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An Improved Method of Direct Ear Head Threshing of Standing Paddy Crop through Self-Propelled Thresher

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ABSTRACT

The unique method of direct ear-head threshing was initially tested in laboratory and then implemented in the field. The direct ear head thresher was affordable for medium-scale farmers which helped in maintaining the timeliness of agricultural operations with reduced labor. It consisted of four sets of crop guiding plates, wire-loop threshing cylinder and collecting tray. The guiding plates gather the ear-heads of upright plants and gradually place them over the rotating cylinder. The grains got separated due the cylinder impact and collected in the tray placed below the cylinder. Thus the straw intake reduces during threshing. It was a self-propelled walk-behind machine equipped with a 3.7 kW gasoline engine and threshes four rows in a single pass. The performance of developed thresher was evaluated under actual field conditions. It was operated at cylinder speed and forward speed of 18.94 m s^{-1} and 0.8 km h^{-1}, respectively. The threshing efficiency, grain throughput capacity, and total grain loss were 98.86%, 346.50 kg h^{-1}, and 4.20%, respectively. The effective field capacity, fuel consumption, labor-time requirement and cost of operation were 0.065 ha h^{-1}, 0.96 l h^{-1}, 16 man-h ha^{-1} and ₹ 3462 ha^{-1}, respectively.

Keywords: Upright threshing, Crop guiding plate, Gradual feeding, Reduced straw intake, Self-propelled thresher

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INTRODUCTION

Mini combine harvesters and head-feed combine harvesters are suitable machines developed for medium-scale farmers. Despite this, the farmer prefers separate machines for cutting and threshing the crop. Probably due to high initial cost and competition in hiring combine harvesters in the peak harvesting period (Khan, 1971). Alternatively, the reaper and stationary power thresher are used to a large extent. The labor time requirement for reapers (1.2 m width), thresher (3.7 kW) and combine harvester (for 1.44 and 3 m width) are 4.6, 12.5, and 3.6, & 1.51 man-h ha^{-1}, respectively, (Murumkar *et al.* 2014; Amponsah *et al.* 2017; and Kalsirisilp and Singh, 2001). According to the statistics of the Agricultural Machinery Manufacturers Association (Anonymous, 2014), in paddy farms, 70 to 80% of mechanization has been done (Singh and Kapoor, 2015). In this, the share of combine harvesters is much less i.e. 26 m ha^{-1}. It shows that the farmers rely more on reapers and threshers than the combine harvesters despite the combine consuming less labor-time. Murumkar *et al*., (2014) reported that the vertical conveyor reaper (VCR) equipped with 1.2 m wide cutter bar consumed 88 man-h ha^{-1} including manual crop collecting and bundling. On the other hand, a mini combine harvester of 1.44 m working width consumes only 3.6 man-h ha^{-1} (Hossain *et al*., 2015). Separate operations for harvesting and threshing will be difficult with reduced agricultural labor. Anonymous (2014) estimated that approximately 26% of agricultural labor force will be decreased by the year 2050. The grain loss was also high while harvesting and threshing the paddy separately. Including crop cutting using VCR, manual handling and power threshing the total grain loss was 4.8% (Khan, 1971 and Murumkar *et al*., 2014). Hossain *et al*., (2015) tested a head feed combine harvester with 50 hp engine power and 1.44 m working width. The average field capacity, harvesting efficiency, grain loss and fuel consumption were reported to be 0.28 ha h^{-1}, 96.60, 4.48% and 18.5 l ha^{-1}, respectively. In a head-feed thresher, the plant is cut and the only upper portion is fed for threshing instead of the whole plant as done in the power thresher. Therefore, the head-feed rice threshers consume less energy as compared to the plant-feed combine harvester (Hossain *et al*., 2015).

