Research article

Performance Evaluation of Power Operated Cyclonic Cotton Picker

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aspirator speed;
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Abstract

A cyclonic cotton picker was developed and its performance was evaluated on the basis of output capacity, picking efficiency, trash content and collection efficiency at the aspirator speeds of 4500 rpm, 5500 rpm and 6500 rpm, and at the pickup pipe diameters of 18 mm, 25 mm and 32 mm. A maximum output capacity of 8.29 kg/h with maximum picking efficiency of 93.27% was determined for pickup pipe diameter of 32 mm at aspirator speed of 6500 rpm. A minimum trash content (6.59%) and maximum collection efficiency (98.67%) were also seen for the aspirator speed of 6500 rpm when a pickup pipe diameter of 18 mm was used. It was found that the developed cyclonic cotton picker performed better when the aspirator speed was increased. Also, the fuel consumption was found to be 0.77 L/h, 0.96 L/h and 1.30 L/h at the aspirator speeds of 4500, 5500 and 6500 rpm, respectively. Cost analysis was also performed to check the economic feasibility of the developed cyclonic cotton picker. The total cost of the developed cyclonic cotton picker was found to be Rs. 135.30/h. Also, the break-even point was estimated to be 487.90 kg per annum, which was 12.30% of the annual utility rate of 480 h. The custom fee and the operating cost for the cyclonic cotton picker were calculated and found to be Rs. 211.40/h and Rs. 124.62/h, respectively. For a harvesting season of 60 days/year, the pay-back period was found to be 4.15 years.

1. Introduction

Cotton is one of the most important crops in the world. It is used to make a wide range of products, ranging from clothing to bedding to medical supplies. It is an agricultural product that is both natural

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and rapidly renewable [1]. Cotton output increased from 13.8 million tonnes in the 1980s to 27 million tonnes in 2018 [2]. Cotton often referred to as the “King of fiber” or "white gold" has been in cultivation in India for more than seven thousand years. Currently, India ranks first in cotton cultivation area and second in raw cotton production, accounting for 33.23% of total cotton cultivation area worldwide [2]. Cotton accounts for approximately 4.7% of the total cropped area in the country, and its cultivation is concentrated in the states of Maharashtra, Gujarat, Tamil Nadu, Uttar Pradesh, Karnataka, Madhya Pradesh, Rajasthan, Punjab, and West Bengal. Despite the fact that most modern countries use machinery to pick cotton, it is still hand-picked in India [3-6]. This causes a number of health issues as well as loss of quality [7]. Additionally, the process of picking cotton is both time-consuming and labor-intensive [8-10], requiring a large workforce to manually pick the cotton bolls from the plants requiring 1560 man-hours per hectare. According to studies, 33 kg/ha of cotton remains on the plant after harvesting, and pickers become infected as a result of contact with and inhalation of defoliating agents [11].

Cyclonic cotton-picking devices have the potential to reduce cotton harvest labor requirements. Cotton cultivation benefits from mechanisation in terms of cost and time [11, 12]. These machines use a combination of suction and centrifugal force to quickly and efficiently remove the cotton bolls from the plants, significantly reducing the time and labor required for harvesting [13]. One of the key benefits of cyclonic cotton-picking devices is their speed and efficiency. These machines are capable of harvesting large quantities of cotton in a short amount of time, reducing the need for a large workforce to manually pick the cotton bolls. The machines can be especially beneficial in areas where labor is scarce or expensive [14], and their use can result in a higher-quality product and a higher yield of usable cotton. There are also environmental benefits to using cyclonic cotton-picking devices and the cost of picking is also found to be lower [15]. In addition to reducing the need for manual labor, the use of a mechanical cotton picker reduces harvest loss by increasing yield by 20 to 25% and farmer profits by up to 20%. Because the machines are more efficient at removing the cotton bolls from the plants, there is less waste material left behind in the fields [11, 16] created a pneumatic cotton picker with a 50 mm pick-up diameter, a 3500 rpmaspirator speed, and a 50 kg collection drum. Cost, time, and energy savings were 15.8%, 67.5%, and 66.6%, respectively, when compared to traditional picking.

