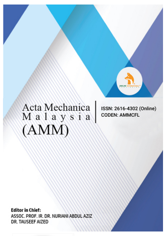
ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2616-4302 (Online)
CODEN: AMMCFL

Acta Mechanica Malaysia (AMM)

DOI: http://doi.org/10.26480/amm.02.2021.27.33



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RESEARCH ARTICLE

ASSESSMENT AND ADAPTATION OF A NAERC PEDAL MILLET THRESHER FOR THRESHING SORGHUM (*Junelo*) IN NEPAL

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ARTICLE DETAILS

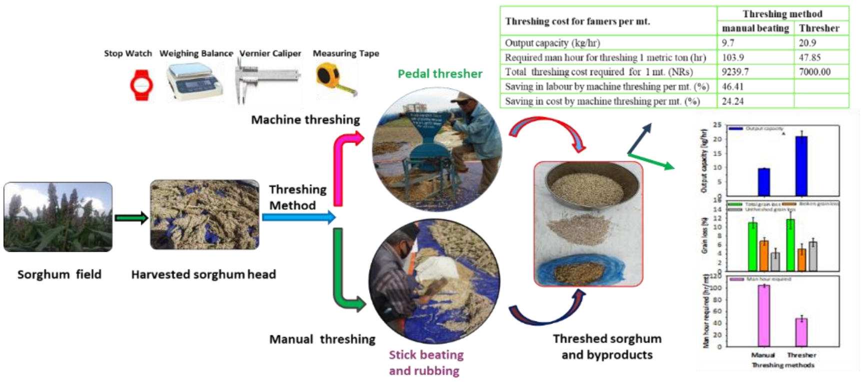
Article History:

Received 30 June 2021
Accepted 13 August 2021
Available online 09 September 2021

ABSTRACT

Traditional threshing (pounding, animal trampling, beating the harvested heads with sticks on bare ground or in bags), a most common manual threshing practice for majority of the farm households is a slow, tedious, drudgerious and labor intensive practices in Nepal. Therefore, there is need of threshing mechanization option suitable for smallholder farmers to replace the manual threshing of sorghum. As most of the farmers have small land holding, poor economy and insufficient electric power supply, a pedal operated millet thresher was playing important role especially for threshing millet in Nepal. Hence, a study was conducted to evaluate the performance of a NAERC pedal millet thresher for threshing sorghum. Thresher was evaluated in terms of different performance parameters such as threshing capacity, threshing efficiency, grain loss, and associated threshing labour and cost. In addition, the physical and engineering properties of sorghum grain namely, moisture content, linear dimensions, 1000 grain weight, particle and bulk density, arithmetic mean diameter, geometric mean diameter, equivalent diameter, shape index, sphericity, aspect ratio, porosity, repose angle and friction properties behavior on different surfaces were studied. The average threshing capacity of the pedal thresher (machine threshing) for sorghum was obtained as 28.20±3.07 kg/hr with a threshing efficiency of 93.36% at an average moisture content of 11.44%, and concave clearance of 6 mm, respectively while that of stick beating (manual method) was 12.2±0.2 kg/hr. The average broken grain losses of 5.00±1.19% and 6.8±0.9% were found in machine threshing and manual threshing, however, unthreshed grain was higher in thresher (6.6±0.91%) than stick beating (4.1±1.2%). Considering economic perspectives, a labour saving of 46.41% was achieved by the use of pedal thresher (47.85 man-hr/mt) compared to manual threshing (103.9 man-hr/mt). Manual threshing needs almost 2.15 hours to thresh equal mass as that by thresher in one hour. Similarly, cost saving of 24.24 % was occurred in custom hired machine threshing (NRs 7000/mt) with respect to manual method (NRs 9239.7/mt). Conclusively, this technology is widely accepted by farmers for threshing finger millet, thus this study on sorghum threshing explored its multi-use benefit in maximizing thresher use per year and increase profitability.

GRAPHICAL ABSTRACT



KEYWORDS

Sorghum, pedal millet thresher, physical properties, manual threshing, efficiency.

Quick Response Code	Access this article online	
	Website: www.actamechanicamalaysia.com	**DOI:** 10.26480/amm.02.2021.27.33

Cite the Article: Shailendra Khatri, Shreemat Shrestha, Ganga Ram Bhandari, Sanjeet Kumar Jha (2021). Assessment And Adaptation of a Naerc Pedal Millet Thresher for Threshing Sorghum (*Junelo*) In Nepal. *Acta Mechanica Malaysia, 4(2): 27-33.*

Highlights

- Performance of pedal millet thresher for sorghum threshing was investigated.
- The pedal thresher has a sorghum threshing capacity of 28.20±3.07 kg/hr with a threshing efficiency of 93.36% at an average moisture content of 11.44%.
- Machine threshing saves 46.41% of the labor required by manual method (stick beating).
- Pedal thresher shortened the threshing cost (24.24% lesser than manual threshing).

