

TECHNOLOGIES, CHALLENGES AND SOLUTIONS IN MECHANICAL HARVESTING OF COTTON: INDIAN PERSPECTIVE

Abstract

About 21% of worldwide fibre production is covered by Cotton. India stands first in the cotton acreage with around 11.91 Mha of land under cotton cultivation. The country has produced about 35 M cotton bales of 170 kg each during 2021-22. Cotton farming involves harvesting as one of its most expensive and important production chain operations. Harvesting expenses depend on factors such as market price, labour availability, wages, type of cultivar, size of the boll, stages of pickings, etc. Seed cotton is harvested either by handpicking or by mechanical means. Handpicking is a labour-intensive and time-consuming operation. Machine harvesting is commonly followed in developed countries. Different types of cotton harvesters have been developed since long back in India. Recently, machine vision and motion control cotton-picking robot has also been attempted for cotton harvesting. This chapter focuses on Indian perspective of cotton harvesting technologies, challenges, and possible solutions for adopting those technologies.

Keywords: Mechanical Harvesting of Cotton

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I. INTRODUCTION

Cotton is a significant cash crop that accounts for about 21% of worldwide fibre production. India stands first in the cotton acreage with around 11.91Mha of land under cotton cultivation contributing 37% of the total 32.63Mha cotton area worldwide. The country has produced about 35M cotton bales of 170 kg each during 2021-22(ICAC, 2022). Harvested cotton is supplied to the ginning industries for processing. It takes many stages of seed cotton processing to convert it into a finished textile product (Hardin *et al.*, 2022). Cotton farming involves harvesting as one of its most expensive production chain operations. It costs almost double the weeding cost and about ten times the cost of irrigation (Muthumilselvan *et al.*, 2007). Broadly, the picking cost is nearly 10-15 % of the total cotton selling cost (Sharma *et al.*, 2014). Cotton harvesting expenses depend on factors such as market price, labour availability, wages, type of cultivar, size of the boll, stages of pickings, etc. (Brown, 2002).

Seed cotton is harvested either by handpicking or by mechanical means. Fibre quality and trash content in seed cotton depend on the method of harvesting. Handpicking is a labour-intensive and time-consuming operation. Machine harvesting is commonly followed in developed countries. Researchers have developed and evaluated different types of cotton harvesters since long back in India. Recently, machine vision and motion control cotton-picking robot has also been attempted for cotton harvesting. However, in the current scenario, none of them are utilized by cotton growers at field levels. Many technologies, including tractor-operated harvesters, self-propelled machines, robotics, portable pickers, pneumatic collectors, strippers, and hand-held pickers, are still under development or experimental stage. There is an absolute requirement for cotton harvesters in India. However, due to several on-field and off-field problems, the successful adoption of cotton harvesters is far behind the goal. Various cotton harvesting technologies, challenges, and possible solutions for adopting those technologies are described in detail in the following sections.

II. HAND PICKING OR MANUAL HARVESTING

Most cotton farmers in the country are small landholders with average farm sizes of 1.5 ha (Majumdar *et al.*, 2020). Also, the Indian cotton varieties possess poor retention of the full-grown bolls; as a result, they require to be harvested multiple times. Additionally, the long-duration cotton hybrids produce fruits over a longer period, so frequent picking of such hybrids becomes necessary. Some agronomic practices, viz. fertilization application and repeated irrigation, also result in continuous boll development and may need more pickings. Therefore, almost 100% of the cotton grown in India is harvested by the manual method of multi-stage hand picking (Fig. 1). Women are mainly employed to pick the cotton, but men are also employed sometimes according to need.