Based on literature values, the estimated cost of operation for the head-feed combine would be ₹10,344 ha^{-1}. Amponsah *et al.* (2017) reported that the grain throughput rate during paddy harvesting was 326 to 1032 kg ha^{-1} at forward speed of 0.23 to 1.25 km h^{-1} for a mini combine harvester of 1.36 m working width. The average field capacity, fuel consumption and grain loss were 0.39 ha h^{-1}, 11.38 l ha^{-1} and 4.43%, respectively. Based on the above-reported data, the estimated cost of operation for mini combine harvester would be, ₹6983 ha^{-1}. Khan (1971) reported that the average labor requirement of a Japanese

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two-row harvester was 12.50 man-h ha^{-1}. The grain loss was 6.08%. Based on the above-reported values, the estimated cost of operation would be ₹6,550 ha^{-1}. Marouze (1989) developed stripper harvester EC 60, which works on a longitudinal rotor principle. At the leading portion of this mechanism, a gathering mechanism was mounted which was used to collect the crop with forward of machine. A threshing chamber equipped with a wire loop cylinder was fixed at its rear end. The front portion, raises the lodged plants, strips off the panicles and brings them to the threshing chamber. The plant is pushed towards longitudinal cylinder where the grains are separated and then transported to the hopper at the rear of the machine. A grain separator fixed adjacent to the cylinder separates the grain and straw. It was 1.7 m wide and had only 0.6 m harvesting width. However, this was found unsuitable for scaling up as required for large fields. To maintain the timeliness of agricultural operations with reduced labor and minimize the grain loss and cost of operation, a small-scale low-cost harvester can be developed. Accordingly, the objectives taken for this study were to develop a direct ear-head thresher and evaluate its performance. Development of such machine requires morphological study of the crop. Kharel *et al.* (2018) reported that the average plant height, panicle length and number of panicles hill^{-1} were 96, 23 cm and 14, respectively. Dash *et al.* (2021) reported that for drought tolerance paddy variety Swarna Shreya these values were 110, 23.5 cm and 17.8, respectively. It shows the variation in morphological properties for different varieties. These design considerations were used during machine development.

MATERIALS AND METHODS

The self-propelled direct ear-head thresher was developed and tested in the actual field conditions. The experiment was conducted on the Research Farm of Agricultural and Food Engineering Department, IIT Kharagpur. The plot of dimension 25×35 m area was selected. The normal cultivation practices were adopted and irrigation, puddling and transplantation were done. The crop variety IR-36 was grown and machine was tested at the crop age of 110 days after transplantation. The observations were taken for determining the threshing efficiency, grain loss, fuel consumption, and effective field capacity.

Development of Direct Ear-head Thresher

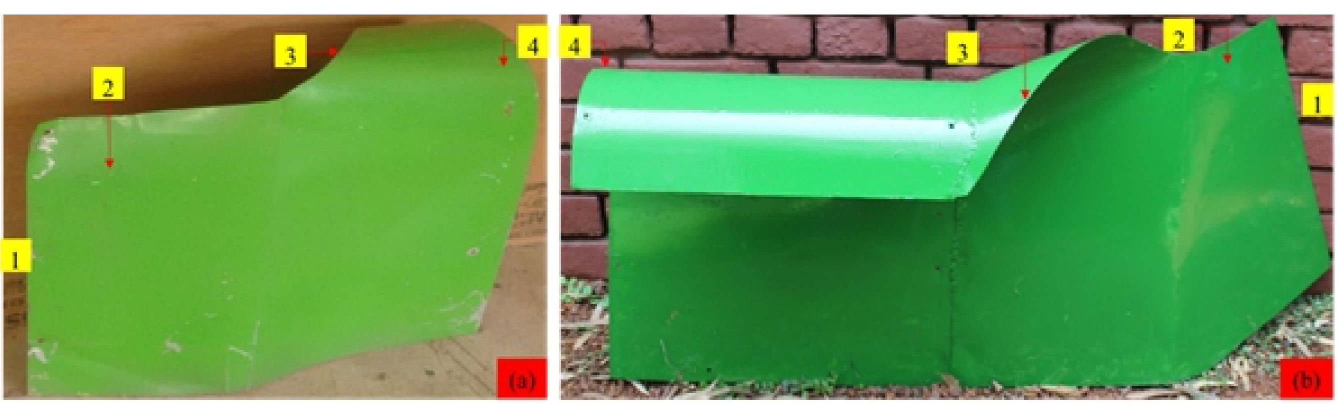
It consisted of a specially designed crop guiding plate, threshing cylinder, concave, transmission system, ground wheels, associated frame and engine. The engine model GX-200, single cylinder, 4 – stroke, air cooled was used as the prime mover. Its rated power was 3.7 kW at 3600 rpm and produces 9.8 Nm torque. Paddy crop properties like row and plant spacing and plant height were considered during development. Accordingly, the cylinder was mounted on the frame keeping its axis height 60 cm from the ground and its adjacent spacing 25 cm. Further, the development of major components is discussed.

