Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

December 2021, Volume 34, Issue 2, Page 76-83

Development and Evaluation of a Thresher for Buckwheat Crop suitable for Hill Farming Conditions

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ARTICLE INFO

Article history:
Received: 15 November, 2021
Revision: 11 December, 2021
Accepted: 25 December, 2021

Key words: buckwheat, thresher, threshing performance, design of thresher, optimization.

ABSTRACT

Buckwheat is an important cereal crop widely cultivated in Himalayan states of India and it is the third largest crop grown in Sikkim. Threshing of buckwheat is done by traditional methods resulting in low level of seed separation, higher seed losses and high labour requirement. A tangential flow through type buckwheat thresher was developed for threshing, separating, and cleaning of buckwheat crop. The major components of the machine are spike tooth cylinder, concave, blower, reciprocating sieves, feeding chute, power transmission system and frame. The thresher was powered by a 2 hp electric motor. The thresher was tested with three different levels of cylinder speed, concave clearance and concave grade opening and the process parameters were optimized using response surface methodology. At optimum conditions, the threshing efficiency, cleaning efficiency, broken grain percentage and total grain losses were found to be 99.21%, 97.25%, 0.44% and 1.13% were obtained at cylinder speed of 10.5 ms^{-1}, concave clearance of 25 mm and concave grade opening of 16 mm. The thresher gave high levels of acceptable performance within the studied range of operating conditions. The machine is light weight, compact and can be adopted by small farmers in the hill regions of India.

1. Introduction

Buckwheat is one of the oldest human foods among the cereal grains. Buckwheat is a highly nutritious cereal, which is a rich source of protein, fiber and energy. Buckwheat flour is gluten free, thus it is an excellent dietary alternative (Kim et al. 2004). Buckwheat is grown favorably in cold region of the world like Russia, Canada, Norway, China, Ukraine, France, Poland, United States, Brazil, Kazakhstan, Lithuania, Japan, India, Nepal, Bhutan, Pakistan etc. In India buckwheat is widely grown at higher elevation in the Himalayan belt. Globally, Russia has the highest buckwheat production followed by China. In India there is no data available on the production and productivity of buckwheat at national level but it is grown in Himalayan states like Himachal Pradesh, Arunachal Pradesh, Uttarakhand, Sikkim, Meghalaya, Manipur and the union territory of Jammu and Kashmir (Hore and Rathi, 2002; Singh et al. 2020). As per the data available, buckwheat in Sikkim was cultivated in 3.43 thousand hectares with a production and productivity of 3.35 thousand tonnes and 976.24 kg/ha respectively during 2017-18 (Anon., 2022).

Buckwheat is the third largest cereal crop grown in Sikkim after maize and rice. The crop is harvested during January to March when 60% to 70% of grains are matured and ready for harvest. Complete harvesting is accomplished in two to three times as all the grains do not mature at a time. The harvested crop is stored and sun dried before threshing is carried out. Presently in Sikkim threshing and winnowing of buckwheat is done by traditional methods which includes foot trampling and hand beating. The traditional methods result in low level of grain separation, high grain damage, seed losses and also it is time and labour-intensive. The crop is bushy in nature and consists of profuse branching.

In the past, threshers for different crops like paddy, wheat, maize etc. have been developed and they play a significant role in mechanization of agriculture in India (Dhananchezhiyan et al. 2013; Mashood et al. 2019; Chaturvedi et al. 2019). In countries like Russia, Canada

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combine harvesters are used for harvesting and threshing of buckwheat grown at low elevation level fields. However, in India in general and Sikkim in particular, buckwheat is mostly cultivated at higher elevation and hilly areas. The nature of the crop is bushy with profuse branching, which is completely different from the characteristics of other cereal crops like wheat, rice etc. At present there is no specific thresher available for threshing buckwheat crop. Moreover, there is no evidence of development of thresher for buckwheat crop in the reported literature. Threshing of buckwheat in the existing tractor operated wheat thresher was tried but excessive grain damage was observed. Moreover, the big size threshers are not suitable for the farming conditions in hills. Therefore, a low cost, light weight buckwheat thresher suitable for hilly areas was developed and evaluated in the present research work.

