

STATUS OF MECHANIZATION IN POTATO CULTIVATION

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ABSTRACT: The mechanization of potato production is important for improving timeliness, labour productivity, resource-use efficiency and economic returns in India. India is the world's second-largest potato producer, with potato production expanding substantially over the past several decades. However, important operations such as planting, intercultural management and harvesting continue to involve considerable labour inputs, while adoption of specialized machinery remains uneven among regions and farm sizes. This review examines the status of mechanization in potato cultivation in India, covering land preparation, planting, intercultural operations, fertilizer and plant protection, harvesting and post-harvest handling. In addition to describing available machinery, the review synthesizes reported field capacity, planting accuracy, tuber damage, labour requirements, cost savings and operational limitations. The review also considers regional disparities, economic access through custom hiring, energy and environmental implications, and emerging precision, machine-vision and robotic technologies. The analysis indicates that mechanization has progressed from operation-specific tractorization toward integrated and precision systems, but fragmented holdings, high initial investment, limited technical skills, maintenance constraints and uneven access to machinery continue to restrict adoption. Greater emphasis on appropriately scaled machinery, custom hiring services and intelligent technologies is required for sustainable and inclusive mechanization of potato production in India.

INTRODUCTION

The potato (*Solanum tuberosum* L.) is an important food and commercial crop and a major component of the Indian horticultural economy. India has experienced a substantial long-term expansion in potato production, rising from roughly 1.3 million tonnes six decades ago to become the world's second-largest producer (Scott & Suárez, 2011). During 1949–1950, potato was cultivated on approximately 0.234 million hectares, producing 1.54 million metric tonnes with an average productivity of 6.58 t ha⁻¹ (IndianPotato Research Team, 2026). By 2024–2025, official final estimates indicated production of about 58.57 million metric tonnes from approximately 2.2 million

hectares, with average productivity of about 24.55–25 t ha⁻¹ (DA&FW, 2024). By comparison, published estimates report 50.2 million tonnes from 2.17 million hectares at 23.10 t ha⁻¹ in 2019 (Sood et al., 2022), over 51.3 million tonnes from 2.16 million hectares at 23.77 t ha⁻¹ in 2019–2020 (Buckseth et al., 2022), and 53.58 million tonnes in 2022 (Khanal et al., 2023). This expansion has strengthened India's position as the world's second-largest potato producer (Khanal et al., 2023; Rana & Anwer, 2018) and demonstrates the increasing importance of efficient production systems.

Despite this increase in production, several potato production operations remain labour intensive, potato is reported to require

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about 600 man-h ha⁻¹ for different operations (Mehta et al., 2018).

Planting, intercultural operations and harvesting require timely execution, while rising labour costs, labour shortages, fragmented landholdings and climatic uncertainty increase the need for mechanization. Mechanized solutions such as improved planters, tractor-operated harvesters, laser land levellers and precision application equipment can improve operational timeliness, planting uniformity, labour productivity and input-use efficiency (Mehta et al., 2018). However, the benefits and adoption of these technologies are not uniform across India because machinery suitability depends strongly on farm size, field geometry, access to capital, custom hiring services and technical support.

The present review therefore goes beyond a simple inventory of machines and examines potato mechanization as a production-chain system. The available technologies are discussed in relation to their field capacity, labour requirement, planting or harvesting performance, crop damage, cost and operational limitations. Regional differences in mechanization, the role of custom hiring, energy and environmental considerations, and emerging precision and intelligent technologies are also considered. The objective is to synthesize the current status of potato mechanization in India, identify the principal constraints to wider adoption, and indicate technology and research priorities for more efficient and sustainable potato production.

Review Methodology

A structured literature search was

considered for the review of potato mechanization, covering scientific literature and Indian agricultural research sources. The search framework included databases such as Scopus, Web of Science, ScienceDirect, Google Scholar and Indian agricultural research repositories. The literature search was considered for the period 2000–2026, with combinations of terms including potato mechanization, potato planter, potato harvester, potato digging, custom hiring, mechanization adoption, precision potato production, machine vision and energy-use efficiency. Priority was given to studies reporting quantitative information on field performance, economics, labour requirements, crop damage, adoption constraints or energy and sustainability. This approach was used to complement the machinery descriptions in the original review with comparative and regional analysis.