Crop guiding plates

The outer plate was made by joining two pieces of GI sheet of 0.8 mm thickness by welding. The first sheet was used for making the leading portion (1), front end (2) and the gradually curved portion (3) as shown in Fig. 1 (b). A sheet of 1010×605×0.8 mm was taken and bent conically from the top. A segment of 200 mm length was cut and removed from the conical curved portion. From the remaining conical portion of 405 mm length, another piece was cut and removed starting from front right side end to rear left side end. Its front end was bent outward as is shown in Fig. 1(b). The rear portion of first piece forms a gradually bent surface (3) Fig. 1 (b). The second sheet was used for fabricating the uniform curved portion (4) (Fig. 1b). A sheet of 780×550×0.8 mm was taken and bent from one end in a half-circle and the other part was kept straight. On the inner periphery of semi-cylindrical surface, three bars of MS sheet were welded longitudinally at the radial interval of 50 mm. The dimension of bar was (L×W×T) 500×40×2 mm. These plates formed plant deflector (Fig. 2). The plate was fixed with the mainframe using mile steel bars.

The inner guiding plate was made similarly but the rear uniform curved sheet was not required. The photograph of inner and outer crop guiding plate is shown in Fig. 1. The guiding plates were fixed on the frame.

The upper portion of the plant remains spread radially from the vertical as shown in stage 1 in Fig. 2. The width of passage between the leading plates was decreased gradually to bring together the upper part of the plants. The gradual curve portion of the plate converges the upper part of the plants as illustrated in stage 2. The converged plants are placed over the circumference of the threshing cylinder as shown in stage 3.



(a) Inner guiding plate (b) Outer guiding plate; 1. Front end, 2. Leading plate, 3. Gradual curve 4. Rear end

Fig. 1: Photograph of the inner and outer crop guiding plate

The rear segment keeps the upper portion of plant bent along the circumference and lower portion vertical. The bent upper portion bears the grain. It comes closer to the rotating threshing cylinder when strikes to the plant deflector. The bending starts after a height of 60 cm. after this height, the panicle portion appears on the plants. The lower portion of the plates supports the plants during feeding in the threshing cylinder and maintains the plants in an upright posture until they exit at the rear end. The uniformly curved portion is the rear portion of outer plate and it works as casing of the threshing cylinder.

