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Development of power-tiller mounted cotton picker for selective picking with women operators

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ABSTRACT

This paper highlights the development of women-operated pneumatic powered cotton picker attachment to power-tiller compatible to major Indian cotton varieties and the performance results with a special emphasis to optimization of functional components. For development of the unit, dimensions of machine parameters, viz. pick-up pipe diameter, filter type, filter height, collection drum capacity, and aspirator speed were optimized through build and test method. The effect of variations of said parameters on pressure, which directly induces picking force, was studied independently and in combination, and the best-suited parameters were selected through statistical analysis. From the statistical analysis, the optimized cotton picker is with pick-up diameter of 25 mm, nylon mesh filter of 400 mm height and with 150 L capacity collection drum with the aspirator speed of 5500 rpm. The cost of picking with picker was ₹ 9.50 per kg of cotton (0.16 USD). The saving in cost, time, and energy compared to manual picking are 17.0, 75.0, and 74.6% respectively. The break-even point and pay-back period for the picker are 5900 kg/annum and 0.45 year respectively. The pneumatic principles adopted in the development of cotton-picker are promising in addressing the requirement of the women for cotton picking in Indian farms.

Key words: Comfort, Cotton picking, Optimization, Women-friendly, Work efficiency

Production of high-quality cotton lint begins with variety selection, continues with attention to all production practices, and ends with a well-planned and well-executed harvest. Amongst all operations, cotton picking is the most difficult, tiresome and tedious job. The average labour requirement in conventional practice of hand-picking of cotton in India was reported to be 517 man h/ha (Prasad *et al.* 2007). It was not only a tedious job but also ten times costlier than irrigation and twice more than the weeding operation. Large scale adoption of Bt hybrid cotton during the last decade with higher boll retention brought lot of changes in cotton harvesting in rural India by limited availability of harvesting women labourers and rise in cost of seed cotton harvesting. Cotton harvesting manually involves a low to moderate drudgery due to posture, load of picked cotton and abrasion of fingers due to sharp points of dried bracts. Hand harvesting operation requires 450-500 women. h/ha (Raju and Gautam 2013).

Cotton is still a principal raw material for the world's textile industry and the invention of the cotton gin paved the way for the important place to cotton that holds in the world today. Grown in more than one hundred countries, cotton is a heavily traded agricultural commodity, with over 150 countries involved in either exports or imports of this universal textile raw material. In India, it is third in total acreage planted among all crops behind rice and wheat, and it was cultivated on about 11.61 Mha producing 33.4 million bales (bale of 170 kg) in 2012-13. In the last ten years, cotton acreage has been growing at an average annual rate of around 3%. However, the average cotton yield in India is only 0.49 tonne/ha compared to a world average of 0.73 tonne/ha (CCI 2013). Although India is currently first in area, second in yarn production, and third in raw cotton production in the world today, entire cotton is hand-picked by human labour. It is tedious work and also ten times costlier than irrigation and about twice that of weeding operation (Goyal *et al.* 2009).

Indian women workers traditionally involving in picking of cotton from bolls while men workers concentrate on remaining activities of cotton cultivation. In India, female agricultural workers constitute 50.2% of the total agricultural work force. Women constitute only 48% of total population in India; but 78% of economically active women in the country are engaged in agriculture compared to 63% of men. Women do approximately 65% of the farm manual labour work. Among the total women workers, 32.9% are

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cultivators and 38.9% are agricultural labourers, whereas among the total men workers, 31.1% are cultivators and 20.8% are agricultural labourers. Emerging studies and data suggest that increasing number of adult women in India are farmers. An analysis of the dynamics of agricultural workers in India shows a clear trend of increased women workforce participation in agriculture. It is also projected that their participation will touch 50% by the year 2020 (Anon. 2011). The women produce between 60 and 80% of the food in most developing countries and are responsible for half of the world's food production. As far as efficiency of work is concerned, it is reported that women labourers are more efficient than men labourer in respect of rice transplanting (16% more), weeding in rice and wheat fields (7-8% more), picking of pearl millet (25% more), and 37% more in picking cotton. To plan the 129 million worker population of women in Indian farms by the year 2020, appropriate tools and equipment are to be developed or modified to address their specific needs (Devangam 2008).