2. Materials and Methods

2.1 Design considerations

The design of thresher was conceptualized as a flow through type unit in which the crop was to be fed from one side of the cylinder and then the crop moves tangentially between cylinder and concave while threshing takes place. The crop after threshing is discharged at the diametrical opposite end of the cylinder. The machine consists of a feeding chute, cylinder, concave, discharge outlet, vibratory sieve and aspirator blower. The thresher was designed to be operated by a single phase 2hp electric motor through belt and pulley drive. Engineering properties of buckwheat seeds were studied and used in the design of the thresher (Mohammad and Satpathy, 2021). The thresher was designed as a compact, lightweight and low cost machine for adoption by small farmers of hilly regions. The computer aided design 3-D model of the thresher is shown in Fig. 1. The thresher was fabricated in the college workshop using easily available raw materials.

2.2. Brief description of the developed thresher

The threshing unit consisted of a spike tooth cylinder and a semi-circular concave. The cylinder was 400 mm in diameter and 400 mm in length. The spikes on the cylinder were made by using M10 size bolts so that the spike length could be adjusted for adjusting the concave clearance. The concave was made by joining MS square rods (10 mm x 10mm) on two semi-circular rings made of MS flat (25 mm x 5 mm) at equal distance so as to obtain the desired grate openings. The feeding chute was designed as a rectangular box section with about 55% covered section at the cylinder end for safety and ease of the feeding operation. The dimensions of the hopper were 520 mm×350 mm×155 mm. The blower consisted of four radial blades mounted on the threshing cylinder shaft and enclosed by a casing. The inlet eye of the blower was connected to the suction pipe, whose open end was placed just above the main grain outlet. The blower was designed to suck lighter non-grain materials from the main grain outlet and discharge outside through the blower outlet. The cleaning unit consisted of a two layered vibratory sieve shaker assembly operated by a crank mechanism. The upper layer was fitted with a sieve of circular opening of 7 mm size to allow passage of clean seeds to the outlet section. The lower layer was fitted with a MS sheet and it was provided with the main grain outlet at one corner for delivering the clean grain. The bigger size non-grain material was discharged by the upper sieve as overflow. The power from the motor was transmitted to the threshing cylinder and cleaning unit by belt and pulley drive. The main frame of the machine was made by using MS angle for required stability and strength. A view of the developed thresher is presented in Fig. 2.

