the following parameters i.e., milling efficiency or recovery, broken and unmilled grain, head rice recovery, grinding efficiency, total losses, input capacity, output capacity. After then economicviability evaluation was performed.

2.4.1. Major Terminology

A) For rice mill series adapted and modified from [9, 10]

- Rough rice: paddy rice as it comes from the field. Rice kernels are still enclosed in their inedible protective husk.
- Brown rice (husked rice): husked removed but still contain the bran layer.Brown rice is edible and chewier than white rice. Brown rice takes longer time to cook than milled rice.
- Milled rice: white rice after removing the husk, bran and germ from rough rice.
- Milling recovery: Total milled rice including broken grains from paddy. Total milling recovery is also called milling efficiency.

$$Milling\ recovery\ or\ efficency(\%) = \frac{weight\ of\ milled\ rice(kg)}{weight\ of\ paddy\ (kg)} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots .2$$

- Head rice: Milled rice having length greater or equal two third of the average length of the whole kernel. It is expressed on a % paddy or rough rice basis (on 14% moisture content basis).
- Head rice recovery: Percentage of head rice excluding broken obtained from paddy.

$$Head\ rice\ (\%) = \frac{weight\ of\ head\ rice}{weight\ of\ milled\ grain\ from\ outlet} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3$$

$$Broken\ rice\ (\%) = \frac{weight\ of\ broken\ grains}{weight\ of\ milled\ grain\ from\ outlet} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots ..4$$

- Whole kernel: unbroken milled rice grain
- Broken kernel: This study considered grains having size less than 75% of the whole kernel size as broken kernel.
- Milling capacity: capacity of machine to mill paddy

$$Milling\ Capacity\ or\ machine\ capacity\left(\frac{kg}{hr}\right) = \frac{Weight\ of\ rice\ (kg)}{Time\ taken\ to\ mill\ (hr)} \ldots\ldots\ldots\ldots ..5$$

$$Output\ capacity(kg/hr)) = \frac{Weight\ of\ grain\ in\ outlet\ (kg)}{time\ taken\ to\ mill(hr)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..6$$

- Total milling losses:

$$Unmillled\ grain(\%) = \frac{Weight\ of\ unmilled\ grain(kg)}{total\ grain\ recived\ at\ outlet\ point\ (kg)} * 100 \ldots\ldots\ldots\ldots\ldots 7$$

$$Broken\ grain\ (\%) = \frac{Weight\ of\ broken\ rice\ (kg)}{total\ grain\ recievd\ at\ outlet\ point(kg)} * 100 \ldots\ldots\ldots\ldots\ldots..8$$

$$Blown\ grain\ in\ husk(\%)) = \frac{Weight\ of\ grain\ in\ husk\ outlet\ (kg)}{total\ grain\ output\ (kg)} * 100 \ldots\ldots\ldots..9$$

B) For grinding series adapted from [11]

- Crushing or grinding efficiency (η_m) is the ability of the machine to grindgrain and expressed in percentage basis.

$$\text{Crushing or grinding efficiency}(\%) = \frac{total\ weight\ of\ grains\ grind\ by\ the\ machine\ (kg)}{total\ weight\ of\ grains\ supplied\ to\ the\ machine\ (kg)} * 100 \ldots\ldots\ldots..10$$

- Grinding rate (Mr) or capacity is the rate of grinding over time.

$$Mr(\frac{kg}{hr}) = \frac{Weight\ of\ grain\ introduced\ into\ the\ machine}{time\ taken\ to\ grind} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots..11$$

2.5. Economic feasibility analysis of the mill and Data analysis

Economic analysis was performed based on the fixed cost and variable costs. Fixed costs include depreciation, interest on machinery investment, insurance and taxes if any. Variable costs include electricity cost,repair,maintenance and operational costs, labour cost and miscellaneous costwhich aredirectly related to the amount of work done bythe machine.Repairs and Maintenance cost is usually 3% of machinery purchase cost.Total annual cost (Rs/yr) was the sum of fixed cost and variable cost. In this study, salvage value was assumed as 10% of the purchase price. Estimated life assumed for machine and motor was 5 years.

