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MECHANIZATION IN ONION HARVESTING: A REVIEW OF TRADITIONAL AND MODERN APPROACHES

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ABSTRACT

Onion harvesting stands as a critical aspect of Indian agricultural practices, presenting notable challenges due to its labour-intensive nature. The manual methods, involving bulb digging and leaf cutting, often leads to inefficiencies and financial burdens for farmers. Despite advancements in mechanization for crops like potatoes, onion harvesting remains largely manual in India. Efforts to automate onion harvesting using equipment designed for root crops have encountered hurdles due to the distinct biometric properties of onion bulbs, leading to low cleaning efficiency and high damage rates. Furthermore, existing harvesters focus solely on uprooting onion bulbs, requiring manual intervention for cutting matured leaves, thus consuming additional time and human resources. This paper critically evaluates manual and mechanized techniques, emphasizing the urgent need for improved mechanization in onion harvesting. It assesses performance metrics such as efficiency, cost-effectiveness and capacity, highlighting the limitations of current methods and identifying research gaps, particularly addressing the simultaneous requirements of digging and leaf cutting. Enhanced mechanization is essential to boost efficiency and reduce labour dependency in onion harvesting. The review outlines opportunities for innovation, emphasizing the necessity of advancing mechanization to benefit farmers and the agricultural sector in India. By addressing challenges and leveraging technological advancements, the paper advocates for a more sustainable and efficient approach to onion harvesting, contributing to the growth and development of agriculture in India.

Keywords: Manual harvesting, Mechanization, Onion Digger, Onion Detopper, Performance Metrics, sustainable Approach

Introduction

Onions (*Allium cepa* L.) have a rich history, dating back over 5000 years and even mentioned in the Bible as consumed by the Israelites. Beyond their culinary significance, onions are essential in global agriculture and offer various health benefits due to their nutritional content, including vitamins, proteins, iron and fiber. They are commonly used in salads, vegetables and spices, contributing to their economic importance and significant role in both domestic and international markets. With factors like population growth, changing dietary habits and the food processing sector's expansion, global onion demand has steadily increased, leading to a 25% rise in production over the last decade, reaching approximately 104 million tons annually. India ranks second in onion production globally, following China [1], with key producing states including Maharashtra, Madhya Pradesh, Karnataka, Gujarat and Rajasthan.

Onion Cultivation in India

Onions are versatile plants forming bulbs from swollen leaf bases attached to the stem's underground part. The ideal temperature for onion growth ranges from 13 to 24 °C [1]. In India, onions are planted via seedlings or bulbs, with transplanting occurring during kharif, late kharif and rabi seasons. Harvesting, around three months later, corresponds to these seasons as well, with the rabi (69.36%) season contributing the most to India's onion production in recent years [2]. Harvesting onions involves digging, detopping and collection. The readiness for harvesting is judged by the flexibility of the bulb's neck. Manual labour is common, but mechanized harvesting has gained attention for its efficiency and cost-effectiveness. However, its adoption faces challenges due to diverse agricultural landscapes and practices.

An assessment of onion harvesting techniques, including manual and mechanized methods, was undertaken to explore their efficiency and practicality in various contexts.

Manual Harvesting

During the harvesting phase, onion bulbs are manually extracted using a khurpi tool, along with their leaves. Subsequently, after 2 to 3 days of sun exposure for curing, the leaves are trimmed to a length of 20-30 mm above the bulbs. However, this traditional approach demands approximately 185 man-hours per hectare [3]. Ashwini *et al*. [4] reported that manually harvesting of matured bulb requires 21.4% of the total expenditure of onion cultivation. Following field curing, the detopping step, which involves manually removing the leaves using shears, becomes pivotal. According to Rani and Srivastava [5], detopping necessitates a considerable labour input, amounting to about 12.5 man-hours per metric ton, equating to roughly 40% of the overall labourduration.Manual digging of fully matured bulbs entails a posture where labourers must bend forward, which is not only inefficient but also physically strenuous for them. This bending posture places significant biomechanical strain on the back, leading to increased energy consumption compared to other work postures [6]. Shirwal *et al*. [7] highlighted that both stooping and squatting postures during work are ergonomically unfavourable, contributing to extensive physical exertion and reduced work efficiency during onion harvesting. Parab *et al*. [8] developed a manually operated onion harvester specifically for Indian farms to enhance labour efficiency. This harvester, designed with ergonomic principles in mind, allows farmers to carry out the harvesting process without the need to bend. The device, employing a five-bar mechanism resembling two slider-crank mechanisms, features a claw to grip onion bulbs and its affordability is a significant advantage, costing approximately 650–700, making it a cost-effective solution.