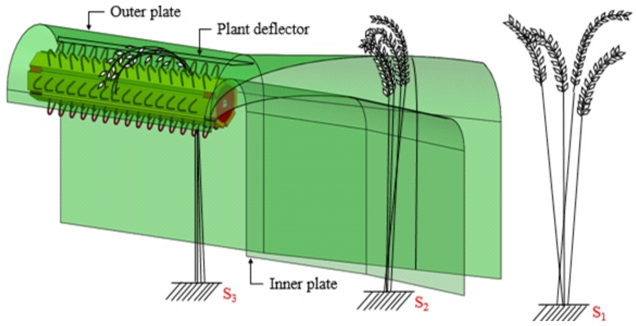


Fig. 2: Illustration of crop convergence and bending of plants over the circumference of threshing cylinder by the guiding plates

Threshing cylinder

A photograph of threshing cylinder fitted with wire-loop threshing elements (1) is shown in Fig. 3. The bars were fixed on the periphery of two separate rings (2) at the ends. A hole of 8 mm diameter was made at each end of the bar (3) so that they can be bolted on the circumference of the rings. The rings were connected to the shaft (4) through a key. This shaft was coupled with engine using the belt drive.

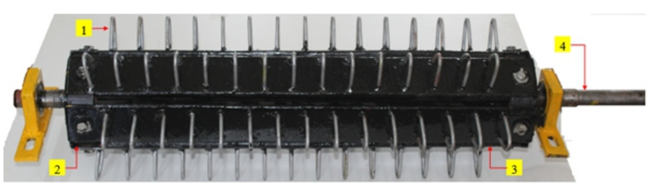


Fig. 3: Photograph of the wire-loop threshing cylinder

Concave

The concave was used to retain the un-threshed grains till threshing. It was 520 mm long and 210 mm wide and encloses the threshing cylinder from both sides. The size of concave opening was 9 mm. The wrap angle of concave with the threshing cylinder was 150°. The axial and curved bars were made of GI wire of 4 mm diameter and 520 mm length, respectively. It was fixed with the mainframe below the cylinder using nuts and bolts. A photograph of the concave is shown in Fig. 4.

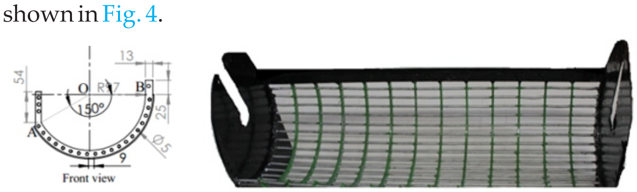


Fig. 4: Photograph of the wire-loop threshing cylinder

The drawing of 3D model of four row direct ear-head harvester was prepared using the licensed version of SOLIDWORKS 2013 edition software. The design and fabrication was done in laboratory and workshop of Agricultural and Food Engineering Department of Indian Institute of Technology Kharagpur (West Bengal). It is shown in Fig. 5.

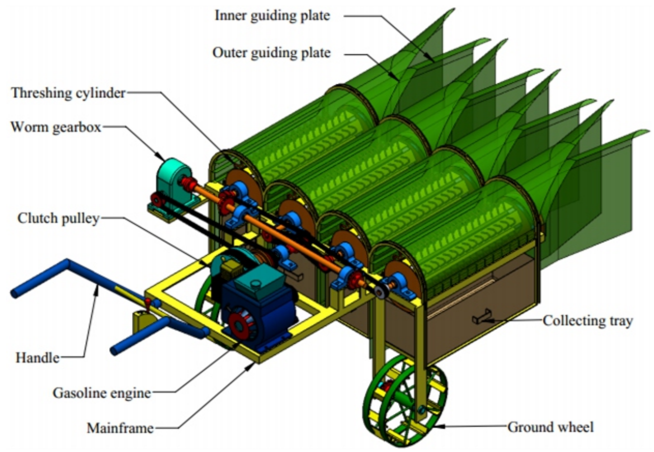


Fig. 5: Diagram of four-row prototype stripper harvester

Testing of direct ear-head thresher

The prototype of the four-row harvester was tested in the Research Farm of the Agricultural and Food Engineering Department, IIT Kharagpur. A two-factor three-level response surface design was used for testing. The two factors viz. cylinder speed (V_P) and forward speed (V_F). In the preliminary trials, it was observed at cylinder speed below 10 ms^{-1}, the threshing efficiency was below 95% and at cylinder speed above 26 ms^{-1} the broken grain was more than 3%. Therefore, considering undesirable outputs, the operating range of cylinder speed was taken between 12 and 24 m s^{-1}. Similarly, at 0.3 km h^{-1} forward speed the field capacity was low and the un-threshed grains remain on the plant at above 0.9 km h^{-1}. Considering these results the operating range of forward speed was taken from 0.32 to 0.88 km h^{-1}. These were set at three levels 12, 18 and 24 m s^{-1} and 0.32, 0.6 and 0.88 km h^{-1}, respectively.