In recent years, it has been observed that labour shortages appear during peak periods of cotton harvesting. There are various types and designs of cotton harvesting machines available in the world. In advanced countries, cotton picking is carried out mechanically by cotton pickers (most commonly used machines) and cotton strippers. These harvesters are designed for the particular planting system, established in the advanced countries. Moreover, the cost of cotton production is excessively high, reducing the profit margin available to the cotton farmer. Since the varieties used in our country require cotton picking at several stages, the use of mechanical cotton pickers is not feasible as in the case of defoliated picking method (Goyal *et al.* 2009). Improvement in present cotton pickers will no doubt contribute to the solution of the above problems. However, complete solution is likely to come only through the use of some entirely different harvesting principle. A harvest method which does not require mechanical contact with the cotton bolls for removal from the bur would be desirable.

Considering the cultural and agronomical practices and staggered blooming characteristics of Indian cotton plant, mechanical harvesters are not considered suitable for Indian cultivars. That is Indian varieties need cotton picking at several stages and the use of mechanical pickers is not feasible, which lead to selective picking method (Singh and Buttar 2012). The only alternate for these problems is focusing towards pneumatic system of picking. Therefore the feasible alternative is to design a pneumatic powered picker. The development of such unit would be the first step into the mechanization of cotton cultivation. Also considering ergonomic limitations of the women operators, a power-tiller attached cotton picker was developed at Tamil Nadu Agricultural University, Coimbatore, India.

This present paper describes the development of women-operated pneumatic powered cotton picker attachment to power-tiller compatible to major Indian cotton varieties and the performance results with a special emphasis to optimization of functional components.

MATERIALS AND METHODS

A pneumatic-powered cotton picker was developed to increase the maneuverability and reduce the drudgery so that it can be used by women labourer by mounting the components in a power-tiller in such a way that it can be conveniently operated in the field and execute picking operation by selective picking method by four women labourers. The components were optimized and the dimensions were arrived (Vatsa and Saraswat 2008). The components are aspirator, cotton-filter, cotton collection drum, cotton pick-up pipe. Aspirator was specially designed with impeller of fifteen leaves for the optimized value of suction force of the four inlet pick-up hoses. The aspirator mounted in front of the power-tiller with suitable frame taps drive through pulley of 225 mm diameter and v-belt. The frame was supported by a ground wheel for easy mobility. The speed of aspirator was stepped up by fixing 75 mm diameter pulley in the aspirator shaft. A guard was provided on the belt and pulley arrangement as safety measure. The aspirator was mounted with the power-tiller. A polypropylene container of 150 L capacity was mounted on the power-tiller vertically with the support of L-angles. A cotton filter of 150 mm diameter and 400 mm height made up of nylon mesh was fixed at the centre of the collection drum vertically with a suitable flange to restrict the entry of cotton inside the aspirator. Four PVC hoses of 25 mm diameter were fixed on top of the collection drum diagonally with tank nipples for a length of 5 m, as pick-up pipes. The above half of the drum was attached with the four tank nipples in diagonally opposite directions. These nipples were in turn provided with 25 mm diameter pick-up hoses for collecting cotton. The bottom of the drum was cut open and fastened with suction duct. The suction duct was connected to the drum with an air-tight flange with clip. To facilitate the user to cover entire strip of the cotton field, four numbers of pick-up hoses of 5 m length were optimized.

Table 1 Specification of the unit

Parameters	Particulars
Overall dimensions (length×width × height), mm	170×950×3000
Prime mover	Power-tiller, 6.7 kW
Type of aspirator	Axial flow type
Max speed of impeller, rpm	5500
Min speed of impeller, rpm	2500
Type of collection drum	Polypropylene
Capacity of collection drum, L	150
Mounting of collection drum	Vertical pattern
Type of cotton filter	Nylon mesh
Mounting of cotton filter	Vertical pattern
Dimension of cotton filter, mm (dia×height)	150×400
Type of cotton pick-up pipe	Hose (pvc)
Number of pick-up pipe	4
Diameter of pick-up pipe, mm	25
Number of operators	4 women

Fig 1 Field operation of the unit

Since the pick-up hose is flexible a 100 mm G. I. pipe nipple was provided at the tip of pick-up hoses. The impeller eye was connected with the bottom of collection drum with a 75 mm diameter duct and sealed air-tightly. The specification of the cotton picker is given in Table 1. The operation of unit is shown in Fig 1.