Despite these benefits, there are some challenges associated with the use of cyclonic cotton-picking devices. One of the main challenges is the cost of the machines, which can be prohibitively expensive for small-scale cotton farmers. Additionally, the machines require regular maintenance to keep them running smoothly, which can also be a significant expense. The majority of farmers are small-scale landowners, and the initial investment and on-going maintenance costs of cotton pickers are high. As a result, Indian farmers are slow to adopt cotton pickers and strippers [17]. Keeping the aforementioned points in mind, a power operated cyclonic cotton picker was developed, and its performance at different suction pipe diameters and aspirator speeds was evaluated. The research included a cost analysis of the developed cotton picker.

2. Materials and Methods

2.1 Conceptual working of cyclonic cotton picker

Pneumatic cotton-picking involves two main processes: the first process involves picking the cotton bolls from the plant burs, and the second process involves removing the cotton bolls from the air stream and conveying them to a collection tank. Cyclonic cotton-picking devices work by creating a strong airflow through a series of ducts and tubes. The cotton plants are fed into the machine, and the airflow quickly separates the cotton bolls from the rest of the plant material. The bolls are then drawn through the ducts and into a collection chamber, where they can be easily removed and transported to be processed further.

2.2 Design and development of cyclonic cotton picker

In the proposed cyclonic cotton picker, cotton bolls are picked by applying suction to them using various diameters of the pickup or suction pipe. The suction pressure is generated by the impeller. In general, air enters the impeller eye radially, travels through the impeller guide vanes, and exits through the blower. A pickup pipe is used to collect cotton bolls and transport them to the cyclonic device. The picked cotton bolls are placed in the cyclonic device, the cyclonic action separates the cotton bolls from the air steam, and the vortex created by the cyclonic action removes lower density materials such as fine leaf particles, stem, and clean cotton, which are collected in a collection tank. The outlet of the cyclonic device is connected to the impeller's inlet duct at the impeller housing. The cyclonic device's inlet is connected to the pickup pipe. Figure 1 and Figure 2 show the developed cyclonic cotton picker and its practical trial in the cotton field. The cyclone unit in a pneumatic system is made up of the inlet, vortex finder, cyclone body, cyclone cone, and apex part or discharge outlet of cotton bolls. The cotton bolls are drawn into the cyclone by a suction pipe. In a pneumatic system, the cyclone's inlet is designed as a tangential entry of air with cotton bolls at the cyclone's body [18]. The cyclone's outlet is connected axially at the top of the body. The vortex around the center of the chamber is created by the tangential inlet. Because the whirling air is lighter, it is collected in the center and delivered out the top of the opening as a vortex finder. Heavier materials slide down the cyclone body section's wall to the cyclone cone section. Because of the cone section, the cotton bolls in the slide move inward towards the axis and apex and get discharged from the bottom to the collection tank via the apex. The components of the developed cyclonic cotton picker are secured to the frame with provisions to be operated by a single person. A polypropylene drum of 14 L capacity is mounted vertically upward on the engine and the impeller for collection of cotton bolls. The weight of the machine is 15 kg and the maximum capacity of storage during picking is 8.29 kg. The capacity of the storage may vary due to differences in the bulk density of the cotton bolls. Other than the impeller, all other materials attached to the machine are made up of fibre; hence its weight is very light and easy to carry and operate. The total weight of the cyclonic cotton picker along with a maximum output capacity of cotton is 23.30 kg. Table 1 and Table 2 show the parameters and specifications of the developed cyclonic cotton picker.

Figure 1. The developed cyclonic cotton picker

Figure 2. Cotton picker during field performance

Table 1. Power consumption and diameter of barrel body of cyclonic cotton picker component [5]

Parameter	Method	Value
Pressure drop	$\Delta P = \frac{1}{2} \varrho_g {V_i}^2 H_V$ where ΔP = pressure drop ϱ_g = gas density, 1.293 kg/m^3 V_i = inlet gas velocity, 6.04 m/s H_v = pressure drop, expressed in number of inlet velocity heads, 55.57	1315 Pa
Power requirement	$P_r = Q \times \Delta P$ where P = power requirement, 36 J/s Q = flow rate, 0.0276 m^3/s ΔP = pressure drop	1.162 hp
Power consumption, Power	$P_c = \rho_{air} \times Q_{air} \times H_{air}$ where ρ_{air} = density of air, 1.293 kg/m^3, Q_{air} = air flow rate, m^3/s and H_{air} = air pressure, 221.82 m	0.82 kW
Diameter of the cyclone body (Barrel)	$D = 0.0502 \times 17 \left[\frac{Q \times {\varrho_f}^2 \times (1 - K_b)}{\mu_G \times \varrho_p \times K_a \times {K_b}^{2.2}}\right]^{0.454}$ where D = Optimum cyclone diameter, 0.482 (ft), Q = Gas flow rate, 0.9747 ft^3/s, ϱ_f = Gas density, 0.0807 lb/ft^3, μ_G = Viscosity, 0.0655 lb/ft^3, ϱ_P = Cotton density, 11.674 lb/ft^3, K_a = Design parameter, 0.5, K_b = Design parameter, 0.2	150 mm