Annual depreciation was calculated as per straight line method by the following equation [12]

$$Annual\ deprication, D = \frac{P - S}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..12$$

Where,
D= depreciation, NRs/yr
P=purchase price, NRs
S= salvage value, NRs
L=useful life of the mill, year

Interest or opportunity cost of the investment is an actual cost in agricultural machinery and was determined by straight line method by the following equation [12, 13]. For agricultural machinery, the interest rate is considered to be15% of purchase value.

$$Interest\ on\ investment, I\ \left(\frac{Rs}{yr}\right) = \frac{P + S}{2} * i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

Where,
I= Mean interest on investment (NRs/yr)
P= Purchase value (NRs.)
S= Salvage value (NRs)
i= interest rate (%)

Tax is not considered in this study due to government policy of no taxes for agricultural machines.Total fixed cost was calculated as: Fixed cost, FC = Depreciation + Interest on investment + Tax, insurance and shelter. Total cost was calculated by adding fixed cost and variable cost. Based on the calculated total annual fixed cost, variable cost per hr and assumed per kg milling rate or charge, the expected revenue, profit, and breakeven point were determined. This study didn't considered income generated from byproduct values (husk, bran and broken grain in bran) because there is a trend of taking back by farmer themselves for their use. Rice bran and broken rice areused in livestock and poultry feed whereas husk is used as bedding material for poultry or fuel for various purposes. This study also considered same value for grinding or milling capacity and per kg charge of milling or grinding for economic evaluation.

Revenue, net revenue, net income and gross margin were obtained as per Das et al., 2016[14]by the following formulas,

$$Total\ revenue\left(\frac{NRs}{yr}\right) = total\ milled\ quantity\ (kg) * milling\ charge\ per\ kg\ (NRs) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

$$Net\ income\left(\frac{NRs}{yr}\right) = Total\ revenue - total\ annual\ cost \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

$$Gross\ margin\ \left(\frac{NRs}{quintal}\right) = \frac{Total\ revenue - variable\ cost}{total\ milled\ quantity} \ldots.\ldots\ldots\ldots\ldots\ldots\ldots 16$$

$$Net\ margin\left(\frac{NRs}{quintal}\right) = \frac{Total\ revenue - total\ annual\ cost}{total\ milled\ quantity} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 17$$

Pay back period:
The payback period is thetime taken to recover the cost of an investment and was determined by the following formula.

$$Payback\ period, PBR = \frac{P}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

Where,
PBR= Pay back period (year)
P=purchase value of machine (NRs)
R=profit per year in NRs

Internal rate of return (IRR): Internal rate of return is the rate of return that makes the net present value of all cash flows (both positive and negative) equal to zero for an investment.IRR is calculated based on the following equation [15].

$$P_0 + \frac{P_1}{(1+IRR)} + \frac{P_2}{(1+IRR)^2} + \frac{P_3}{(1+IRR)^3} + \cdots + \frac{P_n}{(1+IRR)^n} = 0(NPV) \ldots\ldots\ldots\ldots\ldots 19$$

Where:

- P_0= Initial investment (cash outflow)
- P_1, P_2, P_3= Cash flows in periods 1, 2, 3, n etc.
- IRR = Internal rate of return
- NPV = Net Present Value
- N =Assumed economic life of the machine (years)

Experiments were performed in triplicate and all analyses and measurements are displayed as average values of triplicate readings. Descriptive analysis was done to summarize data into averages, standard deviations, and standard error values by statistical tool using MS Excel. All inferential analysis and graph was done using Sigma Plot software version 12.5 (Systat Software Inc, USA).