1. Introduction

Sorghum, (scientific name Sorghum bicolor (L.); particularly named as *Junelo* in Nepali) is the world fifth most important cereals which can be used as food and feed grain particularly in sub-Saharan Africa and South Asia (Delserone, 2007). Since decades, a variety of millets such as finger millet (Kodo), foxtail millet (Kaguno), sorghum millet (Junelo), and proso millet (Chino) and buckwheat are cultivated across different agro-climatic zones in Nepal. These neglected and underutilized species are important contributor for food, nutrition and economic security of hills and mountain of Nepal. Sorghum is generally cultivated in mid hill and the terai regions of Nepal. Terai region has tropical with a hot, humid climate which is favorable for the growth of sorghum as it tolerates hot climates better than maize and soybeans (Wikipedia contributors, 2019). Importantly, sorghum has potentiality to become one of the few resilient crops of the future to cope with food insecurity for the developing countries because it can adapt well to future climate change conditions better than maize and soybeans, principally the increasing drought, soil salinity and high temperatures and tougher climates (Ghimire, 2017; ICRISAT, 2021, Wikipedia contributors, 2019). Grains are edible to consume as staple food for humans in different forms such as boiled, roasted or popped grain, porridge and sorghum flour as bread (Roti), cookies, muffins, cakes. Besides, sorghum grain and stover serves as an important source of dry season fodder and feed for livestock, especially in Asian countries. These days, it is also used as a source of bio-fuel especially in developed countries.

Despite having multiple uses, cultivation and promotion of sorghum is still in low and declining stage due to the constraints associated with labour intensive agronomic cultivation practices including post-harvest handling. Truly, post-harvest handling is one of the important processes after harvesting sorghum. Threshing is a crucial postharvest action in sorghum processing. Since primitive age, most of the rural villages of Nepal were dependent on traditional threshing practices such as pounding, animal trampling, rubbing and trampling sorghum heads by hand or feet and beating the harvested heads with sticks on bare ground or in bags. These practices are slow, tedious, drudgerious, labour-intensive and time-consuming practices as this method requires higher energy and must be done by bending or sitting. Besides, low output and grain losses due to spillage, kernel damage, incomplete removal of grains from the heads and grain contamination with soil, stones and other impurities is another demerit of those practices (Africa Harvest, 2020).

A study by group of researcher reported that about 35-54 laborers are required to thresh about 300-400 kg of sorghum per hour traditionally (Desta and Mishra, 1990; Melkamu, 2019). By using manual (foot or hand) operated mechanical thresher, a worker can obtain 15 to 40 kg of product per hour. Thus, mechanized threshing is important in strengthening sorghum value chains for food, nutritional and income security and to increase the cultivation area of Nepal. Presently, with the advancement of technologies, different types of modern mechanical thresher such as tractor or motor-driven stationary threshers having capacity of 600-3000 kg/ hour are being used in the world. Increasing trend of machine threshing has gradually replacing the traditional method of sorghum processing. However, in the context of Nepal, those kinds of bigger and heavy weight imported threshers will have high investment cost and not appropriate for small scale farmers of hills and mountains due to geographical and economic constraints. In addition, low adaptability scenario of those imported machine by Nepalese farmers might be due to difficulty in repair and maintenance, high price and shortage of spare parts. Moreover, pedaling is considered as the most efficient way of utilizing power from human muscles. Considering sustainability aspect; locally made smaller threshing machine powered by human muscle (pedaling) or electricity or gasoline engine could be appropriate for threshing purposes.

Presently, NAERC pedal operated millet thresher is widely accepted by Nepalese farmers for threshing finger millet particularly in the hilly region. Indeed, this technology significantly reduces the work load, grain loss, drudgery and time for postharvest processing of millets and is ergonomically sound with respect to traditional method of threshing as well as strengthen the crop's value chain and contribute to food and income security (Manandhar et al., 2009). Millet is harvested and threshed much like sorghum. The adoption and multi-use of this thresher will also contribute to increase its use, employment creation and in entrepreneurship opportunities especially for youth to provide threshing, repair and maintenance services. Despite sorghum importance for local food security and nutrition, little research has been done in machine threshing of sorghum making it a neglected and underutilized species from a research and development perspective. With due consideration of all these facts and to provide options to enhance the annual working hours of pedal thresher, an experimental study has been conducted on threshing of sorghum by NAERC pedal millet thresher to evaluate its performance focusing multi-crop application and preliminary assessment on adaptation possibility of thresher in future.