Mechanical Harvesting

Mechanized harvesting, which involves digging out onion bulbs, cutting leaves and windrowing the bulbs, leads to significantly higher work productivity, approximately 5 to 6 times more than manual methods [9]. Mechanical harvesters typically consist of a digging blade, a gauge wheel and a rod-type vibrating conveyor. These components serve the purposes of digging the bulbs at a consistent depth, conveying the bulbs to the rear of the machine while separating foreign objects. In some cases, potato or root crop harvesters are repurposed for onion harvesting, using a conveyor cum oscillating mechanism to remove soil from the bulbs. However, the biometric properties of onions differ from potatoes, leading to a higher risk of onion damage during mechanized harvesting. Detopping of onions can occur either before or after digging. When detopping occurs after digging, it's often done using stationary detoppers, while some diggers have mechanisms for detopping during harvesting. However, the efficiency of detopping is significantly affected by the condition of the onion tops.

Onion Digger

Khura *et al*. [3] developed a tractor-drawn onion harvester and evaluated six different shapes of digging blades for their draft requirements. Among these, an inverted V-shaped digging blade was deemed most suitable due to its lower draft requirement. They designed an experimental setup that allowed for adjustments in the length, slope and speed ratio of the elevator. The recommended final design included an inverted V-shaped blade, a speed ratio of 1.25:1, a 1.2 m conveyor length and a 15° slope of the elevator.They found that this harvester saved 44% in onion digging costs, equating to 1170 per hectare compared to manual methods.

Hong *et al*. [10] developed a Welsh onion harvester. The harvester is composed of five main components: a) a pair of cutting disks for soil disruption, b) a device for collecting Welsh onions, c) a mechanism for separating soil, d) a device for feeding Welsh onions and e) a loading and belt conveyor (B/C) feeding device. The harvester utilizes a flat digging blade to extract Welsh onion roots, which are then directed to the soil-separating device equipped with parallel rods set at fixed intervals.

Singh [11] undertook the development of an onion digger designed to harvest onions between tractor wheels. The digger utilized a flat blade constructed from high carbon steel material (EN 45). The study revealed significant labour and cost savings, with a 58% reduction in labour and a 49% decrease in costs compared to traditional harvesting methods.

Mehta and Yadav [12] created an onion harvester designed for tractors with varying row spacing and plant spacing. This harvester can dig up onion bulbs at the desired depth and separate them along with leaves and soil. Its major components include a digging blade and shaking assembly. Compared to manual harvesting, the onion harvester resulted in savings of 87.64% in time required, 46.23% in energy consumed and 78.86% in harvesting costs. Additionally, the overall net realized profit increased by 2.16% when using the mechanical cum manual harvesting method compared to manual harvesting alone.

Narender *et al*. [13] studied a tractor-operated root crop digger's performance, focusing on parameters like exposed, cut and bruised percentages and digging efficiency. They found that at 3.2 km/h speed and 17º blade angle, the digger performed best. It reduced digging costs by 51% compared to manual onion harvesting, showing the economic advantages of mechanization in agriculture.

Omar *et al*. [14] designed a front-mounted tractor onion harvester. This harvester lifts onion bulbs with leaves, oscillates them and conveys them to the rear of the tractor. Its components include a frame, lifting device (blade and collecting roller), elevator and collecting device. Experiments were carried out to evaluate the performance of the developed harvester under parameters: four depths of harvest and four forward speeds under 22% moisture content. It was recommended to operate the developed harvester for harvesting onion crop at a depth harvesting of 10 cm and a forward speed of 0.720 km/h where the lowest criterion cost was 674.33 LE/fed, the lowest losses was 1.9% and the least energy consumed was 59.5 kWh / fed.

Nour *et al*. [15] focused on developing and evaluating a local harvesting machine for onions. This machine is a single-row harvester equipped with a straight-shaped digging blade and double chains with fingernails. The fingernails catch the tops of the loosened plants and lift them as the machine moves, transporting them to the end of the machine. The experimental findings indicated that for optimal field capacity, field efficiency, low specific energy and total cost, the ideal forward speed and soil moisture content were 3.1 km/h and 15.8% (d.b.), respectively. This was achieved with a constant digging depth of 10.0 cm, pulling chain speed of 6.13 m/min and penetration angle of 10°.

Abad *et al*. [16] designed and developed a hand tractor implement for onion harvesting, designed to suit local field conditions and boost profitability in onion farming. This implement combines the tasks of digging, cleaning and collecting onion bulbs into a single operation. Its key components consist of the frame, digger blade, soil-onion separation mechanism, power transmission system and discharge cart.