3. Results and discussion

3.1. Physical properties of paddy

Moisture content of paddy was about 13.5% (wet basis). At moisture content of 13.5% , the average grain length, width and thickness of paddy were 8.32 ± 0.45 mm, 2.47± 0.20 mm and 1.63± 0.18 mm, respectively while that of whole kernel after husk removal were 6.22 ± 0.31 mm, 2.22 ± 0.21 mm and 1.46 ± 0.15 mm, respectively (n=15). Length/width ratio of paddy and whole kernel were 3.39± 0.31 and2.82± 0.27, respectively. Shape of grain can be determined from length, width,and L/W ratio. Based on the standards of IRRI (1996)[16], the rice grainof this experiment was classified as medium grain because calculated L/W value lies within range of medium class (2.1-3.0).

3.2. Milling efficiency

Combine mill operates on a principle of one step milling process where husk and bran removal are happened at the same time and milled or white rice is produced directly from paddy.Combine mill produce four types of products: milled rice, broken rice, rice bran and husks in mixed form.The obtained results of milling and grinding operationbased on milling efficiency, milling rateandmachine efficiency are presented in Table 2. The mean milling recovery obtained from the mill was 69.63±1.0% for khumal-4 variety with maximum and minimum values of 70.40% and 68.5% respectively at the paddy moisture content of 13.5%.The achieved results agree with IRRI [17, 18]. As per IRRI, the maximum milling recovery is 69-70% depending on the rice variety. Some village type rice mills have milling recovery of 55% or lower than this value [9]. Commercial millers are mostly satisfied when they achieve milling recovery of 65% due to presence of unfilled grains and grain imperfections9]**.** Previous studies on the evaluation of different types of milling practices support our results. For instance, Manadhar, G.B.(1985 &1997); and Regmi & KC, (2017) [5, 19-21]evaluated different milling practices and reported rice kernel recovery of home pounding method is about 50-70 % and that of huller and sheller type mills is 68-69% and 69-70% respectively. However, home pounding system of milling is labour intensive and time consuming techniques than machine milling. Only a small amount of rice could be produced from this process, just enough to feed a family for only a few days[5].

3.3. Head rice recovery, broken and unmilled grains:

Head rice recovery can be evaluated based on total milled rice or paddy weight. Head rice recovery obtained from the test was 82.47±3.16% with maximum and minimum values of 85.45% and 79.17% respectively based on total milled rice whereas it was 56.62±1.85% with respect to paddy weight (Table 2).Previous studies byDhanka, P. (2014)[10] shown that under controlled conditions head rice recovery can be as high as 84% of the total milled rice or 58% of the paddy weight. On average, head rice recovery of commercial rice mills and village type rice mills is 55% and 30 % respectively.In order to produce white rice that meets consumer preferences, rice was milled two times or passes. In this study, it was observed that grain from the husk outlet was 2.11±0.31% which includes broken grains, unmilled grain blown always with husk and negligible amount of whole grains. Similarly, unmilled grain obtained from milled grain outlet was 2.29±0.42% in first pass while there was no unmilled grain in second pass (Table 2). The broken grain obtained in this study was 15.24%. Depending on country standards, rice grades in the market will contain from 5-25% broken kernels [5]. Milling quality and percentage of fragmented rice mostly depend on different factors that include harvesting, handling, drying, storage, transport, milling operations (type and condition of mill, motor speed, machine adjustment and operator skills and knowledge on machine usage) and physical and mechanical properties (type and quality of rice, moisture content, rice strain and paddy storage condition) [22].

Table 2: Performance evaluation parameters of combine rice mill cum grinding machine on paddy at 13.5% MC.