Moreover, physical and engineering characteristics are required and necessary to adequately design appropriate equipment and machines for harvesting and post-harvest operations such as threshing, milling, grading, cleaning, conveying and storage. However, from literature survey, we found no any studies regarding those characteristics in Nepal. Thus, we also evaluated physical and engineering characteristics of sorghum grain namely, moisture content, physical dimensions (length, width and thickness), 1000 grain weight, true (particle) and bulk density, arithmetic mean diameter, geometric mean diameter, equivalent diameter, shape index, sphericity, aspect ratio, porosity, repose angle and friction properties behavior (coefficient of static friction) on different surfaces i.e. rubber, galvanized iron sheet metal, mild steel sheet, glass, plastic and wood. The findings on physical characteristics can be useful to use as reference by the researcher for the research on development of sorghum machinery (from planting to post-harvest operation) in future. Furthermore, preliminary economic viability comparative evaluations of machine with manual threshing (stick beating) in terms of associated labour and cost were also integrated in this study.

2. Materials and Methods

2.1 Structure, characteristics and major parts of NAERC pedal thresher

NAERC pedal thresher composed of three major compartment i.e. feeding compartment, threshing compartment and outlet compartment. The different parts and basic technical features of thresher are shown in Figure 1 and Table 1. Alphabet A and B represents side view and B represents front view of machine. Briefly, thresher consists of hopper type feeding device, feed controlling plate (just below the hopper), gear transmission mechanism, pedal operating mechanism, grain outlet port, protective cover, bearings and pulley. Threshing compartment consists of cylindrical shaped rotating threshing drum cylinder with a series of rasp bars (hollow frame type), outer concave chamber, shaft and bearing. Drum is housed inside the concave chamber. Likewise, sieve compartment consists of sheet metal trapezoidal box, sieve at upper part and outlet port. Sieve compartment is fixed with thresher body by adjustable nut and bolt so that angle of hanging sieve can be reduced or increased and sieve can be shaken.

2.2 Working principle of thresher

A thresher is an agricultural machine especially designed and built to separate the grains from the stalk. The basic actions of threshing are rubbing, impact, squeezing and shattering or crushing which occurs concurrently. During threshing, the operator press and release the pedal of thresher by feet making up-down movement. The produced vertical linear motion is converted to rotational motion through gear mechanism that rotates threshing drum (connected to gear through shaft). Weighed sorghum heads fed into the threshing chamber through the feed hopper manually. During threshing process, sorghum heads subjected to a high degree of impact and frictional forces due to the joint action of rasp bar and attached rod of concave surface which rub and detach grains from panicles. And then threshed, partially threshed heads, husk and threshed sorghum grains come out through outlet of drum chamber under the action of centrifugal force and air flow and fell on the oscillating sieve (Figure 2). At the same time when drum rotates, sieve is shaken by connecting metallic box and pedal frame through rubber tube that drive the large particle and stalk out from the threshed grain through oscillating motion and only sorghum grain and husk from outlet port.

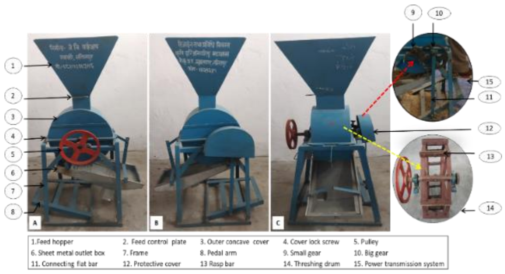


Figure 1: Photographic view of NAERC pedal thresher showing different parts used in this study (A and B- side view, and C-back view)

Table 1: Technical details and general characteristics of the NAERC pedal thresher

S.N	Features	Technical parameters
1.	Make and model	Designed and developed by NAERC, NARC, Nepal
2.	Power transmission unit and drive	Pedal operated, gear and rod drive
3.	Hopper size (L*B*H), mm	400* 400 *350
4.	Bigger gear dia. (mm) and teeth nos.	200 (80 teeth)
5.	Smaller gear dia.(mm) and teeth nos.	60 (21 teeth)
6.	Thresher type	Pedal operated
7.	Threshing drum	Cylindrical and hollow frame type with rasp bar housed inside concave threshing chamber, diameter 18 cm and width of cylinder: 39 cm with strip
8.	Concave width and diameter (mm)	20 and 44
9.	No. of rasp bar on drum	13
10.	No. of rod in concave cover	16
11.	Rasp bar material	Replaceable type flat belt rubber (canvas strip)
12.	Feeding method	Manual feeding
13.	Size of feed opening, mm	150*100
14.	Sieve with shaking mechanism	Oscillating type, size (27*67)cm
15.	Weight (kg)	50
16.	Overall dimensions (mm)	860*500*1300

Figure 2: Photographic view of experiment on machine and manual threshing of sorghum in field (A-side view, B and C-front view of thresher and D-manual threshing (stick beating)