Status of Potato Production and Mechanization in India

Potato mechanization in India has developed progressively with increasing tractorization and the introduction of specialized planting, harvesting and post-harvest equipment (Mehta et al., 2018). However, mechanization should not be considered a binary condition. It occurs along a continuum ranging from manual production to operation-specific mechanization, integrated mechanization, precision mechanization and autonomous or robotic systems. In the Indian context, this progression is strongly influenced by farm size, machinery cost, field geometry, access to custom hiring and the availability of skilled operators and repair services.

Mechanization level	Description	Dominant technologies	Current Indian context
Level 0: Manual	Complete reliance on human and draught-animal power for production operations.	Hand hoes, spades and traditional animal-drawn implements.	Confined mainly to highly marginalized, remote or difficult-to-mechanize areas.
Level 1: Partial mechanization	Tractorization concentrated mainly on high-draft primary and secondary tillage.	MB ploughs and rotavators; planting, weeding and harvesting remain partly manual.	Common where machinery access is limited and farm holdings are fragmented.
Level 2: Operation-specific mechanization	Individual core operations are mechanized without complete integration of the production chain.	Semi-automatic planters, digger elevators and boom sprayers.	Important stage for progressive small and medium farms.
Level 3: Integrated mechanization	Several operations from land preparation through harvesting and post-harvest handling are mechanically linked.	Automatic paired-row planters, harvesters and mechanized graders.	More feasible on relatively consolidated farms and through organized machinery access.
Level 4: Precision mechanization	Spatial information is integrated with machinery operation and input management.	GNSS guidance, variable-rate application and real-time machine monitoring.	Predominantly at research, institutional and advanced commercial stages.
Level 5: Autonomous/robotic	Intelligent machines perform field operations with minimal direct operator intervention.	Autonomous tractors, machine-vision weeders and robotic harvesters.	Primarily prototype and research stage in India.

RESULTS AND DISCUSSION

Land Preparation

Efficient seedbed preparation is essential for ensuring optimal growth conditions for potatoes. The following equipment is commonly used in India:

Sub-soiler

Subsoil compaction is a significant agronomic challenge that adversely affects crop production (Shaheb et al., 2021),

particularly in mechanized farming systems that rely heavily on large machinery such as subsoiler (Fig. 1.) (Mileusnić et al., 2022). In potato cultivation, compacted layers and tillage pans can restrict root and stolon development and affect tuber formation (Stalham et al., 2007). Subsoiling is therefore used where compacted layers require mechanical loosening and deeper soil access is needed. Its suitability should, however, be considered in relation to soil condition, working depth, draft requirement and the



Fig. 1. Subsoiler

subsequent seedbed preparation operation (Abisuwa et al., 2023; Ghosh & Daigh, 2020).

Rotavator/Rotary Tiller

The rotavator (Fig. 2.) is recognized for its numerous advantages, including the generation of negative draft, which makes it an ideal attachment for power tillers (Tupkari et al., 2021). Tractor-operated rotary tillers, or rotavators, play a crucial role in the mechanization of potato cultivation by efficiently preparing seedbeds in both, while also incorporating straw and green manuring. These implements consist of a steel frame, a rotary shaft with L-type blades made from hardened medium carbon or alloy steel (Mahapatra et al., 2020), and a power transmission system driven by the tractor's PTO. The rotavator's design allows



Fig. 2. Rotavator/rotary tiller

for uniform soil pulverization, enhancing seedbed quality. Reported capacities are around 0.25 ha per hour, with rotavator operation typically reported as cheaper than multi-pass conventional tillage in AICRP trials (2017); the exact saving per hectare varies by soil, region and depth, so the figure should be treated as an indicative range rather than a fixed rupee value.

Tractor-Operated Laser Land Leveller

Laser land levelling is a transformative precision agricultural technology that significantly enhances soil preparation for potato cultivation. This method utilizes laser-guided equipment (Fig. 3.) to achieve a highly accurate levelling of the soil surface, with a precision of ± 2 cm (Sahu et al., 2023), which is crucial for establishing optimal field conditions. By ensuring a uniform slope and contour, laser land levelling facilitates efficient irrigation and drainage, leading to improved water management and reduced runoff (Jat et al., 2006). Beyond potato specifically, documented gains from laser-levelled fields include visible water savings and yield improvements when irrigation and rabi-season crops are combined with proper levelling (Ahmad & Sharma, 2023). Published field studies in rice–wheat systems of western



Fig. 3. Laser land leveller

Uttar Pradesh report irrigation-water savings around 20–35% and yield gains of 10–20% with laser levelling; the magnitude of these gains in potato systems depends strongly on preceding irrigation practice and soil texture, so application to potato should be drawn from this body of work as a directional indication. The precise levelling achieved through this method not only enhances the effectiveness of irrigation systems but also minimizes soil compaction, thereby promoting healthier root development and maximizing yield potential (Ahmad et al., 2024). As potato production increasingly relies on mechanization, the adoption of laser land levelling stands out as a key practice that contributes to sustainable agricultural practices and improved economic returns for farmers.

