R-2578
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REVIEW ARTICLE Agricultural Reviews

Harvesting and Threshing Methods for Paddy-II: A Review

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10.18805/ag.R-2578

ABSTRACT

Threshing of paddy crop is carried out using manual, animal or mechanized power sources depends on the farmland size. In a thresher, rasp bar, spike tooth, peg tooth and wire-loop type threshing elements can be fitted with the threshing cylinder irrespective of direction of crop feed and flow. Different elements are responsible to thresh the crop with different actions which include impact, rubbing, combing, squeezing and their combination. This review was carried out to explore the effect of different threshing elements and threshing methods on performance of paddy threshing. Unlike threshing of other cereal crops, hull removal is not required in paddy. Selection of threshing elements based on the crop to be threshed. The type of threshing element determines the threshing efficiency, energy requirement and grain loss. Among rasp bar, spike tooth, peg tooth and wire-loop type threshing elements, wire-loop type was found to be most suitable for paddy threshing. Factors like cylinder speed, cylinder type and diameter, concave clearance and throughput rate affect the threshing performance. A low speed of cylinder produces more un-threshed grains. It can be compensated using for axial flow thresher as it has high crop retention period. Contrarily, a high speed is responsible for better threshing efficiency along with the more grain breakage and energy consumption. Using tangential flow thresher crop retention period can be minimized. The work rate of pedal and power thresher was, respectively 2 and 10 times more than that of manual threshing. The average threshing efficiency of pedal thresher, power thresher and combine harvester was reported to be 97 to 99%, 96.30 to 99.75% and 98.5%, respectively.

Key words: Energy consumption, Grain loss, Threshing efficiency, Threshing mechanism.

Reaping and threshing of the paddy are two important operations which determine the percentage of grain recovery from the crop. It requires appropriate mechanization to produce efficient threshing with minimum grain loss. In India, threshing of paddy is carried out through various methods. The methods adopted for paddy threshing is largely dependent on the field size. Threshing efficiency and throughput capacity are major concern. These concerns can be achieved using power-operated threshers. Nonetheless, non-availability of power-operated threshers in peak season resulted in increase of time requirement and thus increase the input cost. Small scale combine harvester is not very popular in India because of high cost of the machine. The paddy thresher may be equipped with different types of threshing elements. In this study, the mechanism, efficiency, power and grain loss of different types of threshing methods used for paddy threshing and the factors affecting threshing performance are reviewed and discussed.

Threshing is the process of separation of grains from the crop. It involves impact, rubbing, squeezing, combing or a combination of these actions (Miu 2015). In ancient days, paddy threshing was carried out manually by beating the plants on a wooden plank or beating by stick after laying them on the ground, then animal treading was adopted. In animal treading method, the plants were spread on the floor and the farm animals were made to walk on the paddy and the threshing took place by the force applied through animal's feet. The threshing rate of manual and animal power source was very low. To increase the work capacity, mechanical method was introduced. The thresher was invented in 1785 by Mr. Andrew Meikle who was a Scottish mechanical engineer. It had a drum of diameter 25 cm and four rasp bars were mounted on its periphery of the drum. The cylinder could be rotated at a peripheral speed of 4 to 6 m s^{-1} using wind power, horsepower or steam power. Later a pedal-operated mechanical thresher was introduced. It had a cylinder that carried a set of threshing elements. A pedal-operated mechanism was used to rotate the cylinder (Chakraverty *et al*., 2003). The grain bearing portion of the crop was placed over the cylinder and the plants were held in hands at one end. Sketch of a thresher is shown in Fig 1.

The crop is fed in a direction perpendicular to the axis of the threshing cylinder. The plants enter through the inlet. The threshing elements hit the plants imparting impact and rubbing. This results in separation of the grains. The concave

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How to cite this article: Sahu, S.K. (2023). Harvesting and Threshing Methods for Paddy-II: A Review. Agricultural Reviews. doi: 10.18805/ag.R-2578.

Submitted: 28-07-2022 **Accepted:** 13-02-2023 **Online:** 10-04-2023

holds the plants so that the threshing elements act on them repeatedly. The separated grains and the broken stem pass through the concave openings. An ideal thresher should thresh completely at maximum throughput rate without any change in the natural size and shape of the grain. There should be minimum grain loss and quality of grain should be preserved (Miu, 2015 and Anonymous, 2008).

Threshing element

The threshing element plays an important role in threshing performance. Different types of threshing elements that can be used in paddy thresher were studied. When the cylinder rotates, the threshing elements strike the crop and transfers an impact force to various parts of the plant. Due to the impact, the grain gets separated from the pedicel. Different types of threshing elements like rasp bar, spike tooth, peg tooth and wire-loop type are described by Kanafojski and Karwowski, (1976); Kepner *et al*. (2005) and Srivastava *et al*. (2006). Sketches of these elements are given in Fig 2.