2.3 Experimental site and set up description

Experimental work on threshing of sorghum was carried out at National Agronomy Research Centre, Khumaltar, Lalitpur, Nepal during October-November 2019. After then, rest of the analysis work was done at National Agricultural Engineering Research Centre (NAERC), Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal. Geographically, NAERC is located in the central region, Bagmati Province of Nepal having latitude, longitude and average mean sea level of 27°39'N, 85°19'E and 1300 masl., respectively. The sorghum head is a many-branched panicle, with small seeds and attached to a hard main stalk. Main stalk will disturb threshing work by making jam inside threshing chamber resulting operational difficulty. Thus, branched panicles of each head were separated from main stalk manually to remove hard main stalk. Electronic weighing balance (made in India, Model GTP, measuring range of 0-300 kg) was used to measure total mass of rough sorghum head before threshing process. Likewise, weight of kernel, sorghum husk, and whole grain was measured on a digital balance having minimum accuracy of 0.01g. Time taken for threshing was noted using stop watch. Threshed grain samples were taken for determination of physical and engineering properties of sorghum. A schematic view of the experimental set up designed for this study is shown in Figure 3.

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

2.4 Physical and engineering characteristics of sorghum

Physical and engineering characteristics of sorghum grain namely moisture content, linear dimensions (length, width and thickness), 1000 grain weight, true (particle) and bulk density, arithmetic mean diameter, geometric mean diameter, sphericity, angle of repose, friction properties (coefficient of static friction) on different surfaces (rubber, GI sheet metal, MS sheet, glass, plastic and wood) were determined in this study.

2.4.1 Physical properties

a. Moisture content: Moisture content is expressed as a percentage of moisture based on total weight (wet basis) or dry matter (dry basis). The moisture content of the sorghum grain was determined using the conventional oven method (ASAE, 2003). Briefly, samples are normally dried for 24 hours at 100°C to 105°C (212° to 221°F) in hot air oven (Accumax). The moisture content is expressed by following formula.

$$MC\ (\%) = \frac{(W-D)}{W} * 100 \quad (1)$$

Where,

MC is the moisture content on percentage basis,

W is initial weight of the sample before drying (g),

D is dry weight after drying for 24 hrs in oven (g)

b. 1000 grain weight: One thousand grains samples were counted randomly and their weight in grams was measured on a digital balance (SCALETEC) having minimum accuracy of 0.01g.

2.4.2 Geometric properties

Linear dimensions (length, breadth and thickness) were measured and then other properties, such as geometric mean diameter, arithmetic mean diameter and sphericity were calculated based on these parameters.

a. Linear dimensions: The linear dimensions (length, width and thickness in mm) of sorghum (randomly choosing 20 whole grains) along three perpendicular axes was determined by Vernier caliper (accuracy of ±0.01

mm) using magnifying lens to read values in scale. After then, the length/width (L/B) ratio was achieved by dividing length by its corresponding width.

b. Geometric mean diameter was determined from the cubic roots of linear dimensions (Mohsenin, 1986; Ismail, 1988; Simonyan et al., 2007; Simonyan, 2009).

$$Gd\ (mm) = (LBT)^{\frac{1}{3}} \quad (2)$$

G_d= Geometric mean diameter (mm),

L= length of grain (mm),

T= thickness of grain (mm),

B= width of grain (mm)

c. Equivalent diameter: was calculated using the following equation (Simonyan et al., 2007).

$$De\ (mm) = \frac{(F1+F2+F3)}{3} \quad (3)$$

Where,

F1= geometric diameter, mm

F2= arithmetic mean diameter (mm) $= \frac{(L+B+T)}{3}$,

F3= square mean diameter (mm) $= (\frac{(LB+BT+TL)}{3})^{1/2}$

d. Sphericity: Percentage sphericity of grain was obtained from equation 4 where S_p equal to the geometric mean diameter divided by the longest diameter multiply by 100 (Mohsenin, 1986: Golmohammadi & Afkari-Sayyah, 2013).

$$Sp(\%) = \frac{Gd}{L} * 100 \quad (4)$$

Sp= Sphericity in percentage,

G_d= Geometric mean diameter (mm),

L= Length of grain (mm)

e. Aspect ratio: It was calculated using the equation 5.

$$Ra = \frac{W}{L} \quad (5)$$

Where;

Ra= Aspect ratio

L = Length of grain (mm),

B = width of grain (mm)

f. Shape index (S_i): of the each sample was calculated as per following equation (Ismail, 1988; Gamea et al., 2009)

$$Si = \frac{L}{\sqrt{BT}} \quad (6)$$

Where;

S_i= shape index

L = Length of grain (mm),

B = width of grain (mm),

T = thickness of grain (mm)

2.4.3 Gravimetric properties

Bulk density and true or particle density was determined as follows:

a. Particle density or true density of grain was calculated considering the actual volume of the grains and its weight as follows: The mean value of five replicates was obtained.