To optimize the dimensions of the various components used in the prototype was achieved by carrying out an experimental design, i e Factorial Randomized Block Design (FRBD). In this analysis four factors, viz. pick-up pipe diameter, filter type, filter height, and collection drum capacity were considered for the optimization. Three levels were considered each and every factor chosen. The best combination of the dimensions of the various components is one that gives the maximum pressure. The analysis was repeated for the different speeds of engine.

It is essential to optimize the various machine and operational parameters namely, pick-up pipe diameter, filter type, filter height, collection drum capacity and aspirator speed, which control the suction force. The engine was allowed to run steadily at different speeds and the pressure, as well as pressure head loss at the tip of suction pipe were measured with U-tube monometer for different combinations of the above related parameters (Alan and Reza 2012).

A light-weight pvc pipe was used as pick-up pipe to reduce frictional resistance and weight of the unit. The velocity and pressure of air flowing through the suction pipe depends on the diameter of the suction pipe. Hence, the diameter of the suction pipe needs to be optimized with respect to the suction force of air required to be produced to effect pneumatic picking of cotton. The pick-up pipe diameter was varied to study the suction force of air stream generated by the aspirator to optimize the pick-up pipe diameter. Three levels of pick-up pipe diameter, viz. 18 mm, 25 mm and 32 mm were adopted for the experiment. Tank nipples (pvc) were used to connect the pick-up pipes. Suitable screen is to be provided as filter to restrict the entry of cotton into the aspirator and to allow the air alone to pass into the aspirator with less resistance in between the collection tank and the aspirator. The net suction force depends on the type of screen adopted. The nylon mesh, aluminium perforated sheet, and G.I. mesh made filters were selected and the best one was optimized based on the suction force developed at the tip of suction pipe. Three levels of filter height were taken for the study, viz. 300 mm, 400 mm, and 500 mm. The variation in the filter heights is necessary to accommodate the varieties in the height of collection drum (Selvan *et al.* 2010). By measuring the suction force created at the tip of the suction pipe, the filter height was optimized for its best performance.

The capacity plays a vital role in the suction force developed in the container, and hence it is essential to find out the optimum capacity of the container, which is used as collection drum. Three levels of collection drum capacity were selected for the investigation, viz. 100, 150, and 200 L. Aspirator is the pivotal component of the picker, which creates pneumatic force that is used for suction of cotton from boll. Though it is concluded in many conventional applications that the aspirator speed is proportional to the suction force, it is felt essential to study the relationship of suction force with the speed of aspirator so as to find the optimized speed of aspirator to suit pneumatic picking of cotton. For this purpose, four levels of speeds, viz. 2500, 3500, 4500, and 5500 rpm were selected.

The picker was evaluated for its performance in the fields. Twenty plots in which twenty varieties taken for this study were randomly distributed. Cotton picker was evaluated in each variety. Actual time of operation, time lost for unloading cotton, time lost in adjustment, fuel consumption, number of bolls left unpicked were observed during field trial (Brian 2013).

Field with twenty varieties of cotton crop was randomly selected and an area of 5×3 m plots of suitable numbers for three replications in all the varieties were marked. The operators were allowed to pick the cotton variety-wise by machine for known period of time. The weight of the seed cotton picked by the machine was analyzed in comparison with manual picking. The same procedure was repeated with desired interval during three pickings of cotton, viz. first picking, second picking, and third picking. The picking efficiency of cotton picking for twenty varieties with the cotton picker was also determined. The number of bolls in plots selected for determining field capacity including plots for replication was counted before and after picking. This procedure was repeated for all three pickings. The fuel consumption meter used for determining fuel consumption, consists of a measuring jar from which fuel was taken by engine. Fuel consumption was measured by operating cotton picker for known time. The difference in the volume of fuel in the measuring jar gave the volume of fuel consumed (Gisso *et al.* 2008). Trash content was estimated for all samples collected from three pickings with the machine picking as well as manual picking (Jianlong and Hezhong 2014). Trash content was estimated by trash analyzer in which trash is separated when the cotton is fed through inlet after ginning.