Table 2. Design specification of developed cyclonic cotton picker [8, 18]

Specification	Notation	Ratio	Value
Height of the body	H_C	2D	300 mm
Height of cone	H_d	2D	300 mm
Diameter of inlet pipe	d_i	D/2	75 mm
Diameter of exit pipe	d_e	D/2	75 mm
Diameter of cotton bolls outlet	J_c	D/4	38 mm
Length of vortex finder	S_c	$D_c/8$	19 mm
Total height of the cyclone	$H_C + H_D$	4D	600 mm

2.3 Performance evaluation of cyclonic cotton picker

The developed cotton picker's performance was assessed in terms of its picking efficiency, output capacity, collection efficiency, trash content and consumption of fuel (Table 3). For machine testing, the plot size of 1.20 m × 1.0 m was chosen for each parameter. During the field trial, the actual time of operation, time lost for unloading cotton bolls, time lost in adjustment, fuel consumption of the cotton pickers, and numbers of bolls left unpicked were all recorded. As suggested by Rangasamy *et al*. [16], the optimum speed of aspirator for cotton picker ranges from 2200 to 5500 rpm. As a result, three aspirator speeds (4500, 5500, and 6500 rpm) were chosen for the laboratory and field testing of the developed cyclonic cotton picker. The fuel consumption was calculated by filling the fuel measuring cylinder and running the cotton for a known amount of time in L/h.

Table 3. Performance evaluating parameters of the developed cyclonic cotton picker [13, 17]

Parameter	Method	Notation
Picking efficiency	$\eta_p = \frac{n_1 - n_2}{n_1} \times 100$	η_p = picking efficiency, per cent n_1 = number of bolls present before picking, n_2 = number of bolls present after picking
Trash content	$T = \frac{W_1}{W_2} \times 100$	T = trash content, per cent W_1 = weight of trash separated, g W_2 = weight of cotton received in drum, g
Output capacity	$OC = \frac{W_{mc}}{t_{mc}}$	OC = output capacity, kg/h W_{mc} = weight of seed cotton, kg t_{mc} = time, h
Collection efficiency	$\eta_c = \frac{m_c}{m_i} \times 100$	η_c = collection efficiency, % m_c = mass of cotton collected, kg m_i = mass of inlet cotton loading, kg

2.4 Evaluation of economics of cyclonic cotton picker

The unit's material cost and fabrication cost were calculated based on the materials used and labor requirements for the cyclonic cotton picker's fabrication. The RNAM test code procedure was used to calculate the cost of operation per kg of cotton collected by cyclonic cotton picker [19]. This cost was compared to the cost of manually picking 1 kg of cotton. The cost, time, and energy savings of each cotton picker were compared to the conventional method. The break-even point and payback period for cotton pickers were also calculated.

3. Results and Discussion

3.1 Physical properties of cotton bolls

The extracted cotton bolls were found to have an average major diameter, minor diameter, height, volume, bur width, and weight of 60.5 mm, 49.44 mm, 31.99 mm, 404303 mm^3, 12.12 mm, and 4.63 g, respectively.

3.2 Performance evaluation of developed cyclonic cotton picker

The performance of the power operated cyclonic cotton picker was evaluated in terms of its output capacity, picking efficiency, trash content and collection efficiency. The pressure required to pick the cotton bolls and the velocity of air flow were considered to be 0.025 kg/cm^2 and 54.40 m/s [18].