The speed ratio was changed by changing the pulleys to get their different levels. The v-belt drive was used to transmit the power to the threshing cylinder. The pulleys of grooves A and B were used. In groove A, a total of 7 pulleys: 4 nos of driven pulleys of 2-inch diameter and 3 nos of driving pulleys of 2, 4 and 6-inch diameter were used, respectively. In groove B, driving and driven pulleys of 2 and 8-inch diameter, respectively were used. The chain-sprocket transmission was used to drive the ground wheels. Total 4 no of sprockets: 2-driven and 2-driving carry 11 teeth. The sprocket shaft receives power from an intermediate shaft at a speed ratio of 1, 2 and 2.5. The pulley diameter was 2, 4 and 5-inch corresponding to these speed ratios. The rotational speed of the threshing cylinder before and during threshing was measured using a tachometer. It was a laser phot non-contacting type tachometer (manufacture: Triplett and model no TA150-NIST). In order to measure the forward speed, the known length of crop row i.e. 30 m was divided by the time taken to travel this distance. This time was measured using stopwatch. The headland pattern was followed during the testing. The engine started to run idle for 2 minutes to attain its uniform speed. The threshing started as the machine started to move forward. The threshed mixture was collected in the individual collecting tray. The samples were collected after each run and evaluated to optimize the factors. The parameters like threshing efficiency, percentage of clean grain and grain loss were calculated. Grain to straw ratio and moisture content of the grain and the straw were determined. The optimized speeds of threshing cylinder and forward travel were 18.94 m s^{-1} and 0.8 km h^{-1}, respectively.

The prototype was evaluated in a large size field also using optimized values to determine the effective field capacity and fuel consumption. The experimental plot area was 25×35 m and the crop was grown over an area of 20×30 m. A distance of 2.5 m was left uncultivated from each side of the boundary as turning space of the machine. The time required for turning the machine at the headland and total time required to thresh the whole field was measured using a stopwatch. The standard top-up method was followed to measure fuel consumption. The performance parameters were calculated again.

RESULTS AND DISCUSSION

The machine was tested on the Research Farm of the Agricultural and Food Engineering Department, IIT Kharagpur (West Bengal). The details of the crop used for threshing the direct ear-head thresher are given in Table 1.

Table 1: Plant height, weight of grains per hill, ear-head length and other crop parameters

Sl. No.	Parameter	Values
1	Plant height	110 cm
2	Weight of grains $hill^{-1}$	48 gram
3	Length of ear head	Min. 17 cm and Max. 29 cm
4	Number of ear head $plant^{-1}$	20
5	Variety	IR-36
6	Moisture content	Grain:32 – 36%, Straw: 56 – 62% (wet basis)
7	Grain to straw ratio	1:0.26
8	Crop duration	110 Days after transplanting

The direct ear head thresher was tested and the effect of cylinder speed and forward speed on threshing efficiency, percentage of clean grain and total grain loss were determined. The field capacity, fuel consumption and cost of operation were also determined.

Threshing efficiency (η_{th})

There is a significant effect of the peripheral speed of cylinder (V_P) and forward speed (V_F) on the threshing efficiency (η_{th}) at 1% level of significance as given in ANOVA Table 2. The surface plotted for the threshing efficiency against V_P and V_F as is shown in Fig. 6. It shows that the threshing efficiency increased with the increase in V_P for all levels of V_F. It might be due to the increased frequency and magnitude of the impact force of cylinder. A similar trend has been reported by Alizadeh and Khodabakhshipour (2010). Also, there was a significant effect of V_F on threshing efficiency. It decreased with the increase in V_F for all levels of the V_P. This is because the retention period of plants in the threshing chamber reduced with the increase in forward speed and thus the crop throughput rate.