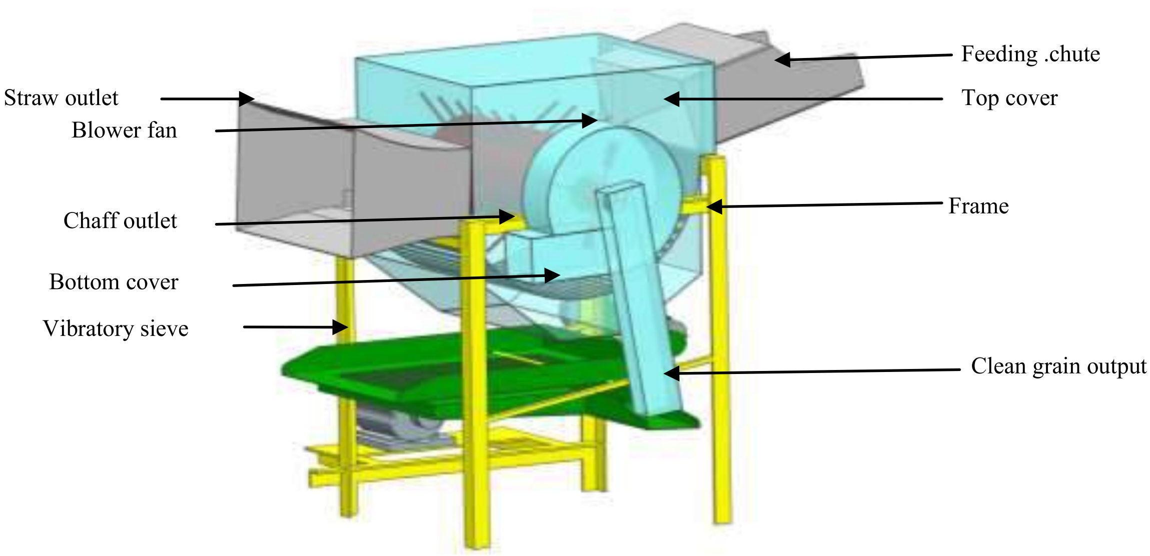

Fig 1. CAD 3-D model of the buckwheat thresher design

Fig 2. Developed buckwheat thresher

2.3 Performance evaluation of the developed thresher

The performance of threshers are influenced by various parameters like cylinder speed, concave clearance, concave grate opening size, crop moisture, federate etc. (Gbabo et al. 2013; Ajav and Adejumo 2005). The operating parameters of threshers also need to be optimized for each type of crop (Pandey and Stevens, 2016). The performance of the developed buckwheat thresher was evaluated at different levels of operating parameters like cylinder speeds, concave clearances and concave grate openings size. The information on cylinder speeds in such flow through threshers and especially for buckwheat crop was not available in the reported literature. Therefore, initial trials were conducted to ascertain the working range of cylinder speed for the designed thresher. The ranges of concave clearance and concave grate opening are selected from available literature on threshers for cereals and pulses (Varshney et al. 2004). The performance of the thresher was evaluated in terms of the threshing efficiency, cleaning efficiency, percentage broken seeds and total seed losses. The details of the independent parameters and dependent parameters are given in Table 1. The cylinder speed was varied by varying the motor speed by using a variable frequency drive. The concave clearance was varied by adjusting the height of the cylinder spikes. For varying the concave grate opening size, three different concaves were fabricated with the desired spacing between the square bars of the concave.

Table 1. Experimental parameters for evaluation of thresher

Independent variables	Levels	Dependent variables
Cylinder peripheral speed, m s^{-1}	3	Threshing efficiency
	(9.5,10.5,11.5)	Cleaning efficiency
Concave clearance, mm	3	Percentage broken seeds
	(10,20,30)	Total seed loss
Concave grate opening size, mm	3	
	(7,16,25)	

Performance evaluation of the developed buckwheat thresher was done according to Bureau of Indian Standards (BIS) test code for cereals crop thresher (IS: 6284:1985). The performance parameters of the thresher are discussed below.

Threshing efficiency

The threshing efficiency was calculated using the following formula.

$$Threshing\ Efficiency, \% = 100 - (\%\ of\ unthreshed\ seeds) \qquad ...(1)$$

The percentage unthreshed seed was determined by analysing samples from the straw outlet and sieve overflow for unthreshed seeds. The percentage of the unthreshed seeds was calculated by the following formula.

$$Unthreshed\ seeds, \% = \frac{H}{A} \times 100 \qquad ...(2)$$

Where, H = Quantity of unthreshed seeds obtained from the sample per unit time; A = Total seeds input per unit time.

Cleaning efficiency

The cleaning efficiency was determined by analyzing samples collected from the main grain outlet for presence of non-grain materials. It was calculated by using the following formula.

$$Cleaning\ Efficiency, \% = \frac{M}{F} \times 100 \qquad ...(3)$$

Where, M = weight of clean seeds in the sample taken at main grain outlet. F = Total weight of sample taken at main outlet.

Broken seed percentage

The broken seed percentage was determined by manually sorting out cracked and broken seeds from the samples taken at the main grain outlet. It was calculated using following formula.

$$Broken\ seeds, \% = \frac{E}{F} \times 100 \qquad ...(4)$$

Where, E = weight of broken seeds in the sample; F = Total weight of sample

Total seed loss

This is the total seed losses due to spillage from the straw outlet or sieve overflow and seeds discharged through the blower outlet. Samples collected from the straw outlet, sieve overflow and blower outlet were analysed for presence of clean seeds and expressed in percentage of total grain input rate.

2.6 Statistical experimental design, analysis and optimization

The experiments were planned using a face centered central composite design. Twenty experimental treatments were obtained by using Design Expert Software 10.0. Analysis of Variance (ANOVA) was done to evaluate the effects of independent parameters on the responses. The optimization of machine parameters was done using response surface methodology (RSM) of Design Expert software. The predicted optimized solution was further validated through experiments and the actual values were compared with predicted values.

3. Results and Discussion

The performance of the developed buckwheat thresher was evaluated in the Farm Machinery Laboratory, Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Post Harvesting Technology, Ranipool, Sikkim. Views from the testing of the thresher are shown in Fig. 3. The results of the performance evaluation are presented in Table 2. The effects of various machine operating parameters on the responses are discussed below.