In this harvesting method, a skillful picker gently clasps the seed cotton with a quick hand movement and carefully extracts it from its boll without contaminating it with leaves or other dried parts of the plant. The labour will visually examine for any foreign material, discard them and grip cotton from 2-3 bolls simultaneously for collecting into a collection bag/pouch/sack (Prentice, 1972). The picker also identifies and eliminates the stained, infested, and inferior bolls, which helps in time-saving during the picking operation. Because of such inbuilt intelligence involved in the manual method of cotton picking, hand-picked

cotton is the cleanest one with a trash content in the range of 1-1.5% on a row cotton basis and is graded higher than machine-harvested cotton.



Figure 1: Conventional Hand Picking of Cotton

Nevertheless, it is a challenging method of cotton harvesting that requires long hours of bending and stooping over the crop to pick bolls from the bottom to the top of the plant as shown in Fig. 1. (Brown, 2002; Chauhan *et al.*, 2015). It creates a moderate amount of drudgery for the labourers by bending over and stooping to collect the lowermost cotton bolls and carrying the picked cotton load throughout the field. The sharp dried tips of the bracts also hurt the fingers, which causes discomfort (Selvan *et al.*, 2014). It is also a labour-intensive operation because every cotton boll is picked individually at a time (Prasad *et al.*, 2007). The labour required for manual cotton picking is around 500 men h/ha (Singh *et al.*, 2014).

If the number of bolls to be picked manually is more, the rate of cotton picking will also be more because the labourers need to spend less time detecting the bolls to pick. On an average day of 6-8 hours, experienced labour may pick 20-40 kg of seed cotton depending upon the number of cotton picking (Singh *et al.*, 2014).

Manual picking is the activity to be conducted throughout the day. However, it is suggested to be done during the morning or evening hours to avoid a hot afternoon. If the picked cotton is stored on a dried grassy field or open earth, it will be contaminated with a considerable amount of undesirable trash and fetch less price at the ginning industries. Care also be taken not to allow artificial threads, plastics, small sachets, human hairs, torn clothes, or any other organic trash into the picked cotton because such contaminants are tough to remove in the ginning industries. Moisture tends to stain the cotton due to heat generation during storage which ultimately reduces the quality of the cotton; therefore, cotton should be allowed to be dried in the field before picking if there is dew in the morning. Due to all these reasons, the cotton must be picked considering following important instructions to pick clean and good quality seed cotton.

- Picking should start from the bottommost to the topmost bolls to avoid trash contamination from upper-dried bracts, leaves, and branches.

- Wait for the dew to evaporate in the early morning, but try to start picking during morning and evening hours when the climate is cooler to reduce human drudgery during operation.
- Avoid direct sun drying of cotton if the moisture content is more because exposure to the direct sun may cause yellowing, thus deteriorating the colour grade of cotton.
- Avoid using non-cotton materials like plastic bags, hessian covers, jute bags, and synthetic polymer bags for the collection, storage, and transportation of seed cotton so that the addition of foreign material can be avoided.

III. PORTABLE HANDHELD PICKERS

A few handheld cotton picker models have been introduced and evaluated recently. These handheld pickers are developed to facilitate human pickers in hand picking of cotton. Portable handheld pickers are battery-operated small-size equipment claimed to be lightweight, low cost, simple in construction, and efficient in cotton picking. It works on two different mechanisms, viz., roller mechanism and chain mechanism. The chain-type handheld picker consists of an endless chain, whereas the roller-type handheld picker consists of a cylindrical roller.

The main components of the machine are picking head, power unit, and collection bag. The picking head comprises of a spiked rotating cylinder for picking opened bolls, a doffing mechanism to guide the picked seed cotton towards the outlet, the main body of the picking unit with an ON/OFF and safety switch, a power drive arrangement and a handle to hold the unit. The power unit comprises of 11 W DC motor, which drives the rotating cylinder with a belt drive. The power is supplied with a 12-volt rechargeable battery. The operating speed of the cylinder is around 5400 rpm. The weight of the picking unit is 750 gm, and the battery is 2250 gm. Fig. 2a shows one of the types of battery-operated handheld pickers developed for cotton picking in India.