Table 2: PCombined ANOVA for performance parameters of paddy thresher tested

Source of variation	df	*F*-value		
		Threshing efficiency (η_{th})	Percen tage of clean grain (η_c)	Total grain loss (L_{gt})
Model	5	103.91 **	17.16**	13.91 **
A-Peripheral speed of cylinder, m s^{-1}	1	536.52 **	58.55**	19.32 **
B-Speed of plant feeding, km h^{-1}	1	22.75 **	6.20 ns	0.67 ns
A×B	1	5.93 ns	8.87 ns	13.20 **
A^2	1	28.53.48 **	5.77 ns	23.15 **
B^2	1	0.46 ns	0.23 ns	0.39 ns
Residual	4	0.38 ns	0.51 ns	0.75 ns
Total	14			

** Denotes highly significant at the 1% level, df: Degrees of freedom, ns: Non-significant.

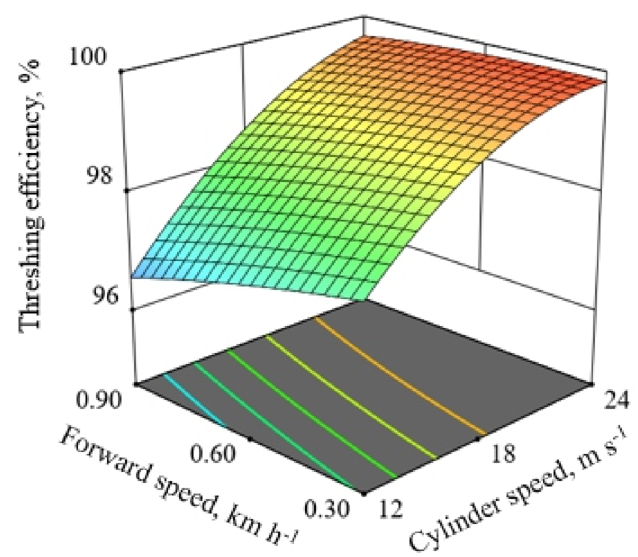


Fig. 6: Surface plot showing the effect of cylinder speed and forward speed on threshing efficiency

Percentage of clean grain

The clean grain excludes straw, chaff, unfilled grains, un-threshed grains and damaged grains from the threshed mixture collected in the tray. The ANOVA shown in Table 2 represents that the percentage of clean grain was significantly influenced by the cylinder speed at 1% level of significance. A plotted surface shown in Fig. 7 depicts that the clean grain was initially increased and then decreased with the increase in V_P for all levels of V_F. Because cylinder transfers low momentum to the crop at a low V_P. This resulted in no damage low breakage of the straw and chaff. By increasing V_P up to some extent, the clean grain was found to be increased. Probably due to the increase in threshed grain. With a further increase in the cylinder speed, the clean grains started to decrease significantly. Such variation could be attributed due to the breakage of grains, and breakage of more straw and chaff.

