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Comparative evaluation of developed onion digger with manual harvesting method

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Abstract
Onion harvesting is a labor-intensive and time-consuming process that significantly impacts the overall efficiency and profitability of onion cultivation. In this study, we present a comparative evaluation of a newly developed mechanized onion digger with the traditional manual harvesting method. The objective is to assess the performance, efficiency, labor requirements, and potential economic benefits of using the onion digger over the manual harvesting technique. The newly developed onion digger was designed to efficiently lift and separate mature onion bulbs from the soil, minimizing damage and improving overall crop yield. The study was conducted in a commercial onion field, comparing the digger's performance with the standard manual harvesting method commonly employed in the region. Benefit cost ratio in onion cultivation was found 3.64 with developed onion digger, which was 11.54% higher than manual harvesting.

Keywords: Onion harvesting, onion digger, manual harvesting, harvesting efficiency, cost of operation, energy requirement

Introduction
India's role as a prominent vegetable producer is well-established, contributing more than 20% to the nation's GDP. Among its agricultural achievements, India stands as the world's second-largest producer of onions, with China holding the lead with a production of 26.73 million metric tons in 2020 (Anon. 2022) [5]. However, despite its impressive output, India's onion productivity has fallen short compared to other countries, and this could be attributed to the limited mechanization in onion farming (Kumawat & Raheman 2022) [26]. Traditional manual techniques, including khurpa, kudali (both traditional tools), and hand pulling, have been conventionally employed for onion harvesting in India. Unfortunately, this approach has proven to be arduous, time-consuming, labor-intensive, and costly (Jadhav *et al*. 1995, Mehta and Yadav 2015, Nisha and Shridar 2018, Ghule *et al*. 2018) [19, 29, 33, 15]. Additionally, manual harvesting incurs almost half the cost of cultivating onions, and labor shortages during peak periods lead to delays in harvesting, negatively affecting the quality of onion bulbs (Nisha and Shridar 2018) [33]. Furthermore, later-harvested onion bulbs are more susceptible to skin splitting compared to their earlier-harvested counterparts (Tucker and Drew 1982) [45]. To address these challenges, agricultural mechanization offers a promising solution to enhance operational efficiency, reduce costs, and improve productivity in the onion farming sector (Negrete, 2018; Khalequzzaman, 2007) [32, 21]. Various endeavors have been made to develop mechanized onion harvesters, aiming to overcome the limitations of manual methods. One such innovation by Khura *et al*. (2011) [24] resulted in a tractor-drawn onion harvester equipped with a V-shaped blade for digging, conveying, and separating units. Field testing showcased the prototype's impressive performance, achieving a digging efficiency of 97.7%, a separation index of 79.1%, a bulb damage rate of 3.5%, a fuel consumption of 4.10 liters per hour, and a draught of 1099.25 kg. Similarly, Khambalkar *et al*. (2014) [22] engineered an onion harvester powered by small tractors, boasting a working width of 0.6 m and a depth of 0.1 m. Singh (2014) [42] successfully tested a fabricated onion digger, which operated at a depth of 76.20 mm without causing any harm to the onion bulbs. This ingenious design achieved a digging efficiency of 89.80% and a harvesting capacity of 2.77 tons per hour, resulting in substantial labor and cost savings. Furthermore, Mehta and Yadav (2015) [29] developed an onion harvester that outperformed hand harvesting, significantly saving time, energy, and operational costs. The importance of blade rake angles in determining digging efficiency has been extensively studied. Ibrahim *et al*. (2008) [18] found that a 18° rake angle was optimal for potato harvesting, while Massah *et al*. (2012) [27] confirmed that a 20° rake angle was most

effective for onion harvesting, with forward speed also influencing efficiency (Mehta and Yadav, 2015) [29]. Notably, a survey conducted in the Chhattisgarh plain, a crucial onion-producing region, revealed a lack of tractor-driven onion harvesters, underscoring the necessity for research and development of a tractor-drawn onion digger tailored to the specific soil conditions of the region. In conclusion, although India's position as a leading vegetable producer is undeniable, improvements in onion harvesting techniques through agricultural mechanization present a promising opportunity to boost productivity, reduce costs, and address labor challenges. The development, construction, and testing of a tractor-drawn onion digger hold considerable potential in enhancing onion harvesting efficiency and fortifying the onion farming sector in India.