Figure 2: a) Portable Handheld Picker b) Cotton Picking by Handheld Picker

The operator has to take the picking head near the targeted open bolls (Fig. 2b); the spikes mounted on the picking cylinder remove the locules from the opened boll and are subsequently doffed off by the steel wire doffing mechanism provided on the front side of the picking head. The doffed cotton is allowed to fall by gravity into the collection bag attached to the outlet of the picking machine. The operator has to raise the hand to clear the arm of the collection bag at regular picking intervals to ensure a smooth flow of picked cotton. The zipper at the bottom of the collection bag is given for unloading picked cotton. A safety switch has been provided to stop the machine in case the rotating cylinder gets jammed. Each cotton bolls need to be picked individually and carefully therefore, such devices have been found to require significantly more labour and time to harvest seed cotton than manual handpicking (Singh *et al.*, 2014). In addition, the trash content in harvested cotton is also more than in manual handpicking. Moreover, the labour must also carry an additional weight of at least 2 kg, including the device and battery throughout the field. The only benefit of handheld devices is that finger injuries caused by touching sharp pointed cotton kernels in manual picking can be avoided (Raju and Majumdar, 2013). Due to all these reasons, portable handheld pickers are less famous for cotton harvesting in India.

IV. MECHANICAL HARVESTING

Although manual harvesting ensures the cleanest seed cotton with preserved fibre quality, it is highly time-consuming, labour-intensive, and expensive. Also, both handpicking and handheld pickers are not desirable for harvesting seed cotton from large cotton fields. Though machine-harvested cotton may contain 8-30 % of trash, it is still harvested mechanically in developed countries like the USA, Russia, Australia, and Brazil (Mishra *et al.*, 2023). It is because the mechanical pickers can pick 870-2180 kg of seed cotton daily, equivalent to 50-100 human pickers (ICAC, 2004). Majorly, two types of cotton harvesters are being used in different parts of the world (i) spindle pickers and (ii) stripper harvesters, depending on the cultivars of cotton grown, method used for cultivation, agronomic practices, initial cost, operational cost, quality and efficiency of picking (Shukla *et al.*, 2017). Both types of cotton harvesters are discussed below;

1. Spindle Pickers: Spindle pickers are predominantly used mechanical harvesters for harvesting seed cotton in developed nations. These are selective pickers that can pick fully opened bolls only, leaving the green, semi-opened, or unopened bolls so that a second or third harvest is also possible. The machine consists of the picker head, bar, spindles, doffer, vacuum tube, and accumulator basket. The picker head runs along each row of cotton as shown in Fig. 3. Inside each head are bars of “spindles” that circulate like tracks on an excavator. Each spindle also turns, and their screw-like thread winds the fibre out of the boll. The spindles rotate at a speed of 1850-3250 rpm (Prasad and Majumdar, 1999). A “doffer” swipes the fibres from the spindles as each bar rotates back into the head. The cotton is then sucked into chutes at the back of the head. The fibres are then collected into an accumulator basket (storage basket) by passing through long black vacuum tubes (pneumatic conveyer). A pressure cover pushes the crop from outside of the row to a working zone so that spindles, when entered into the zone, clear the plates by 3.18-6.35 mm at the narrowest point along the entire height of the bars (Wanjura *et al.*, 2017). Before the spindles re-enter the crop zone, they allow going through moistening pads to apply a wetting agent to help in the attachment of cotton fibres. The wetting agent also removes trash and dirt from the spindle, making it clean and shiny. As

the cotton fills the accumulator, it is squashed down and rolled into the baler until the desirable weight and diameter are achieved. The right size bale is then wrapped in layers of plastic, and the driver opens the rear door to eject the bale onto the tailgate. Finally, the tailgate lowers and gently drops the cotton bale onto the ground.