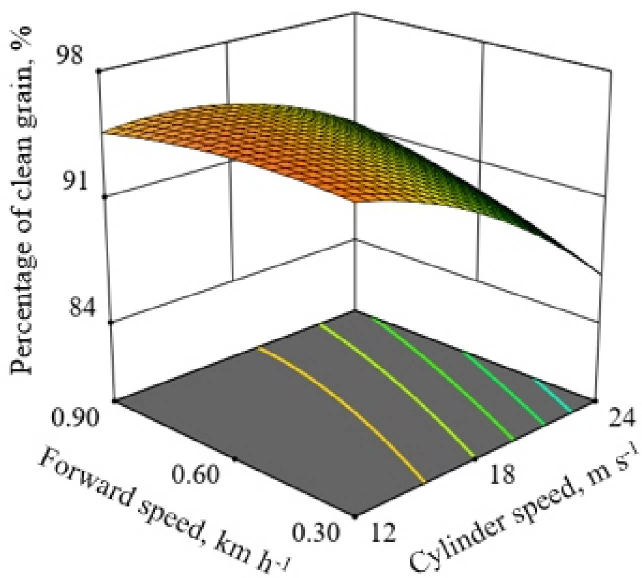


Fig. 7: Surface plot showing the effect of cylinder speed and forward speed on clean grain

Total grain loss

The total grain loss is the ratio of sum of shattered (W_s), un-threshed (W_u) and damaged grain (W_d) to the total weight of grain fed (W_{gf}) to thresher. The shattered grain collected from the field after threshing. The un-threshed grain collected from the threshed mixture of grain collecting tray and from the plants bears the grains after being threshed. The damaged grain collected from the threshed mixture of collecting tray. The total grain fed is the sum of grain of collecting tray, shattered grain (W_s) and the grains that remain on the plants after threshing. The total grain loss varied from 3.28 to 6.8%. There was a significant effect of V_P on the L_{gt} at 1% level of significance. This is given in ANOVA Table 2. The response surface of total grain loss was plotted with the V_P and V_F as shown in Fig. 8. It is shown that at a low V_P, the total grain loss was high for all levels of V_F. Probably due to un-threshed grains. Gradually it decreased with an increase in V_P. Further, with high V_P, there was a reduction in total grain loss could be due to the increased damage and shattered grain. However, V_F was non-significant in total grain loss in the range of V_F studied. The interaction effect of V_P and V_F was also significant. The variation in the relationship between total grain loss and peripheral speed due to the change in forward speed was because of a change in the retention period.

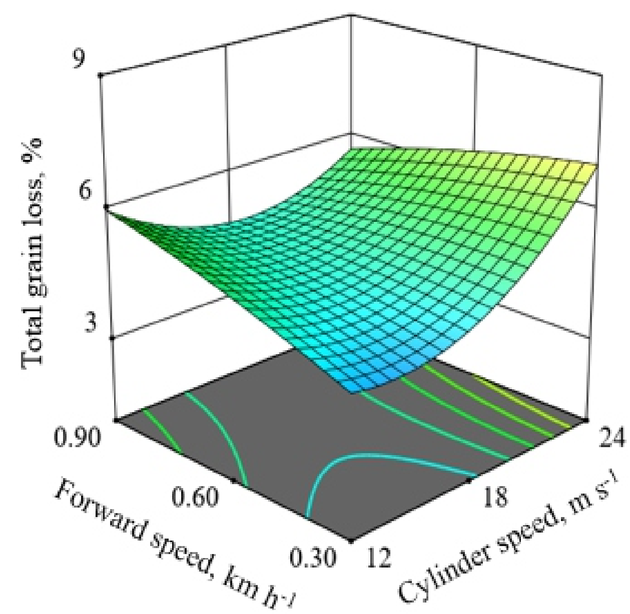


Fig. 8: Surface plot showing the effect of cylinder speed and forward speed on total grain loss

The four-row prototype thresher was also tested in the large field of 50×40 m (0.2ha) after optimizing the speeds of threshing cylinder and forward travel i.e. 18.94 m s^{-1} and 0.8 km h^{-1}, respectively. The overall dimension of the machine was 2.1×1.1×0.90 m. The working width, track width, wheelbase and weight of the machine were 1.0, 0.80, 0.54 m and 92 kg, respectively. The photograph of the direct ear-head thresher during field testing is given in Fig. 9.

Fig. 9: Photograph of four-row prototype direct ear-head harvester during field testing.