3.2.1 Output capacity

The output capacity of the cotton picker was found to be minimum (14.00 kg/h) at 4500 rpm when a pickup diameter of 18 mm was used, while the maximum output capacity of 8.29 kg/h was observed with a pickup pipe diameter of 32 mm and an aspirator speed of 6500 rpm. From Figure 3, it can be seen that the output capacity of the developed cyclonic cotton picker increased with the increase in the aspirator speed. It was also found that the matured and disease-free cotton bolls had a higher output capacity. The output capacity of cyclonic cotton picker was found to be lower for a pickup diameter of 18 mm when compared to 25 mm and 32 mm pickup diameter for all the aspirator speeds. The 32 mm pickup pipe diameter was found to give the maximum output capacity of 4.62 kg/h and 8.29 kg/h at aspirator speeds of 4500 rpm and 6500 rpm, respectively. The capacity of the holding tank was 4 kg to 5 kg depending on the bulk density of the cotton bolls. Fuel refilling was done every hour and the capacity of fuel was kept less (1.5 L) to ease operation and make the machine light. As per technical bulletin of Central Institute for Cotton Research, Nagpur, the average picking rate of person lies between 20 to 70 kg per day [20]. Generally, the cotton picker labor is available for picking work of 10 h, because the cost of picking is based on picking per kg of cotton which is already decided. The pre decided working hour is based on health hazard caused due to cotton varieties and heavy uses of pesticide (including Lambda cyhalothrin, Acetamipride, and so many systematic and contact insecticides, fungicide) on the crop that creates unhealthy condition, subsequently labor suffers from bruise and itching on hand.

3.2.2 Picking efficiency

The picking efficiency of the developed cyclonic cotton picker is presented in Figure 4. Pickup diameter of 32 mm at aspirator speed of 6500 rpm gave the maximum picking efficiency of 93.27%, whereas the minimum picking efficiency was seen in the case of pickup diameter of 18 mm at 4500 rpm aspirator speed. It can be seen from the graph that the picking efficiency increased with increase in aspirator speed and pickup diameter. The picking efficiency of the developed cyclonic cotton picker did not exhibit high differences for the considered pickup diameters at aspirator speed of 4500 rpm. When the aspirator speed was increased to 5500 rpm and 6500 rpm, the picking efficiency was found to increase from 90.79% to 91.64%, 91.59% to 92.66% and 91.80% to 93.27% for pickup diameters of 18 mm, 25 mm and 32 mm, respectively. Weather conditions (precipitation and rainfall amount) also have the great impact on picker efficiency, followed by crop moisture content, harvesting season length, machine reliability, travel time between fields, and so on [21].

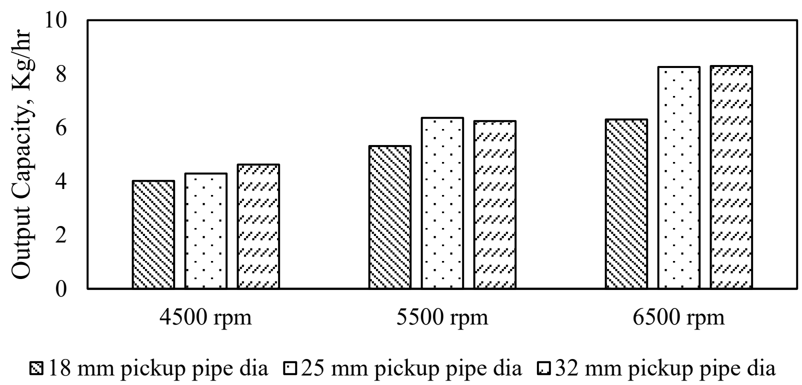

Figure 3. Effect of the aspirator speed on output capacity for different diameter of pickup pipe