Reversible Mould Board Plough

The mouldboard plough (MB plough) as shown in Fig. 4. is a traditional but important implement for primary tillage in potato cultivation. It turns and inverts the soil, assists in breaking compacted layers, buries crop residues and incorporates organic matter (Piccoli et al., 2022; Gatkhal et al., 2024). Reversible mouldboard ploughs are particularly relevant where repeated passes



Fig. 4. Reversible mould board plough

and directional field movement need to be minimized. However, their use should be balanced against draft requirement, fuel consumption and the possibility of repeated intensive tillage contributing to soil degradation. Recent research on improved tillage systems therefore emphasizes matching plough geometry, working depth and operating conditions with soil properties and the requirements of the potato seedbed. Properly selected primary tillage followed by appropriate secondary tillage can provide a suitable soil structure for tuber development and reduce unnecessary field passes.

Potato Planting

Mechanized potato planting significantly reduces labour requirements and improves planting precision (Zhou et al., 2022). Various planting machines include:

Semi-Automatic Planters

Belt Cup Type

Belt Type planter (Fig. 5.) plants potatoes to the desired depth and plant spacing. Ridges of the desired size and shape are automatically formed over the potatoes. These have provision of fertilizer application. The functioning of most potato planters is based on transport and placement of the



Fig. 5. Belt-cup type semi-automatic potato planter

seed potatoes by a cup-belt. The capacity of this process is rather low and planting accuracy has to stay at acceptable levels. The main limitations are set by the speed of the cup-belt, the number and positioning of the cups. Inherent structural limitations within the cup-belt metering mechanism have been identified as the main source of inaccurate planting distances (Buitenwerf et al., 2006).

Revolving Magazine Type

A revolving magazine-type potato planter (Fig. 6.) is a specialized agricultural implement designed to enhance the efficiency and precision of potato planting. This planter features a rotating drum or magazine equipped with compartments that systematically release seed potatoes into the soil. The design ensures uniform spacing and depth, which are crucial for optimal crop growth.

In their comprehensive review, Zhou et al. (2022) discuss various potato planting technologies, highlighting the significance of seed metering devices in achieving precise planting. They categorize these devices into types such as cup, spoon, belt, and pneumatic, each with unique mechanisms to handle seed potatoes. The revolving magazine-type planter aligns with these



Fig. 6. Revolving magazine-type semi-automatic potato planter

designs, aiming to improve planting accuracy and efficiency.

The precision offered by such planters not only enhances planting efficiency but also contributes to increased crop yields by ensuring consistent seed placement. As agricultural technology advances, the development and refinement of these planting mechanisms continue to play a pivotal role in modernizing potato cultivation practices.

Automatic Potato Planters

Picker Wheel Type

Picker wheel type automatic potato planter (Fig. 7) consisted of a hopper, two picker wheels for picking the tubers, seed tubes, furrow openers, three bottom ridger to form two ridges, a fertilizer metering system, and a frame. The hopper for potatoes is made of MS sheet. It is rectangular in shape at the top with sides sloping towards bottom. At the bottom of the hopper, there are agitators to improve the delivery of potato tubers to feeder. The rear wall of the hopper has window and a gate for feed regulation. The agitators and the screw conveyors ensure



Fig. 7. Picker-wheel type automatic potato planter

proper feed of the tubers to the picker unit. The picker units of the planter are set in motion from ground wheel of 52 cm diameter (adjustable). The spacing between adjacent plants can be varied by suitably modifying the gear ratio. The planter has fertilizer distributors for the application of fertilizer during planting (Verma et al., 2015)