Materials and Methods

Development of onion digger

An onion digger was designed and developed at engineering workshop of Swami Vivekanand CAET&RS, IGKV, Raipur (C.G.). Various parameters were considered and measured for design of onion digger *viz.* engineering properties of onion bulb (Gautam *et al*., 2021; Sahay and Singh. 1995; Khura *et al*., 2010; Ghaffari *et al*., 2013;) [13, 41, 23, 14], agronomical characteristics of onion crop (Tekle, 2015; Mahala *et al*., 2019) [46, 47], soil parameters (Punamia and Jain, 2005) [37] and various machine components. Based on agronomical parameters i.e. depth of onion bulb and row spacing the size of the digger was conceived. The working width of digging blade was kept 600 mm, designed to work up to 100 mm depth from ground surface as depth taken by Mehta *et al*. (2015) [29]. The required power to operate the onion digger was calculated as 14.04 kW (Singh, 2007; Rotz and Muhtar, 1992; Alhaseen *et al*., 2015) [48, 39, 2]. Based on soil draft working on the digging unit a 6 mm thick MS sheet (AISI 1018) was used to manufacture digging blade (Hettiarachi *et al*., 1966; Bernacki, 1972; Budynas and Nisbett, 2011; Bhandari, 2010) [17, 7, 9, 8], which was easily detachable. Based on the dugout material a separator unit was designed, which attached just behind the digging blade (Khura *et al*., 2010; Alhaseen, 2015; Khurmi and Gupta, 2005) [23, 2, 25]. The rotary power from tractor PTO was used to drive the separator with the help of transmission unit, which consist PTO bush, universal joint, gear box unit and chain drive from PTO of tractor to separator unit. Layout of the transmission system given in Fig 1 in which number denotes various components i.e. 1. gear box input shaft, 2. gear box, 3. Sprocket (56 teeth), 4. Square bars, 5. Sprocket (17 teeth), 6. Separator shaft, 7. Separator, 8. Link attachment chain, 9. Chain, 10. Gear box output shaft. A windrowing unit was attached behind the digger just below the separator to reduce the impact of sudden fall of onion behind it and also discharge the onion in center of the machine. The overall dimension of the developed onion digger was 1500×850×800 mm, which was small in size to reduce the capital cost and make it affordable for small farmers. CREO parametric computer software and auto cad was used to design and drawing the onion digger shown in Fig. 2, which consists various components 1. Blade, 2. Frame, 3. Wheel, 4. Sprocket (17 teeth), 5. Separator shaft, 6. Chain (Transmission), 7. Sprocket (56 teeth), 8. Gear box, 9. Windrower, 10. Lower link, 11. Upper link, 12. Separator. Specification of the developed onion digger is presented in Table 1.

Table 1: Specification of the developed onion digger

Particulars	Specifications
Length × Width × height	1500 mm× 850 mm × 800 mm
Material of frame	Mild steel
No. of blade	1 (V-Shape)
Transmission unit	
Gear box	worm gear
Reduction ratio	17:1
Chain drive	
Type	Dual chain
Pitch	12.7 mm
Driver sprocket	56 teeth
Driven sprocket	17 teeth
Material of sprocket	Cast iron
Separation unit	
Type	Chain drive (link attachment chain)
Velocity ratio	1
Sprocket	4 Nos (23 teeth)
Spacing between bars,	20 mm
Size of bar	8 mm
Material of bar	Mild steel
Diameter of shaft	20 mm
Material of shaft	Mild steel
Separator speed	1.0 m s^{-1}(at PTO speed 1000 rpm)
Power source of separator	Tractor PTO
Power required	18 hp