Performances indices	Milling series	Grinding series (flour)
Total milling recovery or efficiency (%)	69.63±1.0	-
Head rice recovery (%)		-
a) Based on total milled rice	82.47±3.16	-
b) Based on rough paddy weight	56.62±1.85	
Milling capacitybased on rough rice (kg/hr)	86.91±4.13	-
Broken grain (%)	15.24±3.57	-
Unmilled grain at first pass (%)	2.29±0.42	-
Grain in husk (%)	2.11±0.31	-
Grinding/crushing rate (kg/hr)	-	119.87±1.34
Grinding/Crushing efficiency (%)	-	88.82±0.69
Output capacity based on milled rice (kg/hr)	59.67±2.82	-

All values are expressed as means ± standard deviation of triplicate readings

3.4. Milling capacity

The mean milling capacity of mill obtained from the test was 86.91±4.13% with maximum and minimum values of 91.43% and 83.33% respectively based on rough rice or paddy at 13.4% moisture content. The output capacity (kg/hr)/ based on milled rice was 59.67±2.82%.Proper machine knob spacing adjustment, timely maintenance and machine setting, and adequate operator skills and knowledge on milling machine are prime factors for reducing the rice breakage percentage and for increasing milling efficiency or output capacity. Statistical summary of the mill performance parameters (means, the standard deviations, minimum and maximum values) are presented Table 3.

3.5. Grinding efficiency and grinding rate

Grinding rate is the rate of grinding over time. The mean grain grinding efficiency of combine mill obtained from this study was 88.82±0.69% and grinding rate is 119.87±1.34 kg/hr.

Table 3: Descriptive statistics of performance parameters of mill

Parameters	Replicates	Maximum	Minimum	Mean	St. dev.	Std error
Weight of rough paddy(kg)	3	-	-	8	-	-
Operating time, first plus second pass (min)	3	5.58	5.25	5.41	0.17	0.10
Head rice -based on total milled rice (%)	3	85.45	79.17	82.47	3.16	1.05
Broken rice (%)	3	18.94	11.82	15.24	3.57	1.19
Milling efficiency or recovery (%)	3	70.4	68.5	69.63	1	0.33
Output capacity (kg/hr)	3	62.86	57.49	59.67	2.82	0.94
Milling capacity based on paddy weight (kg/hr)	3	91.43	83.33	86.91	4.13	1.38

Table 4: Major differences among traditional practices and combine mill used in this study

Milling type	**Milling recovery or efficiency**	**Capacity**	**Power requirement**	**Husking/ grinding**	**Grain separation, cleaning and grading**	**References**
Combine Rice mill	69.63 %	a) Milling:87 kg/hr paddy b) Grain Grinding:119 kg/hr	Electrical or mechanical power	1-2 pass	manual	This study
Mortar and pestle (Hand pounding or leg pounding)	70-73% milling recovery [5] 50-60% recovery (paddy) [20]	Hand pounding: 4-8 kg/hr (Paddy), Leg Pounding :6.5-9kg/hr	Manual muscle power	2-3 pass	manual	[5, 19, 20]
Rotary quern	Improved rotary quern 70-72% (black gram)	Traditional quern : Grain grinding: 2-8kg/hr(wheat, maize, black gram) Improved quern: 15.4 kg/hr	Manual muscle power	1-2 pass	manual	[19-21]
a.Traditional Water mill b. Improved water mill	95-97: recovery rate [20] Operational efficiency below 25% 95-97% recovery rate [20] Operational efficiency 30-50%	Grain Grinding 10-25 kg per hour Dehusking/partial polishing 50-60 kg/hr Grain grinding 20-50 kg/hr	Water energy	1-2 pass	manual	[8, 19, 20]

3.6. Economical aspects of combine mill

An economic analysis of combine mill using relevant cost assumptions was performed and shown in Table 5. As per table, the total fixed cost was NRs 10500 per year and total variable cost per year was NRs 111986.4 giving a total cost of mill operation as NRs 102.07 per hour at an estimated annual working hour of 1200. Total cost of milling per kilogram output is NRs 1.7 and assumed milling charge of milled rice per kg is NRs 2-2.5. The estimated profit is about NRs 0.3 per kg charging a minimum milling fee of NRs 2/kg of milled rice. This resulted annual net income of NRS 21513 for a total annual capacity of the rice mill of 720 quintal with annual machine use of 1200 hr.