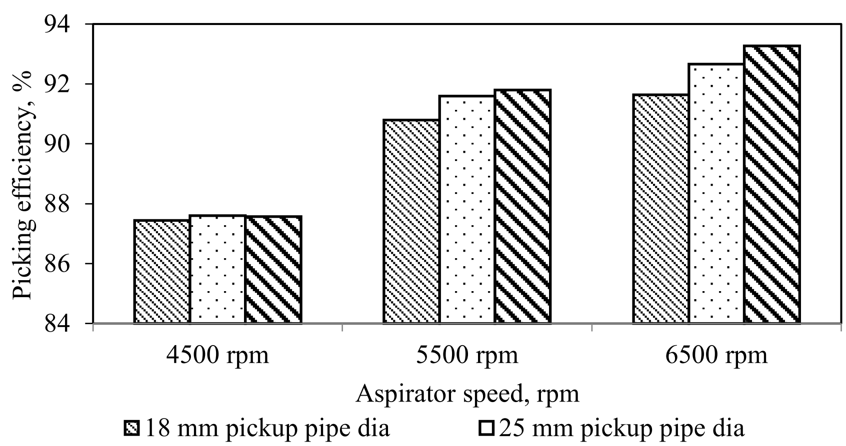

Figure 4. Effect of aspirator speed on the picking efficiency

3.2.3 Trash content

It can be seen from Figure 5 that the trash content decreased with increase in the aspirator speed. The maximum trash content (9.37%) was observed for pickup diameter of 32 mm at 4500 rpm aspirator speed, while the minimum trash content 6.59%) was seen when 18 mm pick diameter at aspirator speed of 6500 rpm. Very little variation in the trash content was seen for 18 mm and 25 mm pickup diameter for the different aspirator speeds, whereas the trash content was found to vary more when a pickup diameter of 32 mm was used. The trash content decreased from 8.16% to 6.59%, 8.22% to 6.67% and 9.37% to 7.73% for 18 mm, 25 mm and 32 mm pickup diameter, respectively, when the aspirator speed was increased from 4500 rpm to 6500 rpm.

3.2.4 Collection efficiency

Figure 6 shows the variation of collection efficiency of the developed cyclonic cotton picker when the speed of aspirator and diameter of pickup pipe were changed. The collection efficiency was found to increase with the increase in aspirator speed for all the diameters of the pickup pipe considered for the study, whereas the collection efficiency was seen to decrease when the pickup pipe diameter was increased from 18 mm to 32 mm at all aspirator speeds. The maximum (98.67%) and minimum (95.60%) collection efficiency were observed when pickup pipe diameters of 18 mm and 32 mm were used at aspirator speeds of 6500 rpm and 4500 rpm, respectively. The 32 mm pickup pipe diameter exhibited the lowest collection efficiency in comparison with the 18 mm and 25 mm pickup pipe diameters for all aspirator speeds.

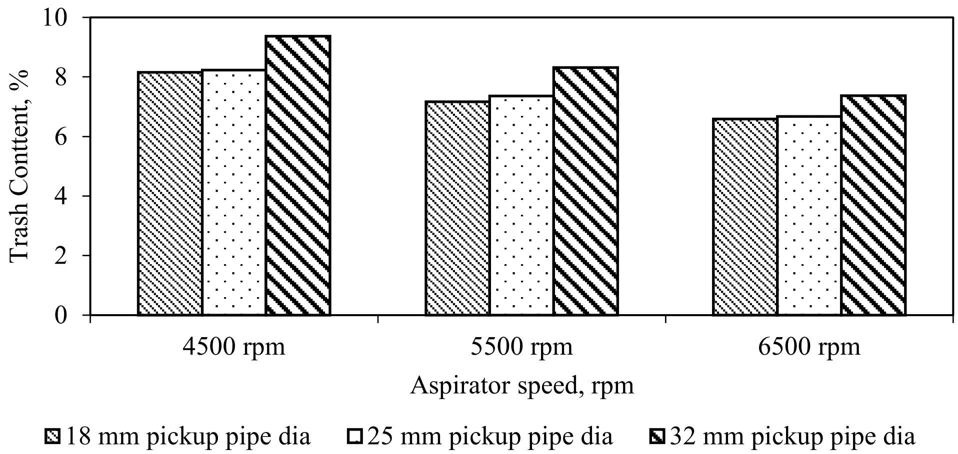

Figure 5. Effect of aspirator speed on trash content for different diameter of pickup pipe

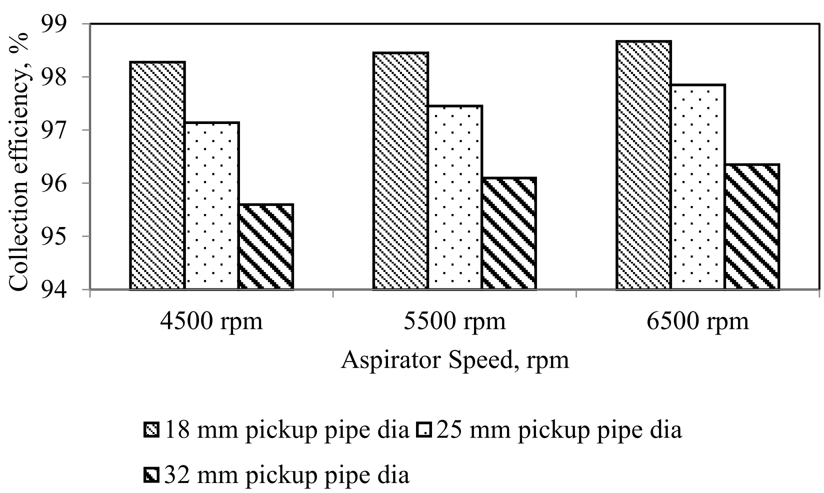

Figure 6. Effect of aspirator speed on collection efficiency of cyclonic cotton picker