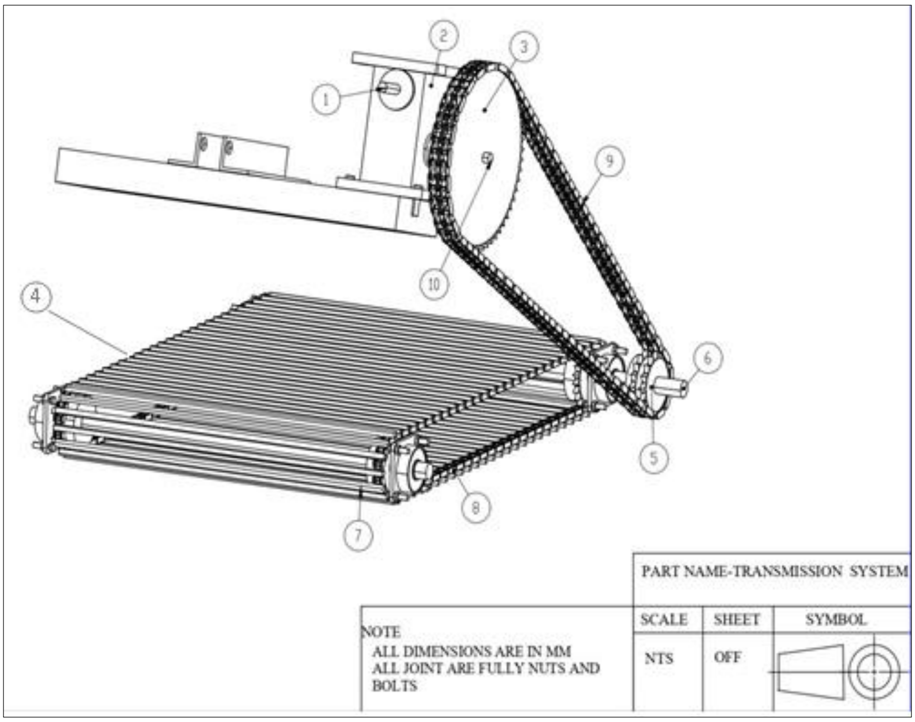

Fig 1: CAD view of power transmission system

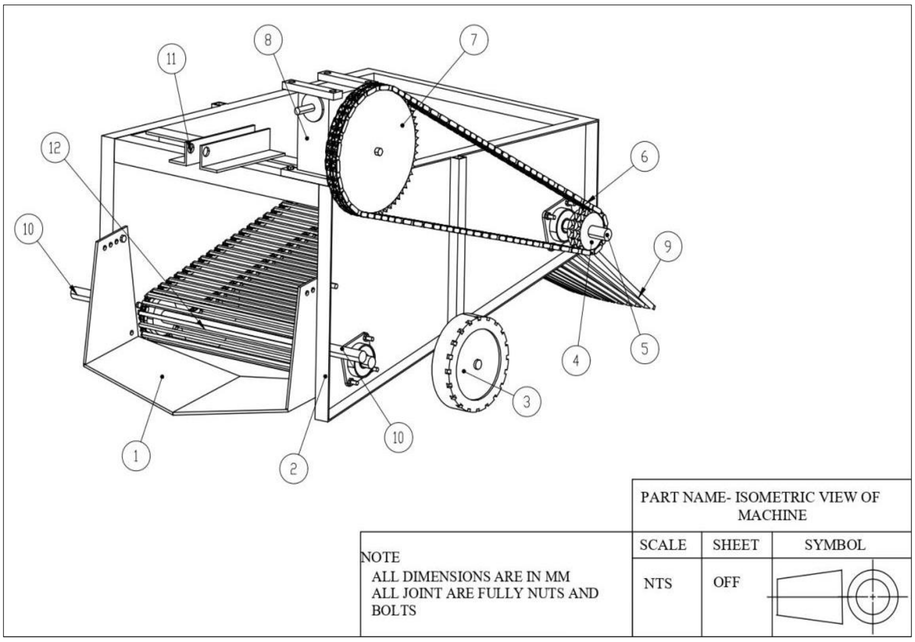

Fig 2: CAD view of onion digger

Performance evaluation

The developed prototype of onion digger shown in Fig. 1 and 2 was evaluated and compared with manual harvesting method in experimental field of IGKV, Raipur (C.G.) in *rabi* season 2020-21. The rectangular field was prepared by ploughing with one pass of cultivator and one pass of rotavator. Rectangular field was selected to reduce the turning loss of onion digger.