All these operations are automatic, for which the machine is programmed with various monitors, sensors, and computers. The camera is also fitted with the machine for the driver to see what is happening inside and behind the picker. The program develop a map showing how much cotton is picked. Furthermore, the harvested bales are tagged with radio frequency identification (RFID) codes to trace them back to the exact row where they were picked.

Spindle pickers collect less trash, around 68 kg/bale, compared to stripper-type harvesters, which collect trash up to 170 kg/bale (Wanjura *et al.*, 2017). In addition, the fibre quality of cotton harvested by spindle pickers is better graded than that harvested by stripper harvesters (ICAC, 2004). It costs more to own, operate and maintain a spindle picker than a stripper harvester.

- 2. Cotton Stripper:** These are comparatively simpler in construction and working with fewer settings and expertise required for their operation. Unlike spindle pickers, strippers are one-time harvesters, so the second picking stage is impossible. Whether the cotton boll is open, the strippers “strip/pull” the cotton boll along with bur, branches, or stem. Fig. 4 demonstrates mechanical harvesting of cotton using a two row type of cotton stripper.



These machines are of two types, viz. finger and brush roll types. The finger-type strippers have a series of fingers in an inverted ‘V’ fashion, similar to combing teeth. When the machine moves through the plant row, the inverted “V” fingers strip the plant like by combing actions on the plants during operation. The plant material opened bolls, green bolls, semi-opened bolls, stems, bracts, sticks, burs, and leaves are stripped off the stem. The striped material is beaten and passed to a cross auger and then to the cleaning unit using a conveyor to remove unwanted material like unopened bolls, sticks, and burs. The clean cotton is fed to the storage tank. Cotton harvested with finger-type strippers collects more trash even after performing in-machine cleaning. It is mainly suitable for narrow-spaced, short plants, broadcasted crops, or plants with smaller, thinner stems (Majumdar *et al.*, 2020).

The second kind of stripper is the brush roll typewhich gently harvests the cotton and collects less trash than finger strippers. Cotton plants pass through two brush rolls, rotating opposite each other and inclined at about 30° from the ground surface. The rolls are the primary striper mechanism lined with three brush bristles oscillating with three rubber bats, rotating counter wise to impart an upward motion from both sides of the plant, thus separating the bolls, a few branches, burs, and leaves onto the augers for conveying the stripped material backward into the main auger. Finally, the material flows through a pneumatic conveyor to the field cleaner. A pneumatic conveyor discharges green bolls from the material (Colwick *et al.*, 1984). The job of field cleaners is to remove sticks and burs from stripped material in the first cleaning stage. In the first stage, cleaned cotton is fed to the top section of the field cleaner, where it moves with the force of gravity. A beating cylinder breaks up the material and feeds it to a primary saw cylinder. The saws sling the cotton across grid bars arranged in series dislodging foreign matter by the centrifugal force and passing the material on the secondary saw cylinder. The same phenomenon is repeated, and trash is removed through grid bars. After cleaning the cotton in a pair of cylinders, a doffer brush collects the clean cotton from the cylinder and deposits it in an air flow moving upwards, which takes the cotton into a storage basket. The cotton-picking efficiency of strippers is higher (97-99%) as compared to spindle-type harvesters (85-90%) (Wanjura *et al.*, 2013; Mishra *et al.*, 2023).

Table 1 presents a broad idea about some famous cotton harvesting methods followed in India and other parts of the world.

Table 1: Comparative Information of Some Popular Harvesting Mechanisms

Parameter	Manual Picking	Portable Handheld Picker	Spindle Picker (six row)	Stripper Harvester
Initial cost	Less	Less	High	Less
Operation and maintenance cost	Nil	Low	High	Low
Setting and adjustments	Nil	Very few	Many	Few
Skilled operator	Not necessary	Required	Required	Not required