3.3 Optimum variables for the operation of the developed cotton picker

The optimal diameter of the pickup pipe and aspirator speed needed to be determined in order to achieve maximum output capacity and picking efficiency with minimal trash content. The primary criteria for constrained optimization were minimum trash content and maximum output capacity, picking efficiency and collection efficiency. The pickup pipe diameter of 32 mm and aspirator speed of 6500 rpm were discovered to result in maximum output capacity, picking efficiency and collection efficiency, while the pickup pipe diameter of 18 mm produced the minimum trash content and maximum collection efficiency at the same aspirator speed. At optimal levels, the output capacity, picking efficiency, collection efficiency and trash content were 8.29 kg/h, 93.27%, 98.67% and 6.59%, respectively. Ahmed *et al*. [22] also developed a modified cotton picker with a high actual field capacity of 14.69 kg/h, a picking efficiency of 97%, and a lower specific energy requirement of 19 kJ/kg. A pneumatic cotton picker with a centrifugal blower and a 3.3 kW, 3000 rev/min petrol start kerosene run engine was also developed and tested by Majumdar *et al*. [23]. The developed cotton picker could pick the cotton at a rate of 3 kg/h and the machine's break-even capacity was determined to be 7.2 kg/h.

3.4 Cost economics of the developed cyclonic cotton picker

The cost economics of the developed cyclonic cotton picker were examined using the RNAM test code and harvester procedure [24]. The unit's break-even point and payback period were also calculated. From Table 4, it can be seen that the total cost of the developed cyclonic cotton picker was Rs. 135.30/h. Further, the cost of picking was found to be Rs. 16.20 per kg for output capacity of 8.29 kg/h and 8 hours of operation. The cost economic analysis of the cyclonic cotton picker gave a cost saving percentage of 10% when compared with the traditional hand-picking method. The break-even point was estimated to be 487.90 kg per annum, i.e., 12.30% of the annual utility rate of 480 h. The custom fee and the operating cost of the cyclonic cotton picker were Rs. 211.40/h and Rs. 124.62/h, respectively. The harvesting season of the cotton is 60 days/year so the pay-back period was found to be 4.15 years. It can be inferred that the developed cotton picker was technically as well as economically feasible. The manually cotton-picking rate ranges were from 15 to 20 kg in 6 to 8 h in day. Generally, cost of picking per kg was Rs. 21 per kg for a daily wage of Rs. 420 for a maximum picking capacity of 20 kg [22]. It depends on labor dexterous hands, number of cotton boll picking, concentration of open bolls and time interval between the picking of the bolls.

4. Conclusions

Cyclonic cotton-picking devices are an innovative and efficient technology that has the potential to revolutionize cotton production around the world. The maximum output capacity and picking efficiency of the developed cyclonic cotton picker was seen for 32 mm pickup pipe diameter at 6500 rpm speed of aspirator. The trash content and collection efficiency were also found to be minimum and maximum for the aspirator speed of 6500 rpm. While there are challenges associated with their use, the benefits of these machines are significant and include increased efficiency, higher quality product, and reduced environmental impact. As technology continues to advance, it is likely that even more innovative solutions to the challenges of cotton production in the years to come will be seen.

Table 4. Cost assumptions and evaluation of cyclonic cotton picker

Annual usage of cotton picker, day		60
Cost of harvesting by conventional method, Rs./kg		18
Actual working hours per day, h		8
Annual usage of cotton picker, h		480
Total life of cotton picker, year		7
Initial cost of cotton picker in Rupees		25,000
Salvage value (10% of initial cost of cotton picker) in Rupees		2500
		Cost (Rs./h)
Fixed cost		
Depreciation		6.7
Interest		2.65
Housing, 1% of purchase		0.52
Taxes, 1% of purchase price		0.52
Insurance, 1% of average price		0.29
	Total fixed cost	**10.68**
Variable cost		
Repair and maintenance, 6% of initial cost		1.12
Labour @ 130 per day		16.25
Fuel @ 78 per litre (1.25 L/h)		97.5
Lubrication, 10% of fuel cost		9.7
	Total variable cost	**124.62**

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