Based on the materials used and labour requirement for the fabrication of the cotton picker, the material cost and fabrication cost of the unit was calculated. The cost of operation per unit weight of cotton collected was worked out using the procedure recommended by RNAM test codes (RNAM 1995). This cost was compared with the cost of picking of one unit of cotton by conventional method. The saving in cost, time, and energy by using the cotton picker against conventional method was compared. The break-even point and pay-back period were also computed for the cotton picker (Dimitri 1999).

RESULTS AND DISCUSSION

Optimization of machine components

The dimensions of machine parameters, viz. pick-up pipe diameter, filter type, filter height, collection drum capacity, and aspirator speed were varied. The effect of variations of said parameters on pressure, which directly induces picking force were studied independently and in combination. The best-suited parameters were selected through statistical analysis (Jianlong 2014).

Pick-up pipe: Pick-up pipe diameter was varied and the effect was studied with different aspirator speeds. From the statistical analysis, the variation in diameter shows positive correlation, and the maximum pressure was obtained in 25 mm diameter pick-up pipe. The improved pressure in 25 mm diameter pick-up pipe may be due to drag coefficient during suction of seed cotton. In real action, the seed cotton is shrunk about half of its projected area due to suction force on cotton which matches with the 25 mm diameter pick-up pipe. In the case of 18 mm diameter pick-up pipe, entry becomes narrow and takes lot of time. In the case of 32 mm diameter pick-up pipe, the drag force gets affected due to very large difference between shrunk seed cotton projected area and pick-up pipe cross-sectional area, which makes atmospheric air entry and nullify the effect on seed cotton.

Filter type: There was very strong correlation between the filter type and pressure in the pick-up pipe. While the pressure with nylon filter (0.0472 kg/cm^2) and G.I. mesh (0.0463 kg/cm^2) are on par, the pressure of 0.0396 kg/cm^2 was drastically affected with the aluminium-perforated sheet. This variation among the filters may be due to the major variation in orifice configuration. Though the effect of nylon mesh filter and G.I. mesh filter were the same on pressure, the nylon mesh was selected for its light weight and anti-corrosive property. It is also evident from the statistical analysis that the nylon mesh filter is the best suited for the cotton picker.

Filter height: This variation among the filter heights was selected by considering the height of collection drum. The effect of filter heights on pressure was shown statistically significant. The maximum pressure could be obtained through height of 400 mm. It is also evident from analysis of variance (ANOVA) that the filter height has significant effect on pressure at the height of 400 mm (Table 2). Further increase of the filter height above the particular height might have created undue losses in suction with turbulence effect due to abstraction at the top of the collection drum for free flow of air.

Collection drum capacity: Three types of collection drum capacities were selected (100, 150, and 200l). From the statistical analysis, it was found that the variation in height has correlation with the pressure in pick-up pipe and 150 L capacity was optimized.

Aspirator speed: From the statistical analysis, it is evident that the aspirator speed had strong positive correlation with pressure in the pick-up pipe. The increase in the speed from 4500 to 5500 rpm does not make much influence on pressure in pick-up pipe. This variation may be due to the indirect power drive (V-belt drive) adopted in power-tiller where in transmission losses mainly through belt slippage could occur in higher range of loads. It is also observed that the pressure produced at speed 5500 rpm is suitable for the operation of four numbers of pick-up pipes.

The combined effect was also studied. The interaction of pick-up pipe diameter, filter type, filter height, collection drum capacity, and aspirator speed was found to be significant effect on pressure. The maximum pressure of 0.061 kg/cm^2 was observed in the picker from the combination of D2 (25 mm), F1 (nylon mesh), H2 (400 mm), C1 (150 L), for speed S4 (5500 rpm).