Abdel- Mageed *et al*. [17] developed a unit for onion harvesting, conducting experiments with four different blade types, various tilt angles of shares and speed ratios across three harvesting depths. The optimal configuration emerged as scoop-shaped blades with a 25º tilt angle of shares and a speed ratio of 2.11 at a harvesting depth of 11 cm. This setup minimized total damage, increased efficiencies and specific energy and reduced overall costs significantly. The total costs demonstrated a 62% decrease compared to traditional onion harvesting methods.

Gautam *et al*. [18] developed and evaluated a tractor-operated onion digger aimed at efficiently lifting and separating mature onion bulbs from the soil, minimizing damage and enhancing overall crop yield. Through an experimental study, various parameters such as rake angles of the V-shaped blade and forward speeds were optimized concerning key harvesting factors like damage percentage, harvesting efficiency and separation index attributed to the machine. Remarkably, the best results were achieved with a rake angle of 20° at a forward speed of 2.0 km/h. The harvesting of onions using this developed digger was also found to be more cost-effective than manual harvesting, with a benefit-cost ratio in onion cultivation of 3.64, which was 11.54% higher than manual methods.

Kumar *et al*. [19] focused on the design and development of a hydraulic-controlled tractor front-mounted twin conveyor onion digger. This digger was equipped with five blades made of mild steel, bolted to the base plate for increased strength. The machine effectively separated onions and soil over the conveying unit. Power from the rear PTO of the tractor was transmitted to front-mounted digging unit. The depth, lifting and lowering functions were controlled using two single-acting hydraulic cylinders.

Table 1 : Performance metric of onion digger.

Study	Digging efficiency	Damage	Field capacity & Field efficiency	Cost
Khura *et al*. [3]	97.7%	3.5%	0.32 ha/hr	992 /ha.
Hong *et al*. [10]	100%	4.55 %	0.034 ha/h	-
Singh [11]	94.9%	5.1%	0.46 ha/h	115 man-h/ha
Mehta and Yadav [12]	96.45%	3.55%	0.45 ha/h&78.95%	1544 /ha
Narender *et al*. [13]	100%	3.39%	-	1885 /ha
Omar *et al*. [14]	99.2%	1.9 %	0.180 fed/h&73.9 %	674 LE/fed
Nour *et al*. [15]	99.54%	0.783%	0.2679 ha/h&90.37%	360 LE/fed
Abad *et al*. [16]	70.93%	-	0.027 ha/h	-
Abdel-Mageed *et al*. [17]	98.92%	1.80 %	0.2931ha/h& 89.3%	-
Gautam *et al*. [18]	97.02%	2.57 %	0.12 ha/h	3346 /ha
Kumar *et al*. [19]	82.55%	13.51%	0.21 ha/h & 87.46%	-

Self-Propelled Onion Harvester

Gavino *et al*. [20] designed a power tiller-driven onion harvester mounted at the rear of a hand tractor. The harvester featured a 250 mm × 530 mm straight digging blade. With 150 kg/h material capacity and an average yield of 10.3 tons/ha, the labour requirement was reduced to 69 man-hours per hectare for mechanical harvesting compared to 122 man-hours per hectare for manual harvesting.

Nisha and Shridar [21] developed an onion harvester operated by a power tiller. The harvester featured a straight type digging blade with a thickness of 12 mm, along with five 75 mm × 15 mm bars welded at the front end of the blade. They conducted a stress analysis of the digging tool, determining that the draft force acting on it was 85 kg. The developed onion harvester resulted in significant cost and time savings, with a reduction of 59.2% in costs and 93.75% in time compared to manual harvesting methods.

Dhananchezhiyan *et al*. [22] designed a self-propelled onion digger specifically for small farmers. The prototype included a power unit, power transmission unit, blade, ground wheel, handle and depth control wheel. Their innovation resulted in significant cost and time savings, with reductions of 81.9% in costs and 91.3% in time compared to conventional onion harvesting methods.

Patel *et al*. [23] designed and built a self-propelled onion digger with four wheels and a two-wheel drive system. The machine is specifically designed to dig onions between its tires, with a track width of 1560 mm and a blade width of 1000 mm. While primarily intended for onion harvesting at maturity, it can be adapted for potato, groundnut and garlic harvesting by adjusting the conveyor and blade angle. The machine's vibration and noise levels are within acceptable limits set by testing codes. Its fuel consumption is reported at 3.5 litres per hour when operating at full capacity.