Break even analysis conducted with respect to annual use of machine and total annual cost or total revenue was shown in Table 5 and Figure 4. As per figure, both the total annual cost and total revenue increased with increasing hour of machine use. From the graph 4, it can be seen that at 393.5 hour of machine use, total annual cost line intersected with annual revenue lines showing the breakeven point. The breakeven point at 393.5 hour of machine resembles 236.14 quintal of rice output at a machine output capacity of 59.67 kg/hr. Thus cost analysis showed that the breakpoint of the mill was 236.14 quintal milled rice per year.The area between the total cost and revenue above the 393.5 hour of machine use point is the potential annual profit that can beaccrued fromcombine mill.From the analysis of economic data, the estimated payback period is 1.895 years with respect to annual net income, milling output, annual machine use and per kg milling charge of NRS 21513 , 720 quintal milled rice ,1200 hr and NRs 2, respectively.Increasing annual machine hour to more than 1200 will reduce payback period. The internal rate of return and B/C ratio achieved from the investment were 46.21% and 1.18.

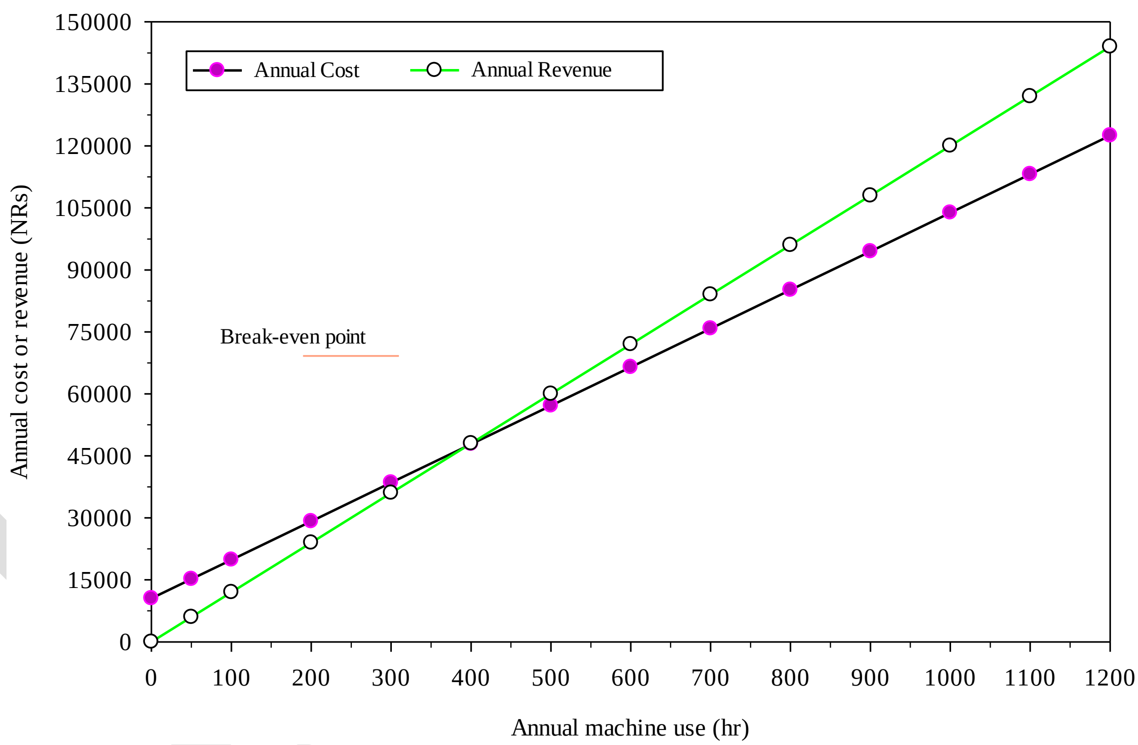


Figure 4: Breakeven point of combine mill use

Additionally, in order to determine the efficiency of machine, comparative evaluations of combine mill machine with other previous studies by different researcher on traditional practices were presented in Table 4.The results showed comparatively better performance than other traditional practices (Table 4).Combine mill run by single phase electric motor which makes it possible to run in remote areas using household single phase electrical line where there is no three phase line. The compact structure of machine needs small space which minimizes additional cost of shade construction. Mill can save time and minimize the workload of women and children involved in grain processing work which allow them more time for other activities such as caring for children, farming and participating in community affairs.