Field evaluation of cotton picker

The field capacity for twenty varieties of cotton crop mainly grown in the country was estimated with the cotton picker and compared with manual picking. From the Table 3, it was evident that there was a significant difference in field capacity of machines in comparison with manual cotton picking. In general the increase in field capacity was about

Table 2 Analysis of variance (ANOVA) for optimization of machine components

SV	DF	SS	MS	F
Treatment	80	6521615.599	81520.195	285.35**
D (D)	2	66535.302	33267.651	116.45**
H (H)	2	775787.432	387893.716	1357.79**
F (F)	2	926653.340	463326.670	1621.83**
C (C)	2	1934075.191	967037.596	3385.03**
D×H	4	35639.198	8909.799	31.19**
D×F	4	72833.957	18208.489	63.74**
D×C	4	44900.049	11225.012	39.29**
H×F	4	94644.438	23661.110	82.82**
H×C	4	129763.309	32440.827	113.56**
F×C	4	1944581.957	486145.489	1701.71**
D×H×F	8	27853.265	3481.658	12.19**
D×H×C	8	44487.284	5560.910	19.47**
D×F×C	8	90672.469	11334.059	39.67**
H×F×C	8	128307.932	16038.492	56.14**
D×H×F×C	16	204880.475	12805.030	44.82**
Error	243	69420.500	285.681	
Total	323	6591036.099		