Table 2: Performance indicators of self-propelled onion harvester

Study	Power	Digging efficiency	Damage	Field capacity & Field efficiency	Cost
Gavino *et al*. [20]	8 hp	-	0.0%	0.086 ha/h&80.52%	69 man-h/ha
Nisha and Shrider [21]	8-13 hp	97.4 %	3.5%	0.08 ha/h&82.6 %	918 /ha
Dhananchezhiyan *et al*. [22]	4 hp	97%	1.67%	0.12 ha/h	-
Patel *et al*. [23]	8 hp	78%	-	0.2 ha/h	-

Onion Detopper

Carson and Williams [24] designed a six-row onion topper with tines to lift lodged tops and six circular blades of 457 mm diameter for top trimming. The blades were positioned close to the tined wheels to cut tops before they were released by the tines. Four gauge wheels ensured a consistent cutting height of the tops. However, they observed that this type of onion topper resulted in non-uniform top heights and inferior topping quality compared to manual labour due to moisture content variations in the tops.

Laryushin and Laryushin [25] examined three energy-saving onion harvesting machines, including the OLL-1.4 machine designed for removing onion leaves and weed plants. This machine incorporates a mechanism for mechanically adjusting the cutting height, with cutting devices comprising shafts and counter-rotating blades housed within a covering. As the machine travels, support wheels gauge the field surface to maintain the specified cutting height, regulated mechanically. The rotation of the machine's implements inside the housing creates an airflow that lifts fallen onion tops, leaves and weed stems into the cutting zone, where they are cut and shredded. The contrarotation of the implements directs the shredded mass towards the housing's edge, leading it through a tops outlet into the inter row space.

Bhanage [26] designed a power-operated onion detopper with a conveying unit and a cutting unit. The conveying unit included two spiral rollers, rotating at a speed of 1.1 m/s, while the cutter rotated at 1832 rpm. Onion bulbs with leaves were manually fed into a feeding hopper and moved towards the detopping mechanism via an inclined flat belt conveyor. The spiral rollers pulled tops into an inverted position, assisting in advancing the bulbs towards the cutting mechanism. The cutting unit, mounted at one end of the spiral rollers, trimmed the onion tops as the cutters rotated. After detopping, the average neck length was measured at 21.09 mm.

Rani and Srivastava [5] developed an onion de-topper at Haryana Agricultural University. The onion bulbs were fed through a chute-type feeding unit onto a belt conveyor moving at a speed of 0.53 m/s, ensuring even transportation of the bulbs to an oscillating conveyor. A cutter was positioned underneath the oscillating conveyor to perform the cutting without harming the bulbs. The machine's optimal performance, suitable for all sizes of onion bulbs, was achieved at a 1.0º slope, a blade.

Heidari *et al*. [27] developed a roller-type onion topper and assessed the impact of rotational speed and clearance between rollers on several factors like the percentage of damaged bulbs, number of bulbs oriented correctly and the forward speed of the bulbs on the machine. They observed that the highest percentage of damaged bulbs (31.8%) occurred with a clearance of 43 mm between rollers. Increasing rotational speed allowed for higher forward speeds of bulbs along the rollers, but at 300 rpm, the percentage of non-oriented bulbs rose to 24%. The optimal configuration for the roller-type topper was found to be a rotational speed of 200 rpm and a clearance of 23 mm between rollers.

Londhe [28] developed a power-operated onion detopper cum grader. It consisted of three main mechanisms: a feeding mechanism, a de-topping mechanism and a grading mechanism. The feeding mechanism included a flat belt conveyor inclined at a 270 angle and operating at a speed of 0.59 m/s. The de-topping mechanism involved the inward motion of spiral rollers and a cutting unit, with peripheral speeds of 266 rpm for the spiral rollers and 1821 rpm for the cutters under load conditions. The grading mechanism featured two divergent rollers made of PVC pipe with an outward motion at 225 rpm and a slope of 70º.After detopping, onions were graded into five categories based on their sizes. The power-operated onion detopper-cum-grader cost 34.72 per quintal to operate, while the traditional manual method cost 81.25 per quintal. This resulted in a net saving of 46.98 per quintal with the power-operated system.

Prasanth *et al*. [29] conducted a laboratory investigation on a detopping unit designed for a mini-tractor operated harvester used for small onions. The detopping unit featured a vertical shaft with a cutting thread at the bottom, made from reinforced composite nylon material for its strength and resistance to breakage. The nylon thread detops the onion leaves in a rotary cutting manner similar to line trimmers. The best performance in detopping onions was observed with the square-shaped cross-sectional type nylon string, using both four strings and eight strings, resulting in an average onion neck length of 23 mm, which was sufficient to minimize storage losses. The optimum peripheral speed of the detopping unit was found to be 6.64 m/s, coupled with a forward speed of 1 km/h.