3.1 Threshing Efficiency

The threshing efficiency varied from 97.12 to 100% between the various treatments combinations. The maximum and minimum threshing efficiency was obtained at cylinder speed of 10.5 $m.s^{-1}$and 11.5 $m.s^{-1}$ concave clearance of 20 and 30 mm and concave grate opening of 16 and 25 mm respectively. However, the effect of cylinder speed and concave grate opening on threshing efficiency was found statistically non-significant (p = 0.05) within the studied range, whereas the effect of concave clearance was found to be significant. The results indicated that the buckwheat threshing performance was not much affected above 9.5 $m.s^{-1}$peripheral speed of cylinder and the concave grate opening had no significant role in the threshing process. The results obtained for buckwheat are in contrast to the results obtained for wheat crop threshed in high capacity threshers, where an increase in threshing efficiency was observed with increase in cylinder speed (Singh et al. 2018; Kumar et al. 2016). This indicates easy thresh ability of buckwheat crop and the grains detachment took place at lower level of cylinder speeds. The threshing efficiency decreased with increase in the concave clearance. At higher concave clearances there was a chance that the crop was passed out without complete threshing and therefore, the efficiency decreased. The effect of concave clearance on threshing efficiency is depicted by the response surface plot in Fig. 4. Similar results were also obtained for paddy crop in a flow through thresher (Dhananchezhiyan et al. 2013)

3.2 Cleaning Efficiency

It was observed that the cleaning efficiency varied from 94.12 to 97.71% between the various treatments combinations. The maximum and minimum cleaning efficiency was obtained at cylinder speed of 10.5 $m.s^{-1}$and 11.5 $m.s^{-1}$; concave clearance of 20 and 10 mm and concave grate opening of 16 and 7 mm respectively. The ANOVA indicated that the cylinder speed, concave clearance and concave grate opening affect the cleaning efficiency significantly (p = 0.05) within the studied range. The cleaning efficiency increased with decrease in cylinder speed, increase in concave clearance and increase in concave grate opening. At higher cylinder speeds and lower concave clearances the crop was broken into fine pieces, which passed through the cleaning sieve and resulted in lower cleaning performance. At higher concave grate opening, more non-grain material passed on to the cleaning sieve, increasing the cleaning load and resulting in lower cleaning efficiency. Stanley et al. (2020) obtained similar results for black gram in small thresher. The effect of the machine operating parameters on cleaning efficiency is depicted in Fig.5.

Fig 3. Performance evaluation of the developed buckwheat thresher

Table 2. Results of the performance evaluation of the buckwheat thresher

Expt. run	Cylinder speed, ms^{-1}	Concave clearance, mm	Concave grade opening, mm	TE,%	CE,%	BS,%	TSL,%
1	10.5	20	25	99.96	96.92	0.514	1.90
2	11.5	30	7	97.13	95.12	0.721	2.02
3	9.5	30	25	97.32	97.03	0.497	1.78
4	10.5	20	16	100	96.12	0.541	1.81
5	10.5	20	16	99.98	97.71	0.517	1.87
6	10.5	20	16	99.89	96.73	0.512	1.82
7	10.5	20	16	100	97.13	0.518	1.81
8	11.5	20	16	98.87	94.99	0.702	2.07
9	9.5	30	7	97.12	96.32	0.432	1.76
10	9.5	10	25	98.91	96.45	0.489	1.72
11	10.5	30	16	97.12	97.14	0.522	1.92
12	11.5	10	7	99.12	94.12	0.789	2.32
13	9.5	20	16	99.36	96.57	0.499	1.72
14	10.5	20	16	100	96.98	0.518	1.79
15	10.5	20	7	99.12	96.13	0.513	1.83
16	10.5	10	16	99.01	95.98	0.678	1.99
17	10.5	20	16	100	96.14	0.571	1.80
18	11.5	10	25	99.61	95.13	0.776	2.18
19	9.5	10	7	99.18	95.93	0.503	1.83
20	11.5	30	25	97.12	96.01	0.699	2.03

TE: Threshing Efficiency, CE: Cleaning Efficiency, BS: Broken Seeds, TSL: Total Seed Losses