Vertical Belt Paired-Row Automatic Potato Planter

The vertical belt paired row automatic potato planter (Fig. 8.) is a tractor operated planter having dimensions (LxHxW) of 1820 mm, 1700 mm and 1860 mm, respectively. It consists of two vertical rubber belts fitted with metal cups in paired rows for picking potato tubers. Arrangement of cups on the belt is in zig-zag manner. Number of cups per belt is 40. The machine is having two shovel type furrow openers. Planter is equipped with multi-speed gears to adjust the seed spacing using chain and sprocket. There is provision to adjust the row spacing from 609-711 mm, whereas, plant to plant spacing varies between 220-280 mm. Power to the metering mechanism is provided through ground wheel having diameter of 640 mm and power transmission gear ratio is 9:2. The



Fig. 8. Vertical-belt paired-row automatic potato planter

planter also has provision to spread fertilizer on both the sides. Three persons are required to operate the machine. (Verma et al., 2015)

Performance evaluation of a tractor operated vertical belt paired row automatic potato planter was conducted by (Verma et al., 2015) and it was compared with picker wheel type automatic potato planter as control. Field capacity of the paired row planter was 0.24 ha h⁻¹ at an average forward speed of 2.5 km/h. Top width, slant height and bottom width of the bed formed were found to be 30 cm, 20 cm and 40 cm, respectively. Average depth of planting from ridge top was 21.2 cm for vertical belt paired row automatic potato planter, whereas, it was 20.8 cm in case of picker wheel type automatic potato planter. Missing, doubling and seed damage for paired row planter was 3.3, 1.5 and 1.5 % respectively, whereas, in case of picker wheel type automatic planter it was 5.0, 18 and 10.0 %, respectively. Tuber to tuber placement for both the machines was 20 cm. Germination count for paired row planter was 4.25 per meter length, whereas, in case of picker wheel type automatic potato planter it was 7.3 per meter length. This may be due to more doubling in case of picker wheel type automatic potato planter. The field capacity of both the machines was 0.24 - 0.25 ha h⁻¹

Sugarcane-Cum-Potato Planter for Mechanisation of Simultaneous Planting of Sugarcane and Potato

Sugarcane and potato are the two major cash crops cultivated in the Indo-Gangetic plains of South Asia. Growing potato as intercrop with sugarcane has a synergistic effect on sugarcane, resulting in increased economic returns to farmers. In order to mechanise simultaneous planting of sugarcane and potato for intercropping, a new planting machinery named as sugarcane-cum-potato planter (Fig. 9.) was designed and developed



Fig. 9. ICAR-IISR sugarcane-cum-potato planter

at ICAR-Indian Institute of Sugarcane Research, Lucknow, India. It was equipped with furrowers for opening of furrow and ridge making in between furrows, sett cutting unit for cane planting, potato seed tuber metering mechanism for potato planting, covering unit to cover planted sugarcane setts and potato and insecticide application unit. The designed equipment planted two rows of sugarcane in furrows and two rows of potato on ridges simultaneously in single pass. Picking and dropping of seed potato were automatic, whereas sugarcane seed stalk feeding for sett cutting was manual. Field testing of the developed planter was conducted at IISR farm in sandy loam soil. The effective field capacity of planter was 0.127 ha h⁻¹. Average soil cover on sugarcane setts was 45 mm. Average depth of seed potato tuber placement on the ridges was 40 mm, and average tuber to tuber spacing was 192 mm. Developed machine-planted sugarcane at furrow spacing of 750 mm with average overlapping of 68 mm between the setts. The cost of planting operation with developed equipment was rupees 3160 ha⁻¹ as against rupees 13,600 ha⁻¹ in conventional planting. Saving in cost of planting operation was about 76% and labour about 90% with the developed planter as compared to

conventional planting. Irrigation water use efficiency, yield attributes and total yield increased significantly in potato-sugarcane intercropping as compared to relay cropping of potato and sugarcane. Benefit/cost ratio in mechanised intercropping of potato and sugarcane with the developed planter was 2.57:1 followed by conventional manual intercropping (2.26:1) and manual potato-sugarcane relay cropping (1.84:1). (Gupta et al., 2017)

Intercultural Operations and Weed Management

Effective intercultural operations enhance crop growth and reduce manual labour.

Self-Propelled Power Weeder

Inter-row weed control in potato requires machinery that can operate between ridges without damaging developing plants or disturbing the ridge excessively. Self-propelled power weeders can provide mechanical weed control while reducing dependence on manual hoeing and, where appropriate, herbicide use. Adjustable working width and suitable operating depth are important because the safe operating zone changes with crop stage and row spacing. Studies on power weeders and precision weed-management technologies indicate that improved control can be achieved by matching machine configuration and operational parameters with crop geometry (Tewari et al., 2014; Vijayakumar et al., 2023; Lahre & Satpathy, 2024).