$$pt\ (g/cm^3) = \frac{W}{V_{act}} \quad (7)$$

Where:

p_t= particle or true density of sorghum (g/cm³),

W = weight of grains (g),

V_{act}= actual volume (cm³)

b. Bulk density of sorghum grain was determined by dividing the weight of a bulk of grain filled on cylinder by known volume of cylinder. In our experiment, a graduated cylinder of 200 mL known volume was used. A bulk grain was put in the cylinder, and then cylinder grains were lightly tamped to the grains incorporation. After then, weight of filled samples was measured. The mean value of ten replicates was obtained.

c. Porosity: It was determined from bulk and particle density as per equation 8

$$p(\%)) = \frac{p_t - p_b}{p_t} * 100 \quad (8)$$

2.4.4 Engineering Properties

a. Angle of repose: The angle of repose is an important engineering property used for the characterization of the bulk of particulate foods such as grains and design of processing, storage, and conveying systems (Mohsenin, 1986). The repose angle is the angle made with the horizontal at which the material will stand when piled. It is measured to know the cohesion among the grains which has a direct relationship with the angle of repose. The angle of repose was calculated as per formula described by (Mohsenin, 1986; Kumar et al., 2018).

$$\theta\ (\text{degree}) = \tan^{-1}\frac{2h}{d} \quad (9)$$

Where,

θ = angle of repose in degree

h = Height of pile, mm

d = Diameter of pile, mm

b. Coefficient of static friction: Inclined plate method was used for measurement of static coefficient of friction on six frictional surfaces i.e. plywood, rubber, galvanized iron (GI) sheet, MS (mild steel) sheet, plastic and glass that are common materials used for transportation, storage and handling of grains. Grains were placed on the plate at one end and slowly lifted that end to make an inclined plate. The angle θ at which the grain just begins to slide was noted. Experiment was replicated five times on all friction surfaces and mean value was calculated. The coefficient of static friction (μ) was calculated from the following equation (Kumar et al., 2018):

$$\mu = \tan\theta = \frac{p}{b} \quad (10)$$

Where,

μ is coefficient of static friction,

θ is the angle of inclination at which samples starts to slide or roll down.

2.5 Determination of performance indices of thresher

Experiments on manual and machine threshing were conducted to obtain the following parameters i.e., threshing efficiency, unthreshed grain, mechanical grain damage, grain losses and output capacity, and labour requirement. Any operational limitations and difficulties were noted during the field experiment to point out constraints related to operation and handling of machine in field.

a. Threshing efficiency: Threshing efficiency was determined from total weight of threshed grain and weight of unthreshed grains in sample and expressed in percentage basis.

$$\eta_t\ (\%) = \left(1 - \frac{W_u}{W_t}\right) * 100 \quad (11)$$

Where,

Wu = weight of unthreshed grains in sample (kg)

Wt = Total weight of threshed grain (kg) = weight of (clean grain + broken grain + unthreshed grain)

b. Unthreshed grain: The unthreshed grain was assessed by separating by the whole grains attached to the threshed earheads of known quantity of sorghum manually using the following formula

$$unthreshed\ grain\ (\%) = \frac{weight\ of\ unthreshed\ grain\ (kg)}{total\ weight\ of\ threshed\ grain\ (kg)} * 100 \qquad (12)$$

c. Damaged or broken grain:

The broken grain is the ratio of the quantity of the damaged and broken grains from outlet per unit time to the total threshed grain input per unit time. The percentage of broken grains was estimated by separating the damaged and broken grains from the sample collected at the outlet using the formula:

$$broken\ grain\ (\%) = \frac{weight\ of\ broken\ grain\ (kg)}{total\ weight\ of\ threshed\ grain\ (kg)} * 100 \qquad (13)$$

d. Total grain loss (TL_{grain})

Total grain loss is the sum of the percentage of broken grain and percent of unthreshed grains.

$$TL_{grain}(\%) = Broken\ grain(\%) + Unthreshed\ grain(\%) \qquad (14)$$

e. Threshing capacity based on raw sorghum head: is the capacity of the thresher to thresh sorghum per unit time.

$$threshing\ capacity\ \left(\frac{kg}{hr}\right) = \frac{weight\ of\ raw\ sorghum\ head\ before\ thresh(kg)}{time\ taken\ to\ thresh\ (hr)} \qquad (15)$$

f. Output capacity: It is the threshed weight of sorghum grain (whole and damaged) per unit time.

$$Output\ capacity\ \left(\frac{kg}{hr}\right) = \frac{weight\ of\ threshed\ sorghum\ grain\ at\ the\ outlet\ (kg)}{time\ taken\ to\ thresh\ (hr)} \qquad (16)$$

2.6 Manual threshing of sorghum

Briefly, the sorghum heads were spread over the threshing yard. After then, manual threshing of sorghum was performed by beating and rubbing action using traditional tools (wooden sticks). Threshing depends on crop condition, the skill of the labor and the personal time loss of the labor. Threshing time for both manual and machine threshing was noted down using stop watch. The number of labour required for manual and machine threshing was noted down to have preliminary insight into economic aspects of the machine and manual threshing.