**Significant at 1% level; CV = 5.6%; D-Pickup pipe diameter; H-Filter height; F-Filter type; C-Collection drum capacity

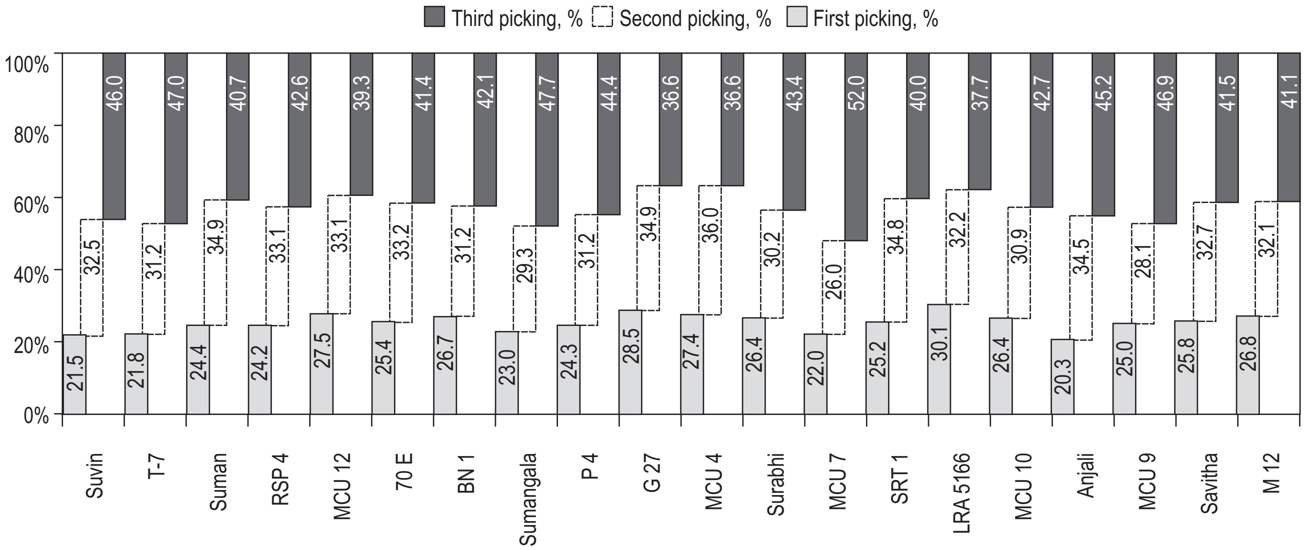

Fig 2 Trend of field capacity of the picker with time of picking

Table 3 Field performance of cotton picker

Variety	Field capacity (kg/h)								Picking efficiency (%)							
	Machine				Manual				Machine				Manual			
	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
Suvin	18.7	19.7	21.5	20.0	1.33	1.40	1.47	1.40	94.5	94.5	94.7	94.6	99.7	99.7	99.7	99.7
T-7	19.4	20.4	20.8	20.2	1.37	1.37	1.40	1.38	94.1	95.1	96.0	95.1	99.5	99.5	99.6	99.5
Suman	20.3	21.0	21.8	21.0	1.43	1.57	1.70	1.57	94.5	94.1	90.2	92.9	99.3	99.3	99.4	99.3
RSP 4	19.3	20.2	21.6	20.4	1.53	1.60	1.63	1.59	94.3	94.3	95.5	94.7	99.3	99.7	99.7	99.6
MCU 12	19.4	19.4	21.6	20.1	1.57	1.60	6.73	3.30	93.4	95.0	95.0	94.5	99.2	99.3	99.3	99.3
70 E	20.1	20.5	21.5	20.7	1.33	1.40	1.43	1.39	95.5	95.5	95.6	95.5	99.2	99.2	99.3	99.2
BN 1	17.8	20.0	21.3	19.7	1.53	1.57	1.67	1.59	94.6	95.9	96.1	95.5	99.7	99.7	99.7	99.7
Sumangala	17.9	19.2	19.7	18.9	1.33	1.40	1.40	1.38	95.0	96.6	97.0	96.2	99.1	99.4	99.6	99.4
P 4	20.2	20.5	20.7	20.5	1.37	1.50	1.63	1.50	92.9	94.9	95.5	94.5	98.1	99.2	99.3	98.8
G 27	19.0	19.5	23.7	20.8	1.33	1.43	1.53	1.43	95.0	96.3	97.2	96.2	98.1	99.5	99.6	99.1
MCU 5	19.9	20.2	20.3	20.1	1.37	1.50	1.63	1.50	93.6	94.0	94.4	94.0	96.1	99.3	99.3	98.3
Surabhi	18.3	19.6	19.7	19.2	1.53	1.60	1.60	1.58	95.7	95.8	96.5	96.0	99.2	99.2	99.5	99.3
MCU 7	19.7	20.6	22.3	20.9	1.20	1.40	1.53	1.38	95.2	95.7	95.7	95.6	98.1	99.0	99.3	98.8
SRT 1	20.6	22.1	23.6	22.1	1.37	1.40	1.63	1.47	95.7	96.4	96.4	96.2	99.2	99.5	99.5	99.4
LRA 5166	21.9	23.3	24.0	23.1	1.47	1.53	1.57	1.52	88.1	95.1	95.7	93.0	98.9	99.0	99.6	99.2
MCU 10	19.4	19.5	22.4	20.4	1.43	1.47	1.47	1.46	93.6	94.4	95.1	94.4	99.2	99.4	99.4	99.3
Anjali	19.2	20.1	21.3	20.2	1.40	1.43	1.43	1.42	96.6	96.8	97.2	96.9	98.7	98.9	98.9	98.9
MCU 9	20.4	20.7	23.0	21.4	1.37	1.40	1.50	1.42	96.6	96.9	97.4	96.9	99.5	99.6	99.7	99.6
Savitha	18.4	18.9	19.4	18.9	1.50	1.60	1.70	1.60	96.4	96.6	96.6	96.5	99.4	99.4	99.7	99.5
M 12	20.6	20.9	21.4	21.0	1.27	1.43	1.58	1.43	96.3	97.6	97.9	97.2	99.2	99.4	99.5	99.4
Mean	19.5	20.3	21.6		1.40	1.48	1.81		94.6	95.6	95.8		98.9	99.4	99.5	
SD	1.0	1.0	1.3		0.10	0.08	1.16		1.9	1.0	1.6		0.8	0.2	0.2	

four times with cotton picker with four women labourers. It was also observed that the field capacity increases with the picking time, i.e. third picking (21.6±0.1 kg/h) has more field capacity than first picking (19.5±0.1 kg/h). This may be due to the full maturity of cotton bolls during third picking (Nagwekar 1983, Ruth 2013).

The field capacity was highest in LRA 5166 variety (23.05±1.1 kg/h) followed by SRT1 (22.11±1.5 kg/h) variety and lowest in Sumangala variety (18.92±0.9 kg/h) followed by Savitha (18.90±0.5 kg/h) variety (Sandhar 1999, Ruth 2013). It was apparent that there was no significant difference in man-hour requirement among the varieties by using cotton picker.