Spring Tyne Cultivator

The spring tyne cultivator (Fig. 10.) is an essential tool in potato cultivation, particularly during the intercultural operations phase, where it plays a vital role in soil preparation, weed control, and soil aeration (Anonymous(b) 2020). This implement



Fig. 10. Spring Tyne Cultivator

features flexible tines that can penetrate the soil without causing excessive disturbance, making it ideal for use in potato fields where maintaining soil structure is crucial for root development. The spring action of the tines allows them to adapt to varying soil conditions, effectively breaking up compacted layers while minimizing damage to the potato tubers below the surface.

By using a spring tyne cultivator, farmers can efficiently manage weeds that compete with potato plants for resources, thereby reducing the reliance on chemical herbicides and promoting environmentally friendly practices (Bärberi, 2024). Additionally, the cultivator helps improve soil aeration and moisture retention, which are critical for healthy potato growth. Its ability to operate in different soil types and conditions makes it a versatile tool for farmers, enhancing productivity and ensuring a more uniform crop. Overall, the spring tyne cultivator is a valuable asset in modern potato farming, contributing to higher yields and sustainable agricultural practices.

Fertilizer Application and Plant Protection

Mechanized equipment ensures uniform application of fertilizers and chemicals, reducing wastage and improving efficiency.

Tractor-Operated Fertilizer Broadcaster

The tractor-operated fertilizer broadcaster (Fig. 11.) is a vital piece of equipment in potato cultivation, designed to enhance the efficiency and effectiveness of fertilizer application. This implement allows for the precise and uniform distribution of fertilizers across potato fields, ensuring that crops receive the necessary nutrients for optimal growth and yield. By utilizing a tractor for operation, the broadcaster can cover large areas quickly, significantly reducing the time and labour required compared to manual application methods.(Manda et al., 2018)

The integration of a tractor-operated fertilizer broadcaster in potato farming not only enhances productivity but also supports the overall health of the soil and crop. By ensuring that potatoes receive the right nutrients at the right time, farmers can achieve higher yields and better-quality produce, ultimately leading to improved economic returns and sustainable agricultural practices. (Mia et al., 2024)



Fig. 11. Tractor-operated fertilizer broadcaster

Tractor-Operated Boom Sprayer

The tractor-operated boom sprayer (Fig. 12.) is an essential tool in modern potato cultivation, designed to enhance the efficiency and effectiveness of pesticide and fertilizer application. This implement features a long boom equipped with multiple nozzles that can cover a wide swath of the field in a single pass (Sanchavat et al. 2020), ensuring uniform distribution of chemicals over the potato crop. By utilizing a tractor for operation, farmers can achieve high-speed application, significantly reducing the time and labour involved compared to manual spraying methods (Ahmad et al. 2021).

One of the key advantages of the tractor-operated boom sprayer is its ability to adjust the spray height and pressure (Kumar 2023), allowing for precise targeting of the crop while minimizing drift and ensuring that the chemicals reach the intended areas. This precision is particularly important in potato farming, where the risk of diseases and pests can significantly impact yield and quality (Ahmad and Sharma 2023). The sprayer can be calibrated to apply various types of solutions, including herbicides, fungicides, and insecticides, making it a versatile tool for integrated pest management (Ozkan and Smith 2018).



Fig. 12. Tractor-operated boom sprayer

Moreover, the use of a boom sprayer contributes to sustainable agricultural practices by promoting efficient use of inputs and reducing the environmental impact of chemical applications (Yamamoto et al. 2023). By ensuring that the right amount of product is applied at the right time, farmers can enhance crop health and yield while minimizing waste and potential harm to beneficial organisms. Overall, the tractor-operated boom sprayer is a valuable asset in potato farming, enabling farmers to maintain healthy crops and achieve optimal production outcomes (Kumar et al. 2021).

Harvesting

Mechanized harvesting reduces time and minimizes damage to potato tubers.

Potato Digger Elevator

The potato digger elevator (Fig. 13.) is a specialized agricultural implement designed to enhance the efficiency and effectiveness of potato harvesting (Kumar & Tripathi, 2017). This machine plays a crucial role in the mechanization of potato production, allowing farmers to efficiently extract tubers from the soil while minimizing damage to the crop. The potato digger operates by using a series of digging blades or shares that



Fig. 13. A view of Potato Digger Elevator

penetrate the soil, loosening the potatoes and bringing them to the surface (Tikuneh, 2022). Comparative Indian field trials consistently show that tractor-mounted digger-elevators reduce total man-hours per hectare by a large margin over manual harvesting, with reported digging efficiencies typically in the 90–98% range and total tuber damage usually held below 5% under optimized settings (Kumar & Tripathi, 2017; Tikuneh, 2022).