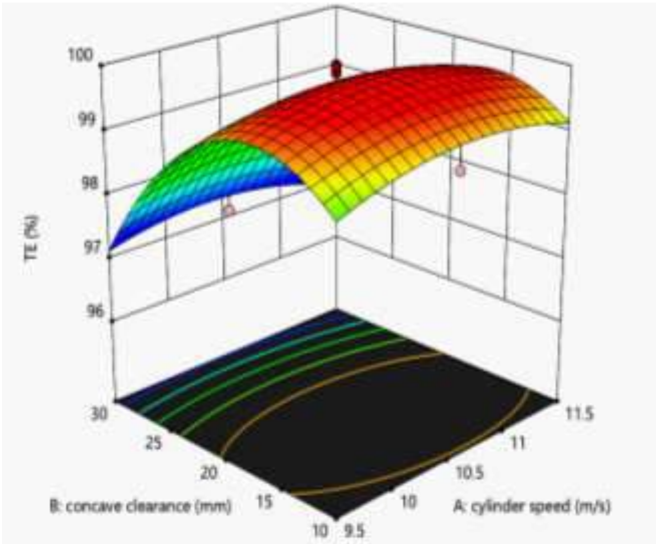

Fig 4.Effect of concave clearance and cylinder speed on the threshing efficiency

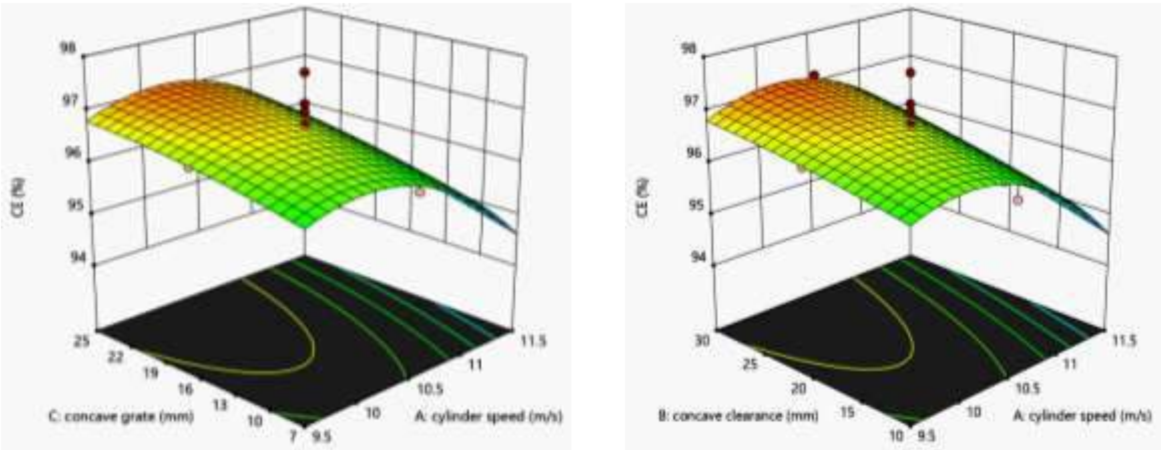

Fig 5.Effect of cylinder speed, concave clearance and concave grate opening on the cleaning efficiency