The maximum picking efficiency of 99.26±0.23% was observed with manual cotton picking. The picking efficiency was highest in MCU 9 variety (95.05±1.57%) and lowest in

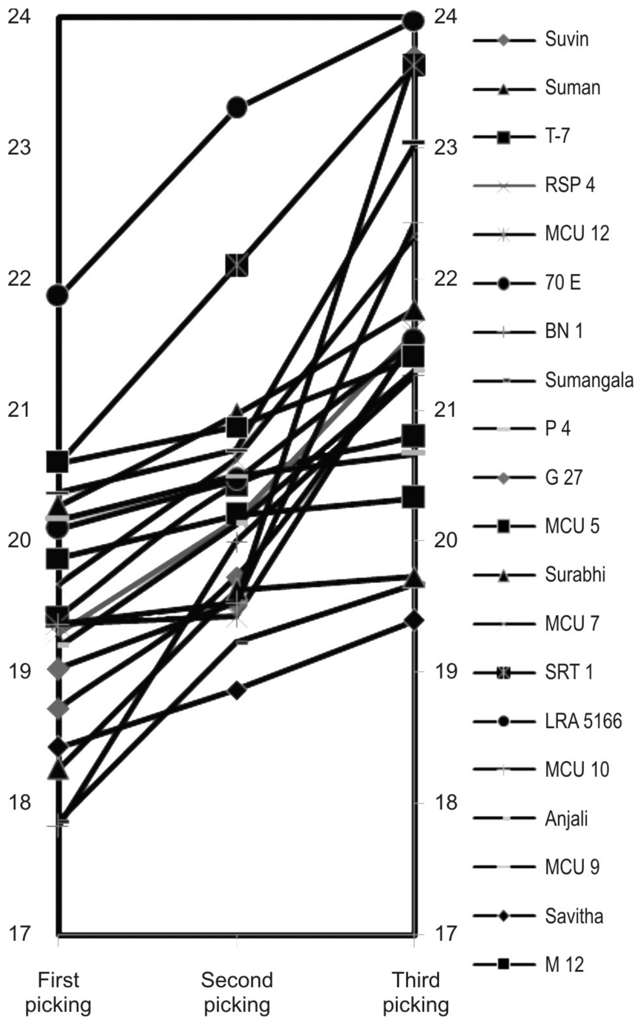

Fig 3 Field capacity of cotton picker

MCU-7 variety (90.66±0.09%). It was also observed that picking efficiency increases with the time of picking, i.e. less in first picking (87.33+0.68%) and more in third picking (88.42+1.18). This shows that the maturity aspect plays a positive role in mechanized cotton harvesting. These results are in accordance with the earlier findings (Ruth 2013).

Mean trash content was observed in machine picking and manual picking as 11.6±1.3 and 4.5±0.5% respectively. In comparison with manual picking, machine picking incorporates more trash as depicted in Table 4. It was observed that picking time also influences the trash content in seed cotton significantly. First picking registered mean trash (8.7%) followed by second picking (11.1%), whereas third picking registered maxium trash content (14.9%) in machine picked cotton (Ying *et al.* 2014). The fuel consumption of the picker was observed as 0.8 L/h.

Cost economics

The cost economics of the cotton picker developed was analyzed as per the RNAM test code and procedure for harvesters (RNAM 1995). The break-even point and the pay-back period for the unit were also calculated.