Harvesting parameters

Three major harvesting parameter of root crop harvester is damage per cent, harvesting efficiency and separation index. Damage per cent is the ratio of damaged onion bulbs to total collected onion bulbs in a 10 m strip of run. Digging efficiency is the onion plant successfully harvested to the total number of onion bulb available in 10 m strip after digging with developed onion digger. When the harvesting efficiency was computed, the damage per cent was subtracted from the digging efficiency. After separation, the whole dugout material was gathered by running the digger at a 10 m strip by placing the carpet (collector) rear end just behind separator and calculated in per cent using Eq. 1 (Mehta and Yadav, 2015, Khura *et al.* 2010) [29, 23].

$$\text{Soil separation index } = (1 - \frac{W_a}{W_t}) \times 100 \qquad (1)$$

Where,

Wa = Actual weight of soil and onion bulb collected at rear end of soil separator, kg; and

Wt = Theoretical weight of soil cut by blade along with onion bulb at a working depth of operation, kg.

Cost of operation

The IS: 9164 was used to calculate the cost of machine assistance. The developed onion harvester operational cost was divided into fixed and variable cost. Fixed cost was independent of operational use and cost of operation was increase/decreases with the variable cost (Kamboj, 2012) [20]. Cost of developed onion digger was calculated ₹ 28,120/- based on the cost of components. Some assumptions were made to determine the cost of operation by considering fixed and variable cost (Sabaji *et al*., 2014) [40]. Expected life of digger was considered 8 year with 250 h annual use. Salvage value, rate of interest, labour required, were considered 10% of initial cost, 10% per annum and 01 respectively. Then diesel cost, fuel consumption, lubrication cost, repair and maintenance cost and shelter tax were taken as 90 ₹ l^{-1}, 2.1 l h^{-1}, 20% of fuel cost, 5% of initial cost and 2% of initial cost, respectively. Breakeven point and payback period of the machine was also calculated as discussed below.

Breakeven point

The breakeven point was calculated by using Eq. 2 (Sabaji *et al*. 2014) [40]

$$\mathrm{BEP} = \frac{\mathrm{FC}}{\mathrm{CH-C}} \qquad (2)$$

Where,
BEP = Breakeven point, h y^{-1};
FC = Annual fixed cost, ₹ y^{-1};
C = Operating cost, ₹ h^{-1}, and
CH = Custom hiring charges, ₹ h^{-1}.
= (C + 25 per cent over head) + 25 per cent profit over new cost

Payback period

Payback period was determined for developed onion digger by using Eq. 3-5 to know the time required to get back the investing, (Reddy *et al*., 2003) [49].

$$\mathrm{PBP} = \frac{\mathrm{IC}}{\mathrm{ANP}} \qquad (3)$$

Where,
PBP = Payback period, year;
IC = Initial cost of machine, ₹; and
ANP= Average net annual profit, ₹ y^{-1}.

$$\mathrm{ANP} = (\mathrm{CH} - \mathrm{C}) \times \mathrm{AU} \qquad (4)$$

$$\mathrm{AU} = \mathrm{AA} \times \mathrm{EC} \qquad (5)$$

Where,
CH = Custom hiring charges, ₹ h^{-1};
AA = Average annual use, h y^{-1}, and
EC = Effective capacity of machine, ha h^{-1}.

Capacity of machine

The capacity of machine was determined by weighing the onion bulb obtained from every plot and divided by the time required to complete per plot, which was presented in terms of kilogram per hour (Mozumder *et al*., 2007, Singh, 2014) [31, 43].