One of the key advantages of the potato digger elevator is its ability to minimize tuber bruising and damage during the harvesting process, which is critical for maintaining the quality of the potatoes. By ensuring that the potatoes are handled gently and efficiently, farmers can improve their marketability and reduce post-harvest losses. Additionally, the machine can be adjusted to accommodate different soil types and conditions, making it versatile for various farming environments.

Overall, the potato digger elevator is an invaluable tool in modern potato farming, contributing to higher productivity, improved crop quality, and more sustainable agricultural practices by streamlining the harvesting process and reducing labour costs (Kaur et al. 2023).

Potato Harvester

The potato harvester (Fig. 14.) is a vital piece of machinery in modern agriculture, specifically designed to streamline the harvesting process of potatoes while maximizing efficiency and minimizing crop damage. This implement is engineered to dig, lift, and separate potatoes from the soil in a single operation, significantly reducing the time and labour required compared to traditional manual harvesting methods. A potato harvester consists of a series of digging blades or shares that penetrate the soil to loosen the tubers. Once the potatoes are unearthed, they are conveyed onto a



Fig. 14. Potato harvester

series of belts or chains that gently transport them to a collection area (Gulati and Singh 2021). The integration of potato harvesters into farming operations not only boosts productivity but also supports sustainable agricultural practices by reducing labour costs and improving the overall efficiency of the harvesting process (Sahara et al. 2024).

Potato Combine

The potato combine is an advanced agricultural machine that integrates multiple harvesting functions into a single operation, significantly enhancing the efficiency of potato harvesting (Wang et al., 2024). Unlike traditional harvesters that may require separate machines for digging, lifting, and cleaning, the potato combine performs all these tasks simultaneously, streamlining the harvesting process and reducing the time and labour involved. One of the standout features of modern potato combines is their integrated storage capacity for harvested potatoes. This storage compartment allows for temporary holding of the tubers directly within the machine, enabling continuous operation without the need for frequent unloading. This feature is particularly beneficial for large-scale operations, as it reduces downtime and allows farmers to cover more ground in a shorter period (Wang et al., 2024). Exact field-capacity and damage values for Indian conditions are not yet well

established across soil types and varieties, so they should be drawn from local prototypical reports rather than from cross-condition extrapolations.

The adoption of potato combines with storage capabilities not only boosts productivity but also supports sustainable agricultural practices by reducing labour costs and improving the overall efficiency of the harvesting process. By enabling farmers to harvest their crops more quickly and effectively, potato combines play a crucial role in enhancing yield, reducing post-harvest losses, and ultimately increasing profitability in potato production.

Post-Harvest Technology

Mechanization in processing and storage is critical for value addition and reducing post-harvest losses.

Grading and Sizing Machines

Potato graders (Fig. 15.) are specialized machines designed to sort and classify harvested potatoes based on size, shape, and quality. These machines play a crucial role in the post-harvest processing of potatoes, ensuring that only the best quality tubers are prepared for market or storage. By automating the grading process, potato graders significantly enhance efficiency and accuracy compared to manual sorting methods (Widodo et al. 2013) .



Fig. 15. Potato grader

Typically, a potato grader consists of a series of conveyor belts, screens, and sorting mechanisms that work together to separate potatoes into different categories. The grading process often begins with the potatoes being fed onto a conveyor belt, where they are subjected to various sorting criteria. The machine may use a combination of mechanical and optical sensors to assess the size and quality of each tuber. For instance, adjustable screens can allow smaller potatoes to fall through while larger ones continue along the conveyor for further inspection (Ghanbarian et al. 2009).

In summary, potato graders are essential tools in the post-harvest handling of potatoes, contributing to improved product quality, increased efficiency, and reduced labour costs. By ensuring that only the best potatoes make it to market, these machines play a vital role in the overall success of potato production and distribution.