Rasp bar

A rasp bar threshing element is made by preparing corrugations on the surface of a flat bar. The corrugation makes an angle with the longitudinal axis of the bar as shown in Fig 2(a). It is used for a wide variety of cereal and pulse crops (Pierre, 1979 and Chakraverty *et al*., 2003). Threshing occurs mainly due to rubbing of the plants between surfaces of the rasp bar and concave and transfer of very little impact force (Singh 2016; and Fu *et al*., 2018). Due to inclination of the corrugation, the plants tend to move towards one side of the bar. To reduce the accumulation due to this movement, the adjacent bars are provided with inclination in opposite directions. The breakage of straw and the power requirement is less (Anon., 2019). The demerit is its low threshing efficiency with moist and long-stemmed plants (Bosoi *et al*., 1987). This type of threshing element is generally used in tangential flow threshers.

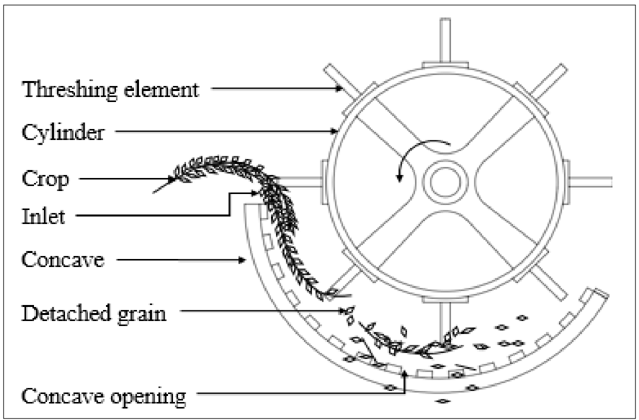

Fig 1: A conceptual diagram of tangential feeding of crop in a thresher.

Spike tooth

The spike tooth threshing element is an impact type threshing element (Fu *et al*., 2018). Threshing occurs when the tooth makes an impact on the grains. Combing also thresh up to some extent. The surface of the tooth which strikes the plant is curved (Fig 2b) like the curve on a cone. It makes a smooth and gradual penetration into the plant layers. The gradual curvature is responsible for reducing the magnitude of impact force (Kanafojski and Karwowski, 1976).

Peg tooth

Peg tooth type threshing element is made of bars having either rectangular or circular cross-section. A rectangular cross-section type element is shown in Fig 2(c). Its striking surface has a larger contact area compared to the spike tooth type which helps in breaking of the pods or cobs of the crop by impact, crushing and squeezing. It is an impact type of threshing element.

Wire-loop

In wire-loop type threshing element separation of grains occurs mainly due to impact and combing actions rather than the rubbing action (Chakraverty *et al*., 2003). It has an inverted V-shape (Fig 2d). It is primarily meant for threshing paddy crop. Indian Standard Specification for Pedal Operated Paddy Thresher (Anonymous, 1982) recommends following specifications. The diameter of the wire should not be less than 3 mm. Distance between the legs should be between 25 and 32 mm. The element height and lateral spacing between two threshing elements on a bar should be about 50 mm and 50 to 70 mm, respectively.

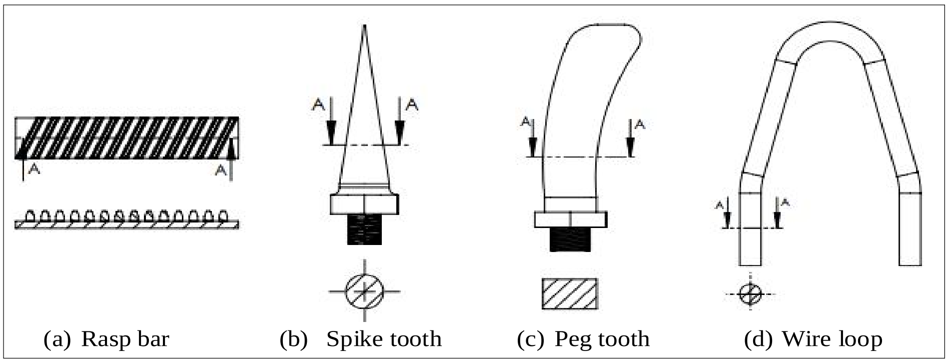

Fig 2: Schematic view of different types of threshing elements.

Submergence in the crop layers is more in peg tooth, spike tooth and wire-loop type threshing elements than in the rasp bar type because of their geometry and spacing. The rasp element has poor penetration in crop layer and the bar slips when it comes in contact with the crop (Kanafojski and Karwowski, 1976). For the same reason, these elements work well in the moist crop conditions also. However, breakage of the straw is also more which increases the load on the cleaning units. Breakage of straw is not required in paddy crop, therefore, peg tooth type element is not used frequently in paddy thresher (Bosoi *et al*., 1987). The conical tip of spike tooth responsible for more straw breakage which is not desirable in paddy. The peg tooth experiences more thrust force compared to rasp bar, spike tooth and wire-loop type threshing element. This is because the striking surface of peg tooth is rectangular which has more contact surface area than the circular one. The pegs are equuiped in axial flow threhser because of good threshing efficiency and smooth axial movment of straw. The breakage of grains and straw is more with spike tooth and peg tooth compared to the other two (Sudajan *et al*., 2002 and Yaoming *et al*., 2008). On the other hand, a wire-loop element has less weight and less frontal area and hence the probability of breakage of grains and straw is less.