2.7 Data analysis

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 and engineering properties of the sorghum

Moisture content of sorghum was about 11.44±0.80% during experimental period. At moisture content of 11.44%, the average length, width and thickness of sorghum head were 285.0 ±15. 8 mm, 92.0±10.3 mm and 68.0± 2.7mm, respectively while that of grain after husk removal were 3.74±0.18 mm, 3.64±0.18 mm and 2.66 ± 0.14mm, respectively (n=20). Average length/width ratio of grain was 1.02±0.03. Shape of grain can be determined from length, width, and L/W ratio. Based on the standards of IRRI, the grain of this experiment was classified as round shaped grain because calculated L/W value lies within range of round class (<1.1)((IRRI, 1996).The average diameter of sorghum grain obtained by arithmetic mean, geometric mean and equivalent diameter methods were 3.30±0.13mm, 3.34±0.13mm and 3.33±0.13mm. The values of geometric mean dia., arithmetic mean dia. and equivalent dia. of the grains varied from 3.11-3.52 mm, 3.13-3.56 mm and 3.12-3.54 mm. The average diameter value obtained from the arithmetic mean and geometric mean was useful in determining the diameter of sieve hole. Likewise, the mean mass, bulk density and particle density for sorghum grain were 0.022±0.001g, 0.69±0.01g/cm3 and 0.89±0.02 g/cm3, respectively. The obtained shape index value was compared with recommended limits as specified by Gamea et al. (2012), to classify grain in two main shapes i.e. spherical and oval. Shape index greater than or equal to 1.5 is classified as oval shape and that lesser than or equal to 1.5 is classified as spherical shape (Gamea et al., 2012). The achieved shape index value (1.20±0.04) of sorghum kernel in our study was less than 1.5, representing spherical shape. The sphericity of sorghum grain was 88.52±2.04% with maximum and minimum values of 92.2% and 84.69%, respectively (Table 2). Regarding engineering properties, angle of repose was found to be 20.02±0.51^0 with maximum and minimum values of 20.76^0 and 19.51^0 respectively. Likewise, the average value of coefficient of static friction was greatest in rubber and mild steel (MS) sheet (0.36±0.01) and that was lowest in glass (0.30±0.01) (Table 2).

Table 2: Physical and engineering properties of sorghum

S.N.	Parameters	Mean	Maximum	Minimum
1.	Sorghum head			
a.	Length (mm)	285.0±15.8	300	260
b.	Width (mm)	92.0±10.3	100	75
c.	Thickness (mm)	68±2.7	70	65
2	Sorghum grain			
a.	Length (mm)	3.74±0.18	4.1	3.5
b.	Width (mm)	3.64±0.18	4	3.2
c.	Thickness (mm)	2.66±0.14	2.9	2.4
d.	Geometric mean dia. (mm)	3.30±0.13	3.52	3.11
e.	Arithmetic mean dia.(mm)	3.34±0.13	3.56	3.13
f.	Equivalent dia.(mm)	3.33±0.13	3.54	3.12
g.	Sphericity (%)	88.52±2.04	92.2	84.69
h.	L/B ratio	1.02±0.03	1.11	1
i.	Shape index	1.20±0.04	1.28	1.12
j.	Aspect ratio	0.97±0.03	1	0.9
k.	Moisture content (%)	11.44±0.80	12.35	10.83
l.	1000 grain weight (g)	24.66±0.94	26	24
m.	Weight of kernel (g)	0.022±0.001	0.024	0.02
n.	Bulk density (g/cm^3)	0.69±0.01	0.7	0.67
o.	Particle density (g/cm^3)	0.89±0.02	0.91	0.86
p.	Porosity (%)	23.09±2.02	25.91	21.15
3.	Angle of repose (degree)	20.02±0.51	20.76	19.51
4.	Coefficient of static friction			
a.	Glass	0.30±0.01	0.31	0.28
b.	Rubber	0.36±0.01	0.39	0.35
c.	Plastic	0.33±0.02	0.35	0.29
d.	Plywood	0.33±0.02	0.37	0.31
e.	GI sheet	0.30±0.03	0.33	0.27
f.	MS sheet	0.36±0.01	0.37	0.35

3.2 Performance evaluation of pedal thresher

3.2.1 Threshing efficiency

Thresher operates on a principle of one step threshing process where husk removal are happened and threshed grain, straw and husk come out from outlet of drum chamber. Thresher produce four types of products: threshed whole grain, unthreshed grain in ear head, broken grain, and husks in mixed form. Figure 3 and Table 3 showed the different performance indices of machine threshing. The obtained results of manual threshing and machine threshing based on threshing efficiency are presented in Table 2. The mean threshing efficiency of the thresher was 93.36±0.91% for sorghum with minimum and maximum values of 95.25% and 96.57% respectively at the sorghum moisture content of 11.4% and concave clearance of 6mm. However, we obtained threshing efficiency of 95.9±1.2% for manual beating.