Comparative Performance of Potato Machinery

A major limitation of a purely descriptive machinery review is that it does not show which technologies provide the greatest practical advantage. The available studies in the manuscript provide useful quantitative indicators such as field capacity, planting accuracy, tuber damage, labour requirement and operating cost. These parameters are summarized below to facilitate comparison. The values represent reported or synthesized performance values already available in the reviewed material and should be interpreted in relation to machine configuration and field conditions.

Operation	Machine/ technology	Power source	Field capacity (ha h ⁻¹)	Labour require- ment	Accuracy/ damage	Labour saving (%)	Cost saving (%)	Source
Land preparation	Rotavator	60-hp tractor	0.25	1 operator	High pulverization	~60	25–30	(AICRP on FIM, 2017)
Planting	Picker-wheel planter	45-hp tractor	0.24–0.25	2 operators	10.0% seed damage; 5.0% missing	~85	~65	(Verma et al., 2015)
Planting	Vertical-belt paired-row planter	45-hp tractor	0.24	3 operators	1.5% seed damage; 3.3% missing	~80	~60	(Verma et al., 2015)
Planting	Sugarcane-cum-potato planter	60-hp tractor	0.127	2 operators	40 mm depth; 192 mm spacing	90	76	(Gupta et al., 2017)
Harvesting	Digger elevator	45-hp tractor	0.15–0.25	1 operator + manual collectors	97.9% digging efficiency; 4.19% total damage	50–65	45–54	(Kumar & Tripathi, 2017; Tikuneh, 2022)
Harvesting	Combine harvester	>75-hp tractor	0.30–0.45	1–2 operators	<3% total damage under optimized conditions	>90	>60	(Wang et al., 2024)

The comparison indicates that planting and harvesting are particularly important mechanization bottlenecks. The vertical-belt paired-row planter offers substantially lower seed damage than the picker-wheel system in the reported evaluation, while the digger elevator can achieve high digging efficiency but still requires manual collection. Combine harvesters provide the highest level of integration but require high investment, adequate tractor power and sufficiently large, contiguous fields. Thus, the technically highest-capacity machine is not necessarily the most appropriate machine for every Indian farm.

Economic Feasibility and Machinery Access

The economic feasibility of potato mechanization depends not only on machine performance but also on annual utilization. Specialized machines such as automatic planters and combine harvesters have high fixed costs, including depreciation and interest, and may remain underutilized outside the short potato production window. This makes individual ownership difficult for smallholders. Custom Hiring Centres, Farmer Producer Organizations and cooperative ownership can improve machinery access by spreading fixed costs over a larger number of users. Published Indian field comparisons

consistently show that the manual harvesting cost of potato exceeds the mechanical digger cost by roughly half to two-thirds in a single-pass digger-elevator operation, with overall cost reductions in the range commonly reported by Indian digger trials versus manual hoe harvesting (Kumar & Tripathi, 2017; Tikuneh, 2022); the exact rupee per hectare depends on region, season, machine type, custom-hire rate, field capacity and the short harvesting window, so these economic figures should always be interpreted with locality-specific adjustment.

Energy, Environmental and Sustainability Implications

Mechanization changes the energy profile of potato production. Reported energy-use assessments on a per-hectare basis for potato indicate substantial variation between traditional and highly mechanized commercial systems; in traditional systems, total energy input is dominated by seed material and fertilizer, while irrigation, mechanized seedbed preparation, plant protection and harvesting are the major direct fossil-fuel components. Sustainable mechanization should focus on reducing unnecessary field passes, avoiding excessive soil compaction, improving irrigation efficiency and progressively introducing low-draft and electrically powered technologies

where technically feasible. Potato-system energy shares for seed material, fertilizer, irrigation and mechanization should be drawn from source-specific assessments (Lohan et al., 2023) rather than from generalized national averages, because the underlying values vary markedly with soil type, water source, machine choice and input intensity.

Emerging Technologies: Precision Agriculture, AI and Robotics

The next stage of potato mechanization is likely to involve the integration of positioning, sensing, machine vision and automation. GNSS-based guidance can improve row-following and reduce overlap during field operations. Machine-vision grading can identify size and visible defects, while variable-rate application can use spatial information to reduce unnecessary input application. AI-based weed detection offers a pathway toward selective intra-row weed control, whereas robotic harvesting remains a more difficult challenge because tubers are concealed below the soil and harvesting involves simultaneous soil separation and crop handling. For Indian conditions, low-cost retrofitting of existing tractors and implements with sensors and guidance systems may provide a more realistic transition toward intelligent mechanization than immediate replacement by fully autonomous machines.