Benefit: cost ratio (B:C)

It was calculated by considering total cost of production of onion crop, gross income and net income from the cultivation of onion. Following Eq. 6 and 7 were used to determine the benefit: cost ratio.

$$\mathrm{B:C\ ratio} = \frac{\text{Gross income } (₹\ \mathrm{ha^{-1}})}{\text{Cost of production} (₹\ \mathrm{ha^{-1}})} \qquad (6)$$

$$\text{Net income } (₹\ \mathrm{ha^{-1}}) = \text{Gross income} - \text{cost of production} \quad (7)$$

Energy analysis

Energy required in harvesting operation by developed onion digger was also calculated by using various relationship (Singh and Mittal, 1992; Pradhan *et al*., 2019) [44, 35]. Total energy consist direct (i.e. human and diesel) and indirect (i.e. tractor and implement) energy sources, which were calculated using Eq. 8 to 13.

Energy of human (MJ ha^{-1}) = 1.96 × working hours per ha (8)

The energy of diesel was calculated by following relation:

Energy of diesel (MJ ha^{-1}) = 56.31 × working hours per ha × fuel consumed (l h^{-1}) (9)

Direct energy was calculated by following relation:

Direct energy (MJ ha^{-1}) = Energy of man + energy of diesel (10)

The energy of tractor was calculated by following relation (Singh and Mittal, 1992; Pradhan *et al*., 2019) [44, 35]:
The indirect energy was obtained from tractor and machinery.

$$\text{Energy of tractor (MJ/ha)} = \frac{68.4 \times \text{Weight of tractor} \times \text{working hour per ha}}{\text{Life of tractor in hours}} \quad (11)$$

The energy of machinery was calculated by following relation:

$$\text{Energy of implement (MJ/ha)} = \frac{68.4 \times \text{Weight of implement} \times \text{Working hour per ha}}{\text{Life of tractor in hours}} \quad (12)$$

Indirect energy = Energy of tractor + energy of machinery (13)

Results and Discussion

Harvesting parameters

It was conclude that best result obtained working with V-shape blade at rack angle 20°with separator velocity 0.7 m s^{-1} and forward speed 2.0 km h^{-1}, at this setting the damage percent was minimum, digging efficiency was maximum about 2.81% and 96.78%, respectively with separation index 53.79%, as depicted in Table 2.

Table 2: Performance of the developed onion digger based on outcomes of preliminary trial

S. No.	Parameters	Mean	SD	CV, %
1	Digging efficiency with considering damage loss, %	96.78±0.55	0.62	0.64
2	Digging efficiency without considering damage loss, %	99.58±0.33	0.38	0.38
3	Damage percent, %	2.81±0.46	0.53	18.90
4	Separation index, %	53.79±1.76	2.01	3.73

Cost of operation of the developed onion digger

Cost of operation of the developed onion digger was calculated by taking unit cost of machine ₹ 28,120/-. Some assumptions were made to determine the cost of operation. Expected life of digger was considered 8 year with 250 h annual use. Salvage value, rate of interest, labour required, were considered 10% of initial cost, 10% per annum and 01 respectively. Then diesel cost, fuel consumption, lubrication cost, repair and maintenance cost and shelter tax were taken as 90 ₹ l^{-1}, 2.1 l h^{-1}, 20% of fuel cost, 5% of initial cost and 2% of initial cost, respectively. Cost of operation was calculated by taking average effective field capacity 0.12 ha h^{-1} and it was found to be ₹ 3,346.72/- per hectare. Details of cost of operation are presented in Table 3. Breakeven point and payback period of the developed onion digger were calculated to be 95 h $year^{-1}$ and 0.54 year respectively.