Table 5: Results of the economic analysis of the rice mill

Parameters	Combine mill
Initial cost of machine (NRs)	40000
Assumed economic life of the machine (years)	5
Salvage value @ 10% of machine price (NRs)	4000
Fixed cost (NRs/yr)	
Annual depreciation value @10% (NRs)	7200
Annual interest on investment@ 15% (NRs)	3300
Total fixed cost (NRs)	10500
Variable cost	
Annual machine run time (hr/yr)	1200
Electricity cost (NRs)	27986.4
Annual repair and maintenance cost @3% of purchase price(NRs)	1200
Annual labour cost (NRs)	82800
Annual variable cost (NRs)	111986.4
Variable cost per hour(NRs/hr)	93.322
Total annual cost(NRs)	122486.4
Total operating cost per hour(NRs/hr)	102.072
Paddy milling capacity (kg/hr)	87
Output capacity(kg/hr)	59.67
Annual total rice output (quintal)	720
Milling rate/price per kg (NRs)	1.5
Revenue generated from milling (NRs)	144000
Net revenue/margin(NRs/quintal)	29.9
Net income(NRs/yr)	21513.6
Gross margin(NRs/quintal)	44.46
Benefit cost ratio	1.18
Payback period (year)	1.85
Internal rate of return (%)	46.2

[a]Using One dollar is equivalent to NRs 113.85; the cost of 1 KWh in Nepal is equals to NRS 7.8 [23]
3 HP motor consumes 2.99 Kwh @ 75% efficiency
Electric power consumption @ Rs 7.8 per kwhr[24]
Annual fixed cost= depreciation + interest on investment
Annual variable cost= electricity cost +annual repair and maintenance
Hourly minimum wage rate= NRs 69 ………………………………[25]
Theassumed annual operating time: 5 hr per day, 24 days in each month and 10 month per year
Paddy milling or grinding charge is about NRs 2-2.5 per kg

4. Conclusions

- The combine mill has a milling capacity of 87 kg/hr rough rice or paddy at 13.4% moisture content.
- The milling efficiency or recovery and head rice recovery of 69.63% and 82.47 % (based on total milled rice was obtained for Khumal-4 paddy variety. Unmilled grain percentages, broken grain and grain in husk from the combine mill were 82.47% 2.29%,15.24%, and 2.11%,
- The grain grinding capacity and grinding efficiency was 119.87 kg/hr and 88.82%
- Considering economic perspectives, the combine mill becomes profitable only after 393.5 h of annual machine use which is equivalent to 236.14 quintal of rice output at a machine output capacity of 59.67 kg/hr with respect to investment cost of NRs 40,000 andmilling charge at NRs 2 per kg. The estimated (B/C ratio), IRR and payback period were 1.18, 46.2% and 1.85 years.

Overall, from the findings, this study suggest that combine mill could be one of the beneficial and efficient milling and grinding options for small communities and farmer's cooperatives in the hills and mountain regions of Nepal where majority of rice processing is done with traditional methods. The combine rice mill can be used by farmers' cooperatives and local entrepreneurs that are interested to engage in custom milling business that will provide additional business opportunities in the rural areas. However, further investigations of the combine mill under a wide range of paddy moisture content and different rice varieties across different agro-ecological zones is recommended because the milling machine performance depends on the paddy conditions, milling duration, operator's skill and paddy varieties.

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