3.2.2 Threshing or Output capacity

Based on threshed grain weight, the average output capacity by hand and machine threshing were 9.7±0.2 kg/hr and 20.90±2.16 kg with the range of maximum-minimum values of 9.9-9.4 kg/hr and 22.40-18.42 kg/hr, respectively (Table 3 and Figure 4). From the data it can be observed that the output capacity for hand threshing was 46.41% lower than machine threshing. Similarly, we also evaluated threshing capacity based on weight of raw sorghum head before threshing. With reference to this, the threshing capacity was 28.20±3.07 kg/hr for machine threshing while that for manual beating was 12.2±0.2kg/hr. In both kind of threshing, the threshing or output capacity basically depends on operator health and physical condition, moisture content of sorghum head, and threshing tool condition. A study by Manandhar et al., (2009) reported an output capacity of 40-50 kg/hr (Table 4) for millet crop which is higher than our study (28.20±3.07 kg/hr). This could be attributed to the difference in crop type, operator and his condition as well as moisture content.

Table 3: Performance evaluation parameters of pedal thresher on sorghum threshing at 11.4% MC.

Performance indices	Threshing method	
	Manual beating	**Thresher**
Output capacity (kg/h)	9.7±0.2	20.90±2.16
Threshing efficiency (%)	95.9±1.2	93.36±0.91
Unthreshed grain (%)	4.1±1.2	6.6±0.91
Broken grain (%)	6.8±0.9	5.00±1.19
Total grain loss	11.0±1.2	11.6±1.9

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

3.2.3 Total grain loss (broken grain and unthreshed grain)

The unthreshed grain in manual method was 4.1±1.2% while that was in machine threshing was 6.64±0.91%. Likewise, broken grain was obtained to be higher in manual beating than machine threshing. For instance, broken grain was 5.00±1.19% for machine threshing while that was 6.8±0.9% for manual beating with stick. In brief, the total grain loss was 11.0±1.2% and 11.6±1.9% for manual and machine threshing, respectively (figure 3).

Conclusively, it can be said that thresher performance indices is dependent on different factors such as operator and his condition, working atmosphere, crop factors (moisture content), machine factor (operational speed, concave clearance, feed rate etc.). Furthermore, the muscle power depends on the person who delivers the energy, his condition and the time period over which the power has to be delivered continuously.

Table 4: Comparative evaluation of thresher for sorghum and millet threshing

Crop type	Threshing efficiency (%)	Output capacity or threshing capacity), kg/hr	Total Grain loss (%)	Unthreshed grain (%)	Reference
Sorghum	93.36	20.90±2.16 (based on threshed sorghum grain) 28.20±3.07 based on raw sorghum head weight)	5	6.64	This study
Millet	97	40-50 (based on raw millet head weight)	<5%	2	Manandhar et al., 2009