Table 3: Cost of operation of developed onion digger

S. No.	Particulars	Amount		
		Tractor	Onion digger	Total
1	Capital cost, ₹	3,50,000.00	28,120.00	-
2	Life, year	10	8	-
3	Life, h $year^{-1}$	1,000	250	-
4	Fixed cost			
	a. Depreciation at 10% salvage value, ₹ h^{-1}	31.50	12.65	-
	b. Interest 10% per annum, ₹ h^{-1}	19.25	6.19	-
	c. Shelter 2% of initial cost, ₹ h^{-1}	7.00	2.25	-
	Total fixed cost, ₹ h^{-1}	57.75	21.09	78.84
5	a. Variable cost			
	b. Fuel rate, ₹ l^{-1}	90.00	-	90.00
	c. Fuel consumption, l h^{-1}	2.10	-	2.10
	d. Fuel cost, ₹ h^{-1}	189.00	-	189.00
	e. Lubrication, ₹ h^{-1}	37.80	-	37.80
	f. Repair cost 5% of initial cost, ₹ h^{-1}	35.00	5.62	23.12
	g. Labour required	1	-	1
	h. Working hour, h ha^{-1}	9.09	9.09	9.09
	i. Labour cost, ₹ day^{-1}	315.00	-	315.00
	j. Labour cost, ₹ h^{-1}	39.38	-	39.38
	k. Total variable, ₹ h^{-1}	283.68	5.62	289.30
6	Cost of operation, ₹ h^{-1}	341.43	26.71	368.14
7	Cost of operation, ₹ ha^{-1}	3,103.86	242.85	3,346.72

Energy requirement to operate developed onion digger

Energy required by tractor, implement, human and fuel was calculated as indirect and direct source of energy and total energy required was found to be 1188.59 MJ ha^{-1} (Table 4).

Table 4: Energy requirement of developed onion digger

S. No.	Particulars	Value
1.	Indirect energy source	
	Total tractor energy, MJ ha^{-1}	46.01
	Total implement energy, MJ ha^{-1}	49.75
	Total energy from indirect energy source	95.76
2.	Direct energy source	
	Total human energy, MJ ha^{-1}	17.82
	Total fuel energy, MJ ha^{-1}	1075.01
	Total energy from direct energy source, MJ ha^{-1}	1092.83
3	Total energy, MJ ha^{-1}	1188.59

Comparison of onion digger with traditional manual harvesting of onion

Developed onion digger was compared with manual harvesting method in terms of field capacity, cost of operation and energy requirement. Field capacity of the onion digger and manual harvesting method was observed about 0.17 ha h^{-1} and 0.0023 ha h^{-1}, respectively. Energy requirement with manual harvesting found 852.17 MJ ha^{-1}, which was 27.85% lower than digging with onion digger (1089.54 MJ ha^{-1}) but cost of energy was found 83.12% higher than onion digger. One of the most important factors for comparison was cost of operation, which was found much lower in digging with developed onion digger than manual harvesting as reported in Table 5. Cost of operation with developed onion digger observed only 15.23% of manual harvesting method. Cultivation cost and benefit of onion production (cultivation with manual harvesting method and mechanical harvesting with developed onion digger) also compared (Appendix-G), B:C ratio was in manual harvesting was found 10.55% lower than the harvesting with developed onion digger.

Table 5: Comparison between manual harvesting and developed onion digger

Parameters	Harvesting method		% Increase (+) or decrease (-) in developed onion digger over manual harvesting
	Manual	Developed onion digger	
	x	y	$\left(\frac{y-x}{x}\right)\times 100$
Cost of operation, ₹ ha^{-1}	17,121.74	3,346.72	- 458.11
Energy requirement, MJ ha^{-1}	852.17	1,188.59	+39.48
Field capacity, ha h^{-1}	0.0023	0.11	+98.08
Energy cost, ₹ MJ^{-1}	20.09	2.82	-613.56
Cost of production, ₹ ha^{-1}	108,030.00	94,377.00	-14.81
Net income, ₹ ha^{-1}	240,178.00	249,141.00	+3.71
B:C ratio	3.22	3.64	+11.54

Conclusion

In conclusion, the comparative evaluation demonstrates the potential of the developed onion digger as a valuable alternative to the manual harvesting method, particularly for large-scale commercial onion cultivation. Economic analysis revealed that the initial investment in the onion digger was offset by the substantial labor savings and improved crop quality over a relatively short period. The developed digger proved to be a cost-effective solution for large-scale commercial onion farms, as it increased productivity and profitability. Cost of operation with manual harvesting was calculated as 17,121.74/- per hectare which was 458.11% higher than the cost of operation of developed onion digger. Benefit cost ratio in onion cultivation was found 3.64 with developed onion digger, which was 11.54% higher than manual harvesting.

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