Force acting on crop

The element strikes to the crop and transfer the required force for separation. The power required for threshing the crop is define using the equation .

$$P = q' = \frac{V_2 - V_1}{1-f}$$

Where,

q' = Crop throughput rate (kg h^{-1}).

V_2 and V_1 = Crop velocity after and before strike (m s^{-1}).

V_2 = 0.7 and 0.85 times of cylinder peripheral speed.

f = Coefficient of rubbing between crop and cylinder material. 0.65 to 0.75 for rasp bar and 0.7 to 0.8 for peg tooth type element.

Movement of crop during threshing

According to the method of feeding the thresher has been classified into two types (Chakraverty *et al*., 2003; Devnani and Ojha, 2016 and Fu *et al*., 2018)-throw-in type and hold-on type. In the throw-in type thresher, the whole crop is fed into the thresher through a feeding chute. Depending on the movement of the crop inside the thresher, this is further divided into tangential and axial flow types (Singh, 2016).

Tangential-flow thresher

In a tangential flow thresher, the crop is fed from one side of the cylinder and the crop moves in a direction tangential to the cylinder and perpendicular to its axis (Miu, 2015 and Fu *et al*., 2018). This is illustrated in Fig 1 earlier. In this arrangement, the crop passes through the space between the cylinder and concave only once (Khan, 1986). Therefore, the time available for separation of grains is less. To overcome poor separation, the cylinder speed is increased which increase the impact force and the frequency of hitting resulting in good separation. Consequently, the grain damage increases and fragmentation of the straw and leaves increases. Consequently, more amount of straw and leaves pass through the concave perforations. These mix with the grains and increases the load on the cleaning units. The power requirement increases. It is used mostly for the crops in which the straw breakage is considered to be advantageous (Singh, 2016).

Axial-flow thresher

In an axial flow thresher, the movement of the crop occurs in a helical path while being threshed. However, the feeding can be kept tangential or axial. The threshing elements are arranged on the cylinder in a helical path (Khan, 1986). This is shown in Fig 3. Movement of the crop takes place parallel to the axis of the cylinder in addition to its movement in tangential direction (Keller, 1969 and Fu *et al*., 2018). The retention time of the crop in the thresher is increased which gives ample time for detachment of the grains. A lower speed of the cylinder may be sufficient to give full separation. Damage to the grains is also less. It does not cause excessive breakage of the straw and is suitable for paddy crop (Singh, 2016). In this type of thresher, the straw comes out from one end of the cylinder after separation. In a hold-on type thresher, only the panicles or ear-heads portion is fed inside the thresher. A pedal-operated paddy thresher is an example of hold-on type thresher.

Thresher performance parameter

Threshing efficiency (η_{th})

It is the ratio of the weight of total threshed grains (W_{gu}) collected from all the sources to the total grains fed to the thresher (W_{gf}). It is calculated using Eq. (1).

$$\eta_{th} = \frac{1-W_{gu}}{W_{gf}} \times 100\% \qquad \dots (1)$$

Threshing capacity (C_{th})

The threshing capacity of a thresher is defined as the ratio of mass of grain (W_g) threshed by the thresher per unit time (t_{th}). It is expressed in kg per hour.

$$C_{th} = \frac{W_g}{t_{th}} \qquad \dots (2)$$

The threshing efficiency and capacity significantly vary according to the type of thresher (Devnani and Ojha, 2016 and Singh, 2016). The manual and animal power operated thresher are pedal-operated thresher and olpad thresher, respectively. The power-operated threshers are driven by a tractor, power tiller, stationary engine or an electrical motor. In pedal-operated thresher, the crop is held in hand. Ear-head portion of the crop is placed over the threshing cylinder. The cylinder is rotated by a pedal-operated mechanism (Anon., 1986, Chakraverty *et al*., 2003 and Agrawal *et al*., 2012). Pinion gear, crank gear, connecting rod and pedal form parts of the mechanism (Fig 4). The pedaling action is converted into the rotary motion of the cylinder using a crank-follower mechanism.