Kumawat and Raheman [30] conducted investigations on cutting torque and efficiency for topping onion leaves using a wire-type rotary unit. Their setup replicated the topping process of an onion topper under actual field conditions, allowing them to analyse the impact of various operational parameters such as rotational speeds of the cutting unit, cutting width and forward speed of the machine on cutting torque and topping efficiency. They recommended that the rotary speed of the cutting unit and the forward speed of the harvester should not exceed 1800 rpm and 1.2 km/h, respectively, to avoid damaging the onion leaves and ensure optimal topping efficiency.

Rathinakumari and Senthil [31] designed an onion detopping machine comprising a feeding chute, detopping unit, collection chutes, main frame and power transmission system. The process involved feeding cured onion crops through a conveyor to the detopping unit, where counter-rotating plain and cutting rollers drew in the onion tops, orienting them downward. The sharp edges of the shearing rollers then detopped the onion tops, which were subsequently droppeddown. Multiple rollers ensured efficient detopping before the onion crop reached the delivery point.

Caguayand Cruz [32] created a trolley-type cutting machine featuring key components such as counter-rotating blades, counter-rotating gears, a frame assembly, a collecting bin, wheelsand a power transmission assembly. The machine operates by feeding onions into the input chute, where the counter-rotating blades are situated to cut them. The cut onions are then gathered and collected in the bin located beneath the machine.

Lee [33] developed a simulation-based tractor-attachable wind-blast-type onion stem cutting machine. The blade was crafted by welding steel at various angles on each side of the central axis. The rotational speed was fixed at 540 rpm. Through their simulations, they recommended the installation angle of the actual stem cutting machine to be 30°, achieving an optimal traveling speed of 0.4 m/s with a stem cutting rate of 96.8%.

Table 3: Performance Overview of Onion Detopper

Study	Topping mechanism	Topping efficiency	Cost/Capacity
Carson and Williams [24]	rotary knife	92%	-
Laryushin and Laryushin [25]	Contrarotating blades	98.7%	-
Rani and Srivastava [5]	Rotary cutter	79%	30 /h&300 kg/h
Bhanage[26]	Two plain & one serrated cutter	86.10%	17.5 /q&306 kg/h
Heidari *et al*. [27]	Roller type	95.5%	-
Londhe [28]	Two plain & one serrated cutter	85.71%	35 /q&237 kg/h
Prasanth *et al*. [29]	Different shape string	-	-
Kumawat and Raheman [30]	wire type rotary unit	85.24- 97.73%	-
Rathinakumari and Senthil [31]	Shearing rollers	95.20 ± 1.42%	373 kg/h
Caguay and Cruz [32]	Counter-rotating blade	95.51%	0.046 php/kg&58 kg/h
Lee [33]	stem cutter blade	96.8%	-

Onion Digger with Detopper

Wingate-Hill [34] designed a single row top-lifting harvester utilizing a rod weeder mechanism to uproot onion bulbs. The harvester employs two contra-rotating lifting belts to grasp onion bulb leaves and elevate them to a topping mechanism. A 250 mm diameter trimming blade, rotating at 2800 rpm, cuts onion tops, positioned to trim leaves above 20 mm from the bulb. The topped onion bulbs drop onto a conveyor, transporting them to a temporary storage bin mounted on a vehicle attached to the harvester.

Naik *et al*. [35] designed an onion digger with a cutter bar topping unit. They conducted a field performance evaluation, investigating the impact of three independent variables: soil moisture content, rake angle and speed of operation. Using central composite design (CCD) in response surface methodology (RSM) and analysing responses like digging efficiency, damage percentage and topping efficiency in Design Expert software, they determined the optimum values of these variables as 11.36% (d.b.) for soil moisture content, 15.12° for rake angle and 3.114 km/h for forward speed.

Table 4: Essential Metrics for Evaluating Onion Digger with detopper.

References	Topping mechanism	Topping efficiency	Digging efficiency	Damage	Field capacity & Field efficiency	Cost
Wingate-Hill [34]	Rotary saw blade	53-80%	-	-	61%,	-
Naik *et al*. [35]	cutter bar	78.46%	93.76%	6.44%	0.17 ha/h & 85%	1716 /ha

Conclusion

This review paper delves into the challenges and opportunities within onion harvesting, examining both traditional and mechanized methods. With the difficulties encountered in manual onion harvesting and the constraints of current mechanical solutions, there arises a crucial demand for a suitable, efficient harvester in India. Such a harvester, integrating topping, digging and bulb separation, would significantly reduce labour and costs while ensuring timely harvesting of onions for farmers.

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