Picking capacity (kg/day)	20-40	25-30	5000	
Picking efficiency (%)	100	75	85-90	98-99
Type of operation	Very slow	Very slow	Quick	Quick
Trash content (%)	1-1.5	Up to 2	12-15	28-30
Onboard cleaner	Not required	Not required	Not required	Required
Affect fibre qualities	No	No	Non-significant	Slight
Varieties	Any	Any	High-yielding, better quality, long-staple, fluffy bolls	Small plants, smaller bolls having storm resistance, poorer quality
Land type	Any	Any	Irrigated, higher plant moisture content.	Dryland
Landholding	Small	Small	Large farm size	Large farm size
Plant height	Any	Any	90-120 cm	60-90 cm
Commercial adoption(in countries)	Developing nations like India, Pakistan, China, Chad, Mali and Uganda	Under on-field trials in India and a few African countries	Developed nations like Australia, Brazil, Russia and the USA	Developed nations like Australia, Brazil, Russia and the USA

V. OTHER COTTON HARVESTING MECHANISM

1. Pneumatic Suction Cotton Harvester: Few electric power vacuum cleaners have also been reported to be used for cotton picking. Such systems require more human labour than hand picking, and clogging can be observed due to low suction pressure; therefore, such systems need modifications (Garg *et al.*, 1999). A similar suction-based principle was used to develop a harvester that can be connected to the three-point linkage of tractors. The machine consists of a suction hose, blower, and tank and can be operated with tractors PTO. The picking efficiency of 63.4-77.5 % was reported at 240 mm of water head suction pressure and a blower speed of 2875 rpm (Sandhar *et al.*, 2003). A pneumatic-based knapsack cotton picker was also employed for cotton picking. This picker was reported to lower labour expenses, energy expenditure, and picking time as compared to conventional hand-picking (Rangaswamy *et al.*, 2006). The performance of a similar knapsack type of engine-operated portable cotton picker was evaluated recently. The average picking efficiency, trash content, and output capacity of 96.47, 10.22, and 4.95 per hour of operation were recorded, respectively (Verma and Mathur, 2016)

2. **Self-Propelled Picker:** An engine-operated self-propelled machine was developed for cotton picking in Egypt. The machine comprises stripping fingers, a stalk bending rod, a paddle, a collecting tank, an operating handle, and an engine. This picker works best at a forward speed of 0.36 m/sec. The picking efficiency can be improved from 70% to 97% by employing the machine for multiple picking three times or more (Ibrahim *et al.*, 2014)
3. **Intelligent Cotton-Picking Robot (ICPR):** As cotton picking is a complex operation that depends on several factors, including plant physiology, climatic conditions, agronomical practices, cotton varieties, etc., the researchers are also developing robotic cotton pickers. This type of system uses machine vision and motion control. Standard cotton grades, whiteness, yellowness, seed size, and other fibre quality parameters are used by robot pickers to pick the cotton from desirable cotton bolls. The images are captured by high-quality cameras along with frame grabbers, then processed, analyzed, and determined the cotton's location to be picked. The robot arm picks cotton from the plant and sends it to the collection chamber by pneumatic suction (Wang *et al.*, 2008). However, further research, large-scale trails, and modifications are required for robotic cotton harvesting technology to become simple, efficient, and economical.
4. **Challenges in Adopting Mechanical Harvesters in India:** Despite having higher picking efficiencies and faster picking rates, the mechanical pickers did not gain acceptance in India for several reasons. Following are some of the practical reasons of mechanical harvesters failed to impress Indian cotton growers;
 - Smaller land holdings than the developed cotton-growing countries like USA, Australia, and Russia.
 - Non-availability of cotton varieties having plant physiology suitable for the mechanical harvesting
 - Multi-stage cotton harvesting (picking cotton more than once) is practiced in India.
 - Many hybrid cotton varieties with non-synchronized boll openings are being planted.
 - Non-availability of effective and significantly optimized defoliants suitable for Indian cotton cultivars and climatic conditions
 - The mass availability of labourers with lower wages as compared to developed countries like the USA
 - Lack of efficient infrastructure for pre-cleaning and post-cleaning of seed cotton in Indian ginning industries
 - Need additional investment for handling and cleaning mechanically harvested cotton.
 - Machine-picked cotton contains more trash than hand-picked cotton.
 - Mechanical harvester needs higher initial cost and a highly skilled and technical workforce to run, maintain, and make several adjustments before and during picking to ensure a clean and efficient operation.
 - Additional expenses on the application of growth regulators, defoliants, and fuel consumption are required for mechanical harvesters.
 - Higher field losses in machine harvesting of cotton.
 - Machine-harvested cotton is one grade less than manually picked cotton in terms of fibre qualities like ginning outturn, staple length, micronaire, and strength.