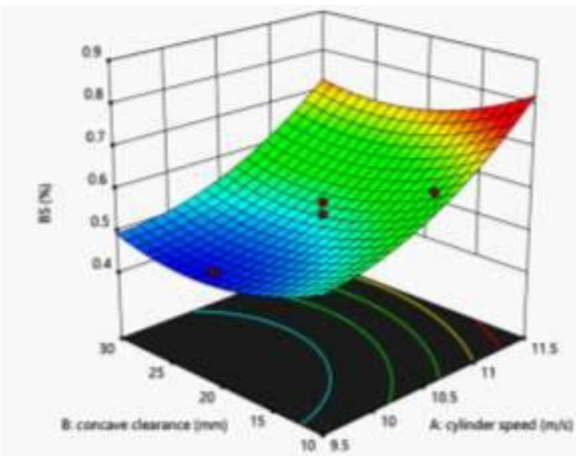

Fig.6.Effect of cylinder speed, concave clearance on the broken seed percentage

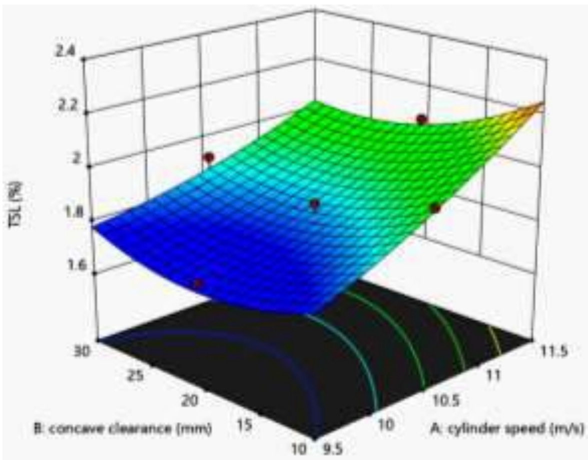

Fig.7.Effect of cylinder speed, concave clearance on the total seed losses

3.3 Broken seed percentage

The broken seeds percentage varied from 0.432% to 0.776% between the various treatments combinations. It was found that the cylinder speed and concave clearance affect the broken seed percentage significantly (p = 0.05) while concave grate opening had no significant effect on the broken seed percentage. The results indicated that the seed breakage was higher at higher cylinder speed and lower concave clearance, which was due to the severity of the impact and rubbing action at these conditions. These results are in conformity to the results obtained in case of paddy crop in a similar type of thresher (Dhananchezhiyan et al. 2013). The effect of the cylinder speed and concave clearance on the broken seed percentage is depicted in Fig.6.

3.4 Total seeds loss

The total seeds loss varied from 2.32% to 1.72% between the various treatments combinations. The values of TSL are well within the acceptable limits as per Bureau of Indian a standard (BIS) test code for specification of power thresher, hammer mill type (IS: 6320:1971). ANOVA indicated that only cylinder speed and concave clearance affect the total seed losses significantly (p = 0.05), while the effect of concave grate opening was found non-significant. The thresher is a flow through type machine and hence at higher cylinder speed the residence time for the crop in the threshing chamber was less resulting in discharge of some of the threshed seeds along with crop. At lower concave clearance it seems that some of the threshed seeds got trapped inside the crop mass and got discharged at the outlet. Moreover, at higher cylinder speed and lower concave clearance, the crop was broken into fine pieces, which increased load on the cleaning sieve resulting in increase in spilled grain over the sieve. Similar results were obtained for black gram (Stanly et al. 2020) and wheat (Singh et al. 2018). The effect of cylinder speed and concave clearance on the total seed losses is depicted in Fig. 7.

3.5 Optimization of machine parameters

Optimization of machine parameters was done by Response Surface Methodology using Design Expert software 10.0 with the goal to maximize threshing efficiency, cleaning efficiency and minimize broken seeds and total seed loss. Equal importance level was attributed to all the responses. The optimization process was carried out using the desirability function of Design Expert software and a total of twenty eight predicted solutions were obtained. The solutions with highest desirability values were considered optimum values for the machine parameters. The optimum values were obtained as peripheral speed of cylinder of 9.8 $m.s^{-1}$, concave clearance of 19 mm and concave grate opening of 25 mm with corresponding values of response as 99.87 %, 97.01 %, 0.46 % and 1.42 % for TE, CE, BS and TSL respectively.

The optimum solution was validated by conducting experiments at the optimum values of the machine parameters and the responses were measured. The results of the predicted values and experimental actual values are presented in Table.3. The actual values were found very close to the predicted model values and hence the optimization model was validated. At the optimum conditions, the throughput capacity of the thresher was found to be 234 kg/h.

4. Conclusion

A buckwheat thresher was designed, developed and tested under different operating conditions of cylinder speed (9.5,10.5,11.5 $m.s^{-1}$), concave clearance (20, 25 and 30 mm) and concave grade opening (7,16 and 25 mm). The thresher gave acceptable performance over the selected range of machine parameters. At optimum conditions, threshing efficiency of 99.21%, cleaning efficiency of 97.25%, broken seeds percentage of 0.41% and total seeds losses of 1.35% were obtained at cylinder speed of 9.8 ms^{-1}, concave clearance of 19 mm and concave grade opening of 25 mm. The throughput capacity of the thresher was found to be 234 kg/h at the optimum operating conditions. The developed thresher was small and weighs only 64kg. The cost of the prototype is estimated to be about ₹25000. The cost of threshing was estimated to be ₹ 22.4 per quintal of the crop. The saving in threshing cost, time and man power requirement in the developed thresher was found to be 60.2 %, 82.9 % and 65.6% respectively as compared to the traditional manual threshing method. The thresher could be developed using simple components and easily available raw materials. The thresher can be very useful for small farmers in hilly regions.

Table 3. Comparison of experimental results with predicted model values for performance parameters

Parameters	Predicted values	Actual values	Difference
Threshing efficiency (%)	99.87	99.21	0.66
Cleaning efficiency (%)	97.01	97.25	0.24
Broken seeds (%)	0.46	0.41	0.05
Total seed Loss (%)	1.42	1.35	0.07

5. Acknowledgements

The authors wish to acknowledge the financial support received from Indian Council of Agricultural Research, New Delhi through the All India Coordinated Research Project on Farm Implement and Machinery for the research work.

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