Table 4 Trash analysis

Variety		Suvin	T-7	Suman	RSP 4	MCU 12	70 E	BN 1	Suman-gala	P 4	G 27	MCU 5	Sura-bhi	MCU 1	SRT 1	LRA 1	MCU 10	Anjali	MCU 10	Savitha	M 12	Mean
Machine	P1	7.2	7.6	8.1	7.9	8.8	9.2	9	8.7	9.2	9.8	9	10.2	8.2	8.2	10	9.2	7	9.7	8.2	9.0	8.7
	P2	10.9	10.9	11.6	10.8	10.6	12	10.5	11.1	11.8	12	11.8	11.7	9.7	11.3	10.7	10.8	11.9	10.9	10.4	10.8	11.1
	P3	15.4	16.4	13.5	13.9	12.6	14.9	14.2	18	16.8	12.6	12	16.8	19.4	13	12.5	14.9	15.6	18.2	13.2	13.8	14.9
	Mean	11.2	11.6	11.1	10.9	10.7	12.0	11.2	12.6	12.6	11.5	10.9	12.9	12.4	10.8	11.1	11.6	11.5	12.9	10.6	11.2	11.6
	SD	4.1	4.4	2.7	3.0	1.9	2.9	2.7	4.8	3.9	1.5	1.7	3.5	6.1	2.4	1.3	2.9	4.3	4.6	2.5	2.4	1.3
Manual	P1	2.4	1.9	1.8	2	2.1	1.8	1.7	1.9	2.5	3	1.6	1.4	2.1	2.1	2.6	2.4	2.3	1.8	1.7	1.8	2.05
	P2	5.1	4.9	4.7	5.6	5.8	5.6	5.1	6	4.8	5.3	4.7	4	5.8	5.3	4.2	5	5.6	4.2	4.5	6.1	5.12
	P3	5.9	6.4	5.8	6.7	5.8	6.5	8.9	6.7	7.5	5.8	5.7	4.6	5.6	5.8	7.6	7.4	4.9	5.4	6	5.4	6.22
	Mean	4.5	4.4	4.1	4.8	4.6	4.6	5.2	4.9	4.9	4.7	4.0	3.3	4.5	4.4	4.8	4.9	4.3	3.8	4.1	4.4	4.5
	SD	1.8	2.3	2.1	2.5	2.1	2.5	3.6	2.6	2.5	1.5	2.1	1.7	2.1	2.0	2.6	2.5	1.7	1.8	2.2	2.3	0.5

P1-first picking; P2-second picking; P3-third picking

Table 5 Cost economics of cotton pickers

Parameter	Machine	Manual
Cost of machine (₹)	20,000	
Cost of picking (₹/kg)	9.50	11.50
Saving in cost compared to conventional method (%)	17.00	
Break-even point (kg/annum)	5900	
Pay-back period (year)	0.45	
Saving in time compared to conventional method (%)	75.00	
Saving in energy compared to conventional method (%)	74.64	

a) The pneumatic principles adopted in the development of cotton-picker are promising in addressing the requirement of pressure force for cotton picking.
b) The optimized cotton picker is with pick-up diameter of 25 mm, nylon-mesh filter of 400 mm height and with 150 L capacity collection drum at the aspirator speed of 5500 rpm.
c) Economic feasibility of the cotton-picker is also enhanced as the cost of picking with picker works out 17.0, 75.0, and 74.6% saving in cost, time, and energy compared to conventional picking respectively.
d) Although the manual picking is best suited in cases of trash content and picking efficiency, on evaluation with other parameters namely field capacity, cost of picking, break-even point, pay-back period, cost saving, time saving and energy saving, picking through the cotton picker is promising to address the need of ever increasing women's role in Indian farms.

An unit of the prototype costs ₹ 20000, while annual usage of power-tiller, annual usage of picker attachment, total life of picker, and salvage value of picker attachment were assumed as 800 h, 60 day, 10 year, and 10% of the inial cost, respectively (Annamalai 1999, Raju and Gautam 2013). The field capacity of picker was taken as 160 kg/day and total cost which includes fixed cost and variable cost worked out ₹ 82.94, and hence of picking of cotton with picker worked out ₹ 9.50 per kg. The amount of cotton harvested by a skilled labour was taken as 10 kg/day which worked out saving of time as 17%. Based on the time required for cotton picking, i.e. 10 kg/day per person in manual method and 160 kg/day per for persons, the saving in time was worked out 75.0%. Based on the calorific requirement of the labourer for picking of cotton, i.e. 1931.5 kCal/person and 10 kg/day, the energy requirement in manual picking worked out 193.15 kCal/kg. Machine requires fuel of 0.8 L/h and four labourers, which worked out 48.99 kCal/kg. Hence saving in energy compared to manual method worked out 74.6%.

The break-even point and pay-back period were determined (Selvan *et al.* 2010). The break-even point is the function of annual fixed cost, effective field capacity, custom fee, and operating cost; while pay-back period is the ratio of initial cost of machine to average net annual benefit. The break-even point and pay-back period for picker were 5900 kg/annum and 0.45 year respectively.

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