The olpad thresher (Fig 5) is made of a set of discs fitted on shafts. Commonly a unit has three parallel shafts carrying a total of 20 number of discs. The front and the rear shafts have 7 discs each and the middle shaft has 6 discs (Devnani and Ojha, 2016). The discs are notched and covered from the top and a seat is provided. The front end of cover is attached with a beam is attached and a single point hitch. The crop is spread over the floor. The thresher

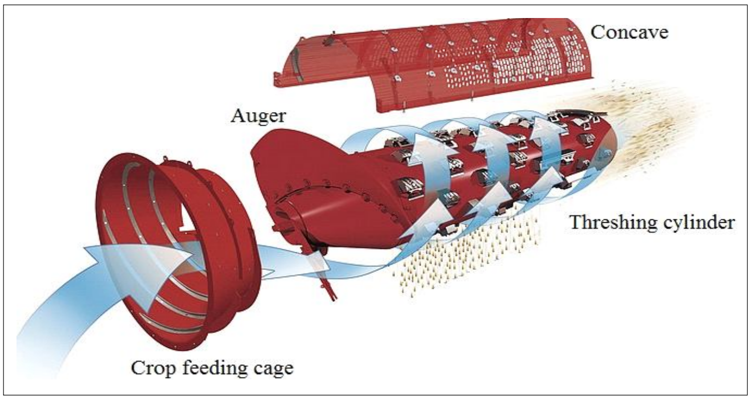

Fig 3: Movement of crop in a helical path in an axial flow thresher (Fu *et al*., 2018).

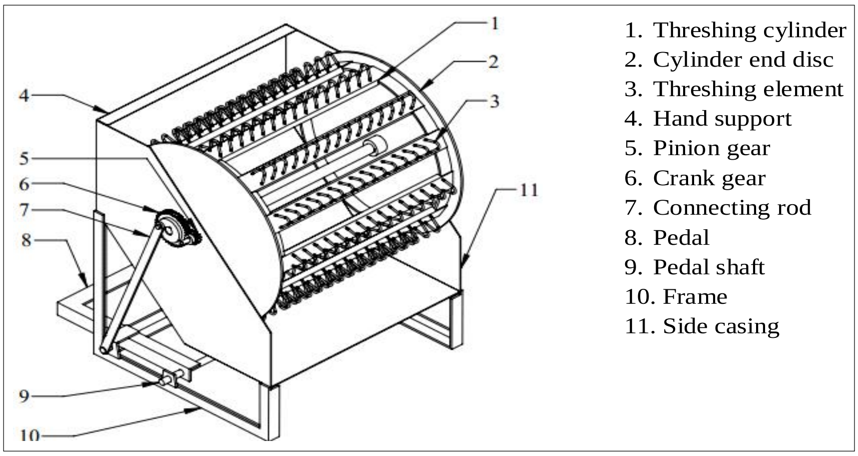

Fig 4: Schematic diagram of a pedal-operated paddy thresher.

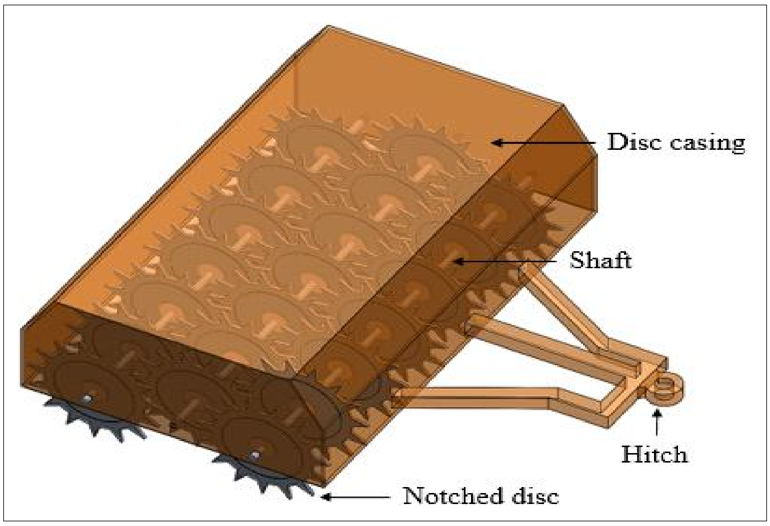

Fig 5: Schematic diagram of olpad thresher.

is pulled over the crop by a pair of bullocks in a circle. An operator sits over the seat and controls the movement of the bullocks. The discs press the plants due to their weight and separate the grains.

The power thresher mainly comprised threshing cylinder, concave, blower, casing, feeding chute, flywheel, straw outlet, sieves and grain and chaff outlets. Electric motor, IC engine, tractor or power tiller can be used as prime mover (Devnani and Ojha, 2016). The crop is fed to the cylinder through the feeding chute. The threshing occurs inside the chamber and threshed mixture fall through the concave openings. A fan produces a high-velocity air stream which sucks the straw and chaff from the mixture and discharges from the straw outlet. Straw residue which cannot be blown away are separated later. The grains and straw pieces get separate through overflow and under flow sieves, respectively. The clean grains get discharged *via* grain outlet (Chakraverty *et al*., 2003). The size of the prime mover used in power threshers varies from 3.5 to 30 kW (Pandey *et al*., 2013).