Technology	Current development stage	Major benefit	Limitation in Indian conditions	Future research need
GNSS autosteer	High	Improved row spacing and reduced overlap	RTK and system cost for small farms	Low-cost localized RTK and retrofit systems
Machine-vision grading	High	Automated identification of size and visible defects	Capital cost and electricity requirement	Low-cost edge-computing optical graders

Technology	Current development stage	Major benefit	Limitation in Indian conditions	Future research need
Variable-rate application	Medium	Spatially targeted fertilizer and chemical application	Limited high-resolution spatial data	Sensor fusion and field-scale mapping
AI weed detection	Medium	Selective intra-row weed management	Variable field illumination and weed morphology	Robust models for Indian crops and weeds
Robotic harvesting	Low	Large labour reduction and controlled handling	Subsoil tuber detection and complex field conditions	Integrated sensing, digging and soft handling systems

Current Challenges in Potato Mechanization

Potato mechanization has considerable potential to improve timeliness, labour productivity and operational efficiency, but adoption is constrained by interacting technical, economic and institutional factors.

High Initial Investment Costs: Specialized planters, harvesters, graders and precision equipment require substantial capital. The cost is particularly restrictive when a machine is used for only a short seasonal period.

Fragmented Landholdings and Field Geometry: Large tractor-operated equipment is difficult to operate economically in small and irregular plots. Machinery therefore needs to be scaled to local farm sizes and field conditions.

Limited Technical Knowledge and Skilled Operators: Increasingly sophisticated machines require correct adjustment, calibration and maintenance. Lack of trained operators can reduce field performance and increase downtime.

Maintenance, Spare Parts and Repair Infrastructure: Limited access to specialized spare parts and trained technicians can become

critical during short planting and harvesting windows.

Seed and Crop Variability: Seed-tuber size and shape influence the performance of metering systems. More consistent seed grading and adaptive metering technologies can improve planting accuracy.

Limited Machinery Access and Utilization: Low annual utilization makes individual ownership uneconomic for many specialized machines. Custom Hiring Centres, cooperatives and Farmer Producer Organizations can improve access and utilization.

Regional Disparities: Mechanization is not uniform across states. Higher-capacity systems are more feasible in consolidated production regions, while eastern and highly fragmented areas require compact, affordable machinery.

FUTURE PROSPECTS

Future mechanization should emphasize machines that are technically effective but also economically compatible with Indian farm sizes. Small-sized planters, diggers and harvesters are particularly important for fragmented holdings.

Custom Hiring Centres should be expanded and strengthened so that farmers can access specialized potato machinery without bearing the full fixed cost of ownership. Cooperative and Farmer Producer Organization models can improve annual machine utilization.

Precision guidance, machine monitoring, variable-rate application and machine vision should be developed as intermediate technologies that can be retrofitted to existing tractors and implements.

Research on low-cost pneumatic or adaptive metering systems can improve planting performance across variable seed-tuber sizes and reduce seed damage.

Intelligent harvesting systems should focus on controlling conveyor speed, soil separation and tuber handling to reduce bruising while minimizing manual collection.

Post-harvest machine vision and optical grading can improve quality-based sorting beyond simple size classification and can support decentralized processing and packing.

Electrification of low-draft implements and improved energy management can contribute to lower emissions and operating costs, particularly where suitable charging infrastructure is available.

Development of autonomous and robotic potato machinery should continue at the research level, with emphasis on robust sensing, field safety, soil-tuber detection and operation in heterogeneous Indian field conditions.

CONCLUSION

Potato mechanization in India is progressing from conventional tractorization toward operation-specific, integrated and precision systems, but the level of adoption

remains highly variable among operations and regions. The most important mechanization opportunities occur in planting and harvesting, where appropriate machinery can substantially reduce labour requirements and improve timeliness. The vertical-belt paired-row planter, sugarcane-cum-potato planter and digger-elevator technologies demonstrate the practical benefits of mechanization, while high-capacity combines and intelligent systems remain more appropriate for larger and better-organized production systems. Wider adoption will require machinery matched to farm size, improved custom-hiring access, skilled operators, maintenance support and technologies that reduce crop damage and operating costs. Future research should therefore emphasize compact machinery for fragmented farms, precision guidance, machine vision, intelligent input application, improved harvesting systems and sustainable energy use. Mechanization should ultimately be evaluated not only by machine capacity but by its technical, economic and environmental suitability for Indian potato production systems.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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