VI. SOLUTIONS TO MAKE MECHANICAL HARVESTERS SUITABLE FOR HARVESTING INDIAN COTTON

A holistic approach needs to be taken up for making mechanical harvesters suitable for harvesting cotton in different cotton-growing agro-climatic regions of the country. Several factors need considerable attention in the form of development, modification, adoption, policymaking, etc. A complete set of possible solutions are mentioned below to successfully accept mechanical harvesters in Indian conditions.

- Development of cotton varieties with plant physiology suitable for mechanical harvesting
- Cultivars that are too tall or too short with cluster fruit bearing (bolls near the main stem) must be avoided because such varieties are not suitable for harvesting cotton mechanically.
- Sowing cotton plants in rows with a population of 85000-125000/ha is beneficial for mechanical picking.
- Development and optimization of efficient and economical defoliant for Indian conditions
- Uniform crop maturity must be ensured so that most cotton bolls open in a short duration; hence the development of short-duration cotton varieties with synchronous boll opening is necessary.
- Increase in cotton productivity to offset additional costs required for defoliation, growth regulation, etc
- Development and installation of an additional line of pre-cleaners and post-cleaners in Indian ginneries
- Formation of village-level farmer clusters for the cultivation of one single variety of cotton so that the total cotton grown area would be desirable for machine harvesting with uniform cotton physiology
- All the cotton stakeholders, viz. research institutions, government organizations, cotton processing industries, farmers, graders, and policymakers, must come together in mission mode for a quick revolution in the adoption of mechanical harvesters in India.

VII. CONCLUSION

Handpicking is a labour-intensive, time-consuming, and expensive process. At present, 100% of the cotton in India is harvested manually. The reason behind this is that the majority of cotton growers in India are small landholders. In addition, the country's present varietal and agricultural practices are centered on handpicking. Thus, to adopt the mechanical harvesting systems as followed in the U.S. and Australia, Indian farmers must change farming practices and the cultivars planted. Globally, only 30% of the area under cotton cultivation is machine harvested. Spindle harvesters and strippers are widely used mechanical harvesters in developing nations. These machines are faster in cotton harvesting, albeit at high trash content. Several new technologies have been attempted by researchers since long back for cotton harvesting. But, all of them failed to reach Indian cotton fields. The adoption of all the developed cotton harvesting technologies, such as pickers, strippers, robotics, pneumatic pickers, and portable handheld types of equipment, is still in the trial and experiment stage in

India. A while ago, there was no scarcity of human resources for farm activities. Hence farmers never felt the need to use harvesting technology. However, there is a severe labour shortage nowadays that will become critical soon. Thus, there is an urgent need for cotton harvesters in India, but due to small land holdings, the complex plant physiology, initial investment, and cumbersome models of machine harvesters, the successful adoption of cotton harvesting technologies at farm levels is far behind the goal. Therefore, a holistic approach needs to be taken up in a mission made for making mechanical harvesters suitable for harvesting cotton in different cotton-growing agro-climatic regions of the country. All the cotton stakeholders, viz. farmers, research institutions, government organizations, cotton processing industries, seed companies, graders, and policymakers, must unite for a quick revolution in adopting mechanical harvesters in India.

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