In a combine-harvester, the crop standing in the field is cut and then fed to a threshing cylinder. The functional components of a combine harvester are header, threshing cylinder, concave, sieve, blower, straw walker, grain storage tank and grain conveyor. The crop cut by the cutter bar and delivered to threshing unit through a conveyor. Threshing process is similar to that of stationary power operated thresher. The grains along with the straw and chaff passes through the concave after threshing and fall over a grain pan. It oscillates and transfers the mixture to a straw walker. It is a perforated sieve. It also oscillates continuously. It passes the grain through the perforations and discharges the straw at its rear end. A blower is provided at this end for removing the chaff. Few of the grains which remain un-threshed falls over a tailing auger through an extension chaffer. This un-threshed portion is transported back to the inlet of the threshing cylinder using an elevator for threshing again (Kepner *et al*., 2005; Bosoi *et al*., 1987; Culpin, 2013 and Miu, 2015). The clean grains fall from the straw walker over a second sieve for removal of any impurities that remain. Then grains are discharged into the grain collecting tank using a grain conveyor. From the tank, the grains may be transferred to a trailer using an unloading conveyor.

Khan (1971) carried out experiments on threshing of paddy crop by manual, animal and mechanized methods. In hand beating and animal treading threshing, the grain throughput rate of 15 to 40 kg h^{-1} could be obtained. Foot treading by man and by animal required a minimum 200 and 89 man-hours ha^{-1}, respectively. In mechanical methods, pedal threshing and threshing with combine harvester were carried out. The threshing capacity was 40 to 70 and 412 kg h^{-1}, respectively. The average labour requirement was 128 and 12.5 man-hours ha^{-1}, respectively. Khan (1971) also investigated the tractor treading threshing. Its capacity and average labour requirement were 640 kg h^{-1} and 80 man-hours ha^{-1}, respectively. The threshing was also done using the combine harvester "IRRI-PAK" variety. It was a two-row model having effective field capacity and fuel consumption of 0.08 ha h^{-1} and 2.26 l h^{-1}, respectively when operated at 0.62 km h^{-1} forward speed.

Varshney *et al*. (2004), Agrawal *et al*. (2012) and Singh *et al*. (2008) investigated the threshing capacity, threshing efficiency and energy requirement of a commercial model pedal-operated paddy thresher. Amponsah *et al*. (2017) compared manual and mechanical methods of threshing on Amankwati paddy variety. In mechanical threshing method, a commercial model power thresher model "Yanmar DB 1000" fitted with a 4 kW diesel engine was used. Diameter and length of its threshing cylinder were 500 and 1000 mm, respectively. The cylinder was operated at speeds of 200, 400 and 600 rpm. The performance parameters of different methods of paddy harvesting conducted by various researchers are summarized as given in Table 1.

Harvesting of paddy with combine harvester

Kalsirisilp and Singh (2001) used a stripper header combine for harvesting paddy variety SP-60 at straw and grain moisture content of 69 and 20% respectively. Diameter and length of the stripper rotor were 540 and 3000 mm respectively. Average forward speed of machine was 5.5 km h^{-1} and speed of stripper rotor was 600 rpm. It was also reported that the power consumed in stripping the panicles by the stripper rotor, threshing, traction and transmission loss was 17.2 (29%), 11.6 (20%), 23 (39%) and 7.2 kW (12%), respectively.

Amponsah *et al*. (2017) evaluated performance of a mini combine harvester Model 4LZ-1.0 fitted with a 16 kW diesel engine and having 1360 mm cutter bar width. Paddy crop varieties IR841 and Nerica L20 were harvested. The harvesting capacity was reported to be in the range of 0.10 to 0.39 ha h^{-1} at forward speed in the range of 2.1 to 4.46 km h^{-1} irrespective of the crop variety. The grain throughput rate was 350 to 1515 kg h^{-1} and 500 to 3160 kg h^{-1}, respectively for crop varieties IR841 and Nerica L20. Fuel consumption was 9.05 down to 7.13 l ha^{-1} irrespective of crop variety.

From the review, it can be said that the throughput rate can be increased by reducing the straw feed rate. The power and energy consumption can be minimized by minimizing the straw intake.

Thresher performance parameters

The parameters that affect performance of a thresher are grouped as machine parameters, crop parameters and operational parameters.