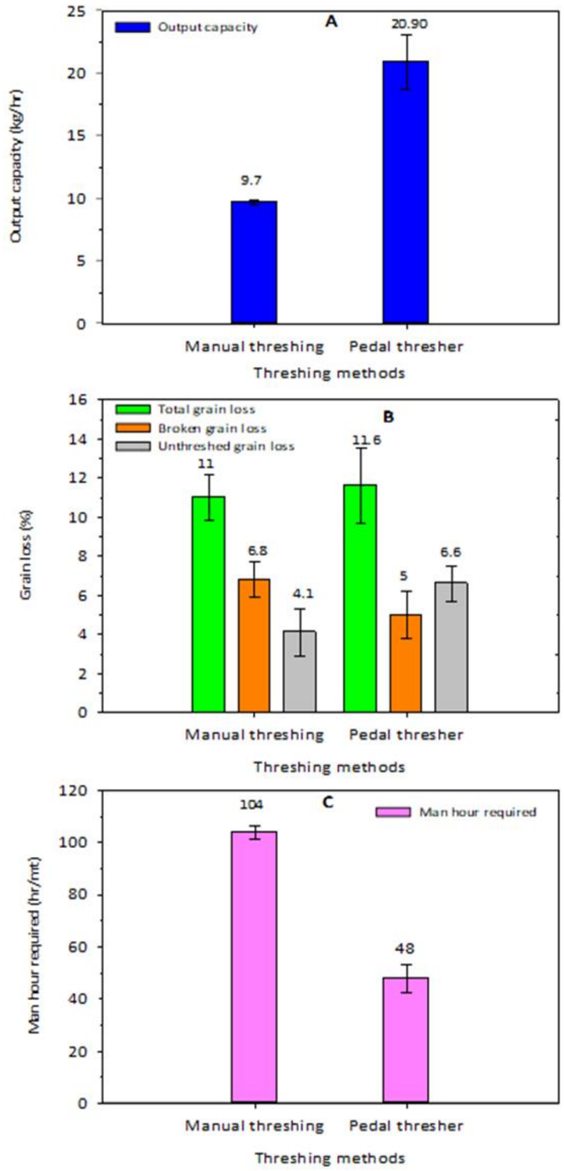


Figure 4: Average output capacity (A), grain loss (B) and labour required (C) of manual and machine threshing

3.3 Preliminary economic evaluation of machine threshing versus manual threshing

In order to make rough preliminary economic considerations based on farmers perspective, we compared the added value related to labour saving in machine threshing relative to manual threshing. During computation, the achieved threshing time of the discussed experiment were extrapolated to man hour required per metric ton of sorghum grain. Table 5 showed the labour required to thresh one mt by manual method as compared with respect to machine threshing (on the basis of custom hiring). The labour requirement for machine threshing by the thresher was 47.85 man-hr/mt and that by manual threshing was 103.09 man-hr/mt in this study (Figure 4 and table 5). A labour saving of 46.41 % was achieved by the use of thresher (Table 5). From the Table 5, it can be said that manual threshing need almost 2.15 hours to thresh equal mass of sorghum as that by thresher in one hour. One labour can thresh 9.7 kg sorghum grain per hour by hand but he can thresh 20.9 kg sorghum grain per hour by thresher which resembles 1.15 times more mass than manual threshing.

Likewise, threshing cost of sorghum by machine and manual threshing were NRs 7000 /mt. and NRs 9239.7/mt., respectively. A cost saving of 24.24 % was occurred in custom hired machine threshing with respect to manual method (Table 5). Besides cost and labor saving from machine threshing, farmers can have extra saved time for other work.

Table 5: Labour and cost requirement between manual and machine threshing

Threshing cost for famers per mt.	Threshing method	
	manual beating	**Machine threshing**
Output capacity (kg/hr)	9.7	20.9
Required man hour for threshing 1 metric ton (hr)	103.9	47.85
Total threshing cost required for 1 mt. (NRs)	9239.7	7000.00
Saving in labour by machine threshing per mt. (%)	46.41	
Saving in cost by machine threshing per mt. (%)	24.24	

Daily minimum wage rate for unskilled worker=NRs 517 (wage) +NRs 200 (lunch) = NRs 717

The assumed custom hire rate for threshing by pedal thresher=NRs 7/kg

The assumed working time: 8 hr per day

1 metric ton=1000 kg

One dollar is equivalent to NRs 113.85

4. Conclusions

- The pedal thresher has a sorghum threshing capacity of 28.20±3.07 kg/hr with a threshing efficiency of 93.36% at an average moisture content of 11.44%, and concave clearance of 6 mm, respectively.
- The average broken grain loss was higher in manual threshing (6.8±0.9%) that that of machine threshing (5.00±1.19%). But unthreshed grain was higher in thresher (6.6±0.91%) than stick beating (4.1±1.2).
- The use of a thresher machine saves 46.41% of the labor required for sorghum threshing by manual method.
- Pedal thresher (custom hiring method) shortened the threshing cost (24.24% lesser) compared to manual threshing.

Overall, from our findings, we suggest that pedal thresher could be one of the beneficial and efficient options for reducing the production and labour cost and improving labour efficiency in threshing task without increasing the grain losses with respect to manual threshing. The thresher can be used by smallholder farmers, farmers' cooperatives or community and local entrepreneurs that are interested to engage in custom hiring business that will provide additional business opportunities in the rural areas. However, further investigation of the thresher under a wide range of operating speed, concave clearance and sorghum moisture content across different agro-ecological zones and economic comparison with manual harvesting in long term mode along with physiological and psychological ergonomics is recommended. Conclusively, this technology is widely accepted by farmers for threshing finger millet, thus this evaluation study on sorghum threshing will help to add its multi-use benefit in maximizing thresher use per year and increase profitability.

Acknowledgments

The authors are grateful to entire family of NAERC, Khumaltar, Lalitpur especially Hari Bahadur Lama, Keshab Prasad Pokharel and National Agronomy Research Centre for their valuable assistance in the experiment. The author likewise greatly appreciates the critical and constructive comments from the anonymous reviewers, which have helped improve this manuscript.

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