The grain throughput rate, threshing efficiency, broken grain and grain loss were 346 kg h^{-1}, 98.36, 94.93 and 4.20%, respectively. In total grain loss, the broken, shattered and damaged grain loss were 0, 2.56 and 1.64%, respectively. The effective field capacity, fuel consumption, labor requirement and cost of operation were 0.065 ha h^{-1}, 0.96 l h^{-1}, 16 man-h ha^{-1} and 3462 ₹ ha^{-1}, respectively. The details of calculation of cost of operation are given in Table 3.

The performance parameters like labor-time requirement, grain loss and cost of operation of developed direct ear-head harvester, traditional mini combine harvester and head feed combine harvester were calculated and compared. The, estimated cost of operation for mini combine harvester and Japanese two-row harvester based on the above-reported data would be ₹ 6983 ha^{-1} and ₹ 6,550 ha^{-1}, respectively. The average labor requirement and grain loss were 8 and 12.50 man-h ha^{-1}, and 5.5 and 6.08%, respectively.

Table 3: Details for calculaton of cost of operation for direct ear-head harvester.

Type of cost	Calculation	Cost, ₹ h^{-1}
1. Fixed cost		
a. Depreciation	$D = \frac{P - S}{L \times H} = \frac{73000 - 7300}{6 \times 300}$	36.50
b. Interest	$I = \frac{A}{H} \times \left(\frac{i}{100}\right) = \frac{40150}{300} \times \left(\frac{14}{100}\right)$	18.73
c. Insurance and housing	$I \text{ and } H = \frac{A}{H} \times \left(\frac{2}{100}\right) = \frac{39050}{300} \times \left(\frac{2}{100}\right)$	2.67
2. Variable cost		
a. Fuel	F = Fuel consumption (l h^{-1}) × fuel cost (₹ l^{-1}) F= 0.96×100	96.00
b. Lubrication	$Lo = F \times \left(\frac{2.5}{100}\right) = 0.96 \times \left(\frac{2.5}{100}\right) \times 300$	7.20
c. Repair and maintenance	$R\&M = \frac{P}{H} \times \left(\frac{3}{100}\right) = \frac{73000}{300} \times \left(\frac{3}{100}\right)$	1.27
d. Wages to the labor	$O = \frac{\text{Wages per day}}{\text{Working hours per day}} = \frac{500}{8}$	62.50
Cost of operation (₹ h^{-1})	Fixed cost + Variable cost = 57.91 + 166.91	224.83
Cost of operation (₹ ha^{-1})	Cost due to machine (₹ h^{-1}) / EFC (ha h^{-1}) = 225/0.065	3462.0

P= Purchase price (₹ 73000), S = Salvage value, 10% of P (₹), L = life of machine (6 years), H = Working hours y-1 (300 h), A = Average purchase price (P+S)/2, i = Annual interest rate (@14%/annum), F= fuel cost (100₹ l-1), Lo = Lubricant cost (300₹ h-1), labor charge = 500₹ d-1.

CONCLUSIONS

The direct ear-head thresher was operated at cylinder speed and forward speed of 18.94 ms^{-1} and 0.8 km h^{-1}, respectively, at which the threshing efficiency, grain throughput capacity, and total grain loss were 98.86%, 346.50 kg h^{-1}, and 4.20%, respectively. The straw intake was reduced by 95% due to feeding only grain-bearing portions. Therefore, no grain cleaning unit was equipped. The fuel consumption of the direct ear-head harvester, existing mini combine and head feed combine was 14.75, 11.80 and 18.50 l ha^{-1}. It was 20% higher than the mini combine and 25% lesser than the head feed combines. The field efficiency was 82%. In comparison to head feed combine, mini combine harvester and Japanese two-row harvester, the cost of operation of the developed harvester was less by ₹6882, 3521 and 3088 ha^{-1}. This shows that the developed direct ear-head harvester was suitable for medium-scale farms.

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