Machine parameters

Type and spacing of threshing element

Sarwar and Khan (1987) conducted a comparative study of the performance of paddy threshers fitted with the rasp bar and wire loop threshing elements. They found that the rasp bar cylinder produced more un-threshed as well as damaged grains than the wire loop. They also reported that at a constant peripheral speed of 22.35 m s^{-1} and at a low concave clearance the percentage of damaged grain was seven times more in the rasp-bar cylinder. Dutt (1993) carried out a comparative study on different types of threshing elements on two varieties of gram crop, B-108 and Vijaya. Three types of threshing elements were used, rasp bar, plastic-covered peg tooth type and plastic covered wire-loop type, at five levels of peripheral speed, 9.43, 10.78, 12.13, 13.48 and 14.83 m s^{-1}; three levels of concave clearance, 10, 12.5 and 15 mm and five levels of crop feed speed, 0.044, 0.088, 0.133, 0.177 and 0.222 m s^{-1}. The threshing efficiencies were 80.02, 72.50 and 75.25% and percentage of damaged grains were 3.99, 6.40 and 5.71%, respectively with the rasp bar, peg tooth and wire loop threshing elements at mid-levels of cylinder speed, concave clearance and crop feeding speed for B-108 crop variety. In identical operating conditions, the threshing efficiencies were 79.76, 75.25 and 77.85% and percentage of damaged grains were 5.40, 7.30 and 7.0%, respectively for Vijaya crop variety. Lohan *et al*., (2007) compared the performance of the thresher with a hammer, spike tooth and rasp bar type threshing elements. Pigeon pea crop was threshed at different combinations of the speed of threshing cylinder of 400, 450 and 500 rpm and concave clearance of 5, 10 and 15 mm. Threshing efficiency was a maximum of 99.02% for the cylinder equipped with spike tooth threshing element. It decreased with decrease in speed and increased with increase in concave clearance. They reported that the damage of grain was a maximum of 16.54% with hammer mill cylinder at speed and concave clearance of 500 rpm and 5 mm, respectively. Minimum damage of 3.5% was with rasp bar threshing element at a cylinder speed of 400 rpm and 15 mm concave clearance.

Singh *et al*. (2008) investigated the effect of spacing between threshing elements on the performance of a pedal-operated paddy thresher. They varied the spacing from 35 to 45 mm at an interval of 2.5 mm. They reported that at a cylinder peripheral speed of 7.32 m s^{-1} the threshing capacity and threshing efficiency were increased with increase in spacing up to 40 mm and thereafter it decreased. Khayer *et al*. (2019) carried out experiments on threshing of paddy crop. They varied tooth spacing in the bar, spacing between the bars fitted on the cylinder, height of teeth and cylinder speed. Each variable was varied in three levels. The wire-loop element spacing was 35, 45 and 55 mm; height was 40, 50 and 60 mm and cylinder speed was 300, 400 and 500 rpm. Spacing between the bars was changed by varying the number of bars fitted on the cylinder which was 12, 13 and 14. The experiment was designed with response surface methodology. They reported that there was a significant effect of element spacing and element height on threshing capacity. At cylinder speed of 400 rpm, it was reported to be more than 52 kg h^{-1} at 35 mm spacing and then increased marginally at about 40 mm and then again decreased at 55 mm.

From the above-discussed finding, it can be concluded that the types and spacing of threshing element affect the performance of thresher. The hammer mill and rasp bar are responsible for most and least damage of grains, respectively. Spacing below or near to 40 mm gives more threshing efficiency and capacity for the pedal-operated thresher. The less number of impact per unit length of bar could be the possible reason for greater spacing. On the other hand, improper penetration and poor combing could be the reason for low spacing.

Table 1: Performance parameters in different methods of threshing and harvesting.

Operation	Field capacity (ha h^{-1})	Grain throughput rate (kg h^{-1})	Fuel consumption (l h^{-1})	Energy consumption (kWh ton^{-1} of crop)	Efficiency (%)	Grain loss (%)	Labor requirement (Man-hour ha^{-1})
Crop cutting							
Sickle	0.006-0.012	NA	NA	2.5-3.05	98.10	3.2	80-160
Rotary blade cutter	0.064	NA	0.25	-	-	2.3	16
VCR	0.28	NA	0.80	-	-	1.05	3.6
Crop collecting + bundling + transportation							
Manually	0.0125–0.025	NA	NA	-	NA	2-4	40-80
Threshing							
Manual treading	NA	15	NA	12.85	-	4.50	200
Hand beating	NA	64.9	NA	1.85	91.67	4.35-8.46	80 (16 ton^{-1})
Animal treading	NA	40	NA	17.90	-	6.20	89
Pedal thresher	NA	40-70	NA	0.78	97–99	1-3	100-128
Tractor treading	NA	640	-	19.75	-	7.0	80
Power thresher	NA	158.4-1000	NA	4.16-9.90	96.30-99.75	1.28-5.95	10-25
Combine-harvester							
Mini	0.10-0.39	1515	11.0	-	98.18	4.4-5.6	7.69
Japanese two row	0.08	412	2.26	-	98.50	6.08	12.5
Head-feed	0.26-0.30	1450	15-18.5	-	96.95	4.48	5.28-7.52
Standard reel header	0.62	2480	18.5	-	97.65	4.42	2.2-4.4
Stripper header	0.66	3640	15.9	7.91	98.05	4.00	7.6

Diameter of threshing cylinder

Abich *et al*. (2017) examined the effect of cylinder diameter and cylinder speed on the performance of a sorghum thresher. They used threshing cylinders of 200, 300 and 400 mm diameter and carried out threshing at 8, 10 and 12 m s^{-1} peripheral speed. The threshing cylinder was equipped with peg tooth type threshing element. The diameter of the threshing cylinder was varied by using the pegs of different length. They observed that the threshing efficiency increased with increase in the cylinder diameter at all levels of peripheral speed. The cylinder diameter and speed significantly affected threshing efficiency. The percentage of grain damage increased with increase in the cylinder diameter at all peripheral speeds. The cylinder diameter and the cylinder speed significantly affected the grain damage. There was a significant effect of cylinder diameter and cylinder speed on the throughput per unit power consumption. It was minimum at 300 mm diameter mainly because the detachment of grains was greater due to the increased height of peg. At 200 mm diameter, the throughput was low due to less detachment of grains. At 400 mm diameter, the throughput per unit power consumption was less because the power consumption was affected by the weight of the cylinder.

Concave clearance

Physical dimensions of the grain affect the concave clearance and its grate size. Vas and Harrison (1969) investigated the grain damage and 'threshability' of wheat crop in a stationary thresher. They took three levels of concave clearance *i.e*. 6.35, 12.70 and 19.05 mm and operated the threshing cylinder at five levels of peripheral speed *i.e.* 22, 25, 28, 31 and 34 m s^{-1}, respectively. They found that the grain damage was a minimum 5% and maximum 8% at concave clearance of 19.05 and 6.35 mm, respectively at all levels of cylinder speed. The low clearance cause thin crop bed therefore, cushioning reduces and direct impact of element increase breakage and vice versa is also true.

Method of threshing

Alizadeh and Bagheri (2009) investigated the effect of threshing methods on two paddy varieties. Four methods of threshing were used. In the first method (T_1), a power tiller operated wire-loop cross-flow thresher was used. The cylinder diameter and speed were 490 mm and 15.40 m s^{-1}, respectively. In the second method (T_2), a tractor-operated spike tooth axial-flow thresher whose cylinder diameter and speed were 400 mm and 13.13 m s^{-1}, respectively, was tested. In third method (T_3), a tractor-operated spike tooth cross-flow thresher was used. The diameter and peripheral speed were 580 mm and 19.60 m s^{-1}, respectively. In the fourth method (T_4), the combine harvester equipped with spike tooth cylinder was tested. The diameter and peripheral speed of cylinder were 600 mm and 19.60 m s^{-1}, respectively. They reported that with the above input parameters, the threshing efficiency was 99.56, 99.52, 99.46 and 99.42% and shattering loss was 0.46, 0.62, 0.52 and 0.57% for the above four methods, respectively with Hashemi variety. The broken and hulled grain losses were affected significantly by the type of threshing method. Minimum loss of 0.98% was found with treatment T_1 and maximum loss of 2.82% was found with treatment T_4. There was hardly any significant difference between the methods in Khazer variety. However, significant effects were reported on grain loss due to shattering and on damage to the grain. Shattering loss was 0.43, 0.56, 0.54 and 0.52% and grain damage was 0.83, 1.80, 2.57 and 3.14%, respectively, with the above four methods.

Based on the above explanation, it was concluded that there was a significant effect of threshing methods on the efficiency and grain loss. The grain loss was reported more at higher cylinder speed and spike tooth type threshing elements. The wire-loop type threshing elements gives low grain loss.

Crop parameters

Moisture content

It has been reported in many studies that the threshing efficiency and breakage of grain decreases with the increase in moisture content whereas the power consumption increases (Vejasit and Salokhe, 2004; Alizadeh and Khodabakhshipour, 2010 and Osueke, 2014). Singh and Singh (1981) investigated the effect of moisture of soybean crop on the threshing efficiency and seed loss. They selected two varieties of soybean Ankur and PK 71-21 and carried out threshing at cylinder speeds of 8.2, 11 and 13.7 m s^{-1}. They observed that the threshing efficiency decreased with increase in moisture content for the range of cylinder speed tried. The percentage of damaged seed decreased with an increase in moisture for both the varieties. The un-threshed seed and power requirement during threshing was less when the crop was dry but the percentage of damaged grain increases. The dried grains are more susceptible to damage as their elasticity is reduced (Kanafojski and Karwowski, 1976). The power requirement for breakage of the straw also decreased because the strength of dried straw is less. It is recommended by the Indian Standard IS: 8122 (Part 1) (Anonymous, 1994) that the ranges of moisture content for the paddy grain and straw should be from 10 to 25% and 20 to 70%, respectively, when it is harvested using a combine harvester.

Amount of non-grain materials in the crop

It has been reported by several researchers (Price, 1993; Chinsuwan, 2010; Sangwijit and Chinsuwan, 2010 and Olaye *et al*., 2016) that the amount of non-grain materials which includes straw, chaff and leaves substantially affects the functioning of a thresher. It is obvious that longer the straw higher is the ratio of MOG to the grain. Relative increase of the amount of straw causes formation of a thick bed between the cylinder and the concave. It reduces the movement of the separated grains. In addition, it creates a cushioning which decreases the effect of the impact force of the threshing elements on the crop. Therefore, threshing efficiency reduces. Price (1993) conducted experiments in laboratory and field on threshing of wheat and barley crops using a modified stripper combine harvester. It was reported that during ear-heads stripping the grains got separated in the stripper rotor itself before reaching the threshing unit. This process was termed pre-separation. To collect this separated grain, a sieve was placed below the conveyor augur and a set of trays were also put below them. The percentage of grain separated at the stripper rotor and the thresher outlet was evaluated with pre-separator as well as without pre-separator. The grain throughput rate was 5, 10 and 15 t h^{-1} and straw throughput rate ranged from 0 to 5 t h^{-1}. Straw intake in a stripper harvester is less when feeding only the ear-heads instead of the whole crop. In the laboratory experiment carried out by Price (1993), the straw to grain ratio was 0.26:1 and 0.52:1 for wheat and barley crops, respectively. It was reported that at zero straw throughput, the threshing efficiency was low because the grain is not retained in the threshing chamber for enough time. It passed easily through the concave when cylinder impacted. The efficiency was increased with increase in the straw feed rate and reported to be a maximum at 1 t h^{-1} throughput. With further increase in the straw feed rate from 1 to 5 t h^{-1} in the machine they used, the efficiency decreased. This was because the impact of the threshing element was dampened by the layer of the non-grain materials.

Operational parameters

Important machine specifications and settings are specified by the Bureau of Indian Standards in a test code IS: 8122-2000 on harvesting paddy crop by a combine harvester (Anonymous., 2000). It is recommended that the peripheral speed of threshing cylinder and concave clearance should be within 6 to 15 m s^{-1} and 5 to 10 mm, respectively. The range of forward speed of operation should be between 2.5 and 4.5 km h^{-1} for standing crop and 1 to 1.5 km h^{-1} in case of lodged crop. The reel index should be in the range of 1.10 to 1.15. Cylinder speed determines the frequency of hitting and the magnitude of momentum transferred to the plant. It has been reported in numerous studies that higher the speed higher the percentage of grain separation. However, the percentage of damaged grain and power consumption increase with the increase in cylinder speed. Studies of some researchers like Kradangnga *et al*. (1991); Sudajan *et al*. (2002); Vejasit and Salokhe, (2004); Osueke, (2014) and Olaye *et al*. (2016) confirms the above facts. Kradangnga *et al*. (1991) studied on threshing of paddy crop using an axial flow thresher. The thresher consisted of a cylinder fitted with spike tooth threshing elements whose diameter and the length was 49 and 122 cm, respectively. The experiment was carried out with the crop variety Luang Pathan at 13.60% grain and 10.20% straw moisture content, respectively. They varied the peripheral speed from 12.83 to 20.52 m s^{-1} at constant concave clearance of 15 mm. Average threshing efficiency, cleaning efficiency and percentage of broken grain were reported as 92.68, 94.07 and 4.15, respectively at the speed of 12.83 m s^{-1}. These values were increased by 5, 1.6 and 93.37%, respectively when the speed increased to 20.52 m s^{-1}. Average grain throughput rate, power consumption and specific energy consumption were 810.70 kg h^{-1}, 3.5 kW and 4.35 kWh ton^{-1} of grain, respectively at the cylinder speed of 12.83 m s^{-1}. These values were increased by 65.77 and 118.10 and 31.29%, respectively when the crop was threshed at 20.52 m s^{-1}. Alizadeh and Khodabakhshipour (2010) investigated the interaction effect of cylinder speed and grain moisture content on damage of paddy grain in an axial flow thresher. They evaluated the performance at five different levels of peripheral speed, 12.01, 14.67, 17.35, 20.01 and 22.37 m s^{-1} and three levels of grain moisture content, 17, 20 and 23% (wet basis). The percentage of broken and cracked grains increased significantly with the increase in peripheral speed at all levels of grain moisture content. The breakage of moist grains was less compared to grains having less moisture. The reason for this behavior was justified as the grain with less moisture has more plasticity and absorb less impact force.

SUMMARY AND CONCLUSION

Threshing capacity of pedal thresher and power operated thresher was reported to be 2 and 10 times higher, respectively than manual threshing. However, in power thresher, energy consumption is also high. It requires 4 to 10 times less labour and produces clean grain which cannot be obtained in manual and pedal threshing. In a cereal crop thresher, different types of threshing elements are used. The wire-loop threshing element is recommended for paddy crop. The tangential flow thresher is recommended where breakage of straw is required along with threshing. A low cylinder speed is suitable of axial flow thresher because of high crop rotations period compared to tangential flow. Different researchers suggested the range of peripheral speed of threshing cylinder from 6 to 25 m s^{-1} at different values of crop moisture content and grain to straw ratio. According to various researchers, the cylinder speed and throughput rate are the most important parameters that influence the performance of a thresher. The selection of cylinder speed depends on the moisture content of the plant, grain to straw ratio and throughput rate. A low cylinder speed is responsible for low threshing efficiency and high speed is accountable for improved threshing efficiency, but it causes more breakage of grains and greater energy consumption.

Conflict of interest: None.

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