

Development of tractor operated onion digger and optimization of different blade rake angle and forward speed

ABSTRACT

In different areas of India, onions are cultivated in two to three seasons. To acquire a higher market price, onion crop harvesting must be completed in a timely way. If delayed, possibilities of losses increase due to rain and other factors in peak time of harvesting. Generally onion harvesting of onions is performed manually by small and medium farmers of Chhattisgarh, India. Because onion harvesting was found tedious, boring and costly operation, a tractor-operated onion digger was designed, developed and evaluated, that consist digging unit, separator, windrower and transmission unit. The required power to operate the onion digger was calculated as 14.04 kW. An experiment was conducted to optimized the different rake angle (15°, 20° and 25°) of V-shape blade and forward speed (2.0, 2.5 and 3.5 km h⁻¹) on harvesting parameters (i.e. damage per cent, harvesting efficiency and separation index) of the developed machine.

Keyword: Onion harvesting, design of onion digger, harvesting efficiency, separation index, cost of operation.

1. INTRODUCTION

India is the world's prominent vegetable producer, accounting for over 20% of the country's GDP. India is the second largest onion grower, followed by China with a production of 26.73 MT (Anon. 2022) at 2020, but productivity was lower than other countries as shown in Fig. (1), it's probable that this is related to onion production's low level of mechanization (Kumawat & Raheman 2022). In India, manual onion harvesting techniques such as *khurpa*, *kudali* (both are traditional tools) and hand pulling were the most common, It was a long, tedious, difficult and expensive procedure (Jadhav *et al.* 1995, Mehta and Yadav 2015, Nisha and Shridar 2018, Ghule *et al.* 2018). It's approximately half the cost of cultivating onions, and delayed in harvesting due to unavailability of the workers during peak time of harvesting also undesirable for the onion bulb (Nisha and Shridar 2018) because later-harvested onion bubs exhibit more skin splitting than earlier-harvested onion bulbs (Tucker and Drew 19820). Agricultural

mechanization can assist reduce operational time and costs in agriculture, while also increasing productivity (Negrete, 2018; Khalequzzaman, 2007).

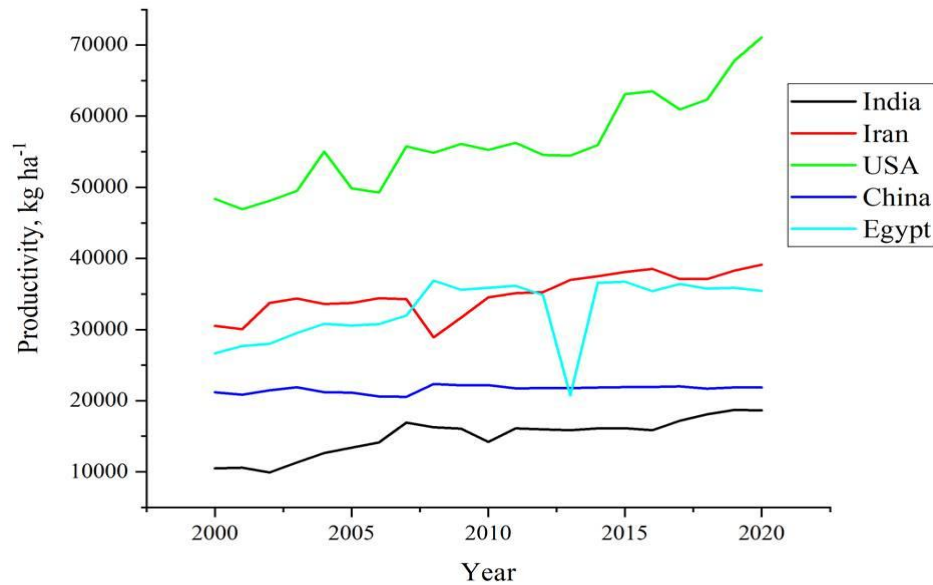


Fig. 1: Productivity of top five onion producing countries (*Faostat*)

Khura *et al.* (2011) developed a tractor-drawn onion harvester and the main components of the harvester were digging (V-shape blade), conveying and separating units. During field testing, the prototype onion digger with the above designed components functioned as expected, with digging efficiency of 97.7%, separation index of 79.1%, bulb damage of 3.5%, fuel consumption of 4.10 l h⁻¹ and draught of 1099.25 kg. Khambalkar *et al.* (2014) designed an onion harvester, which had working width of 0.6 m and depth of about 0.1 m, and it was power by small tractors of power range 10 to 15 kW. The soil mass load on the harvester was worked out to be 1376.62 kg m⁻². The volume of soil discharge per second on the web has been estimated to be 0.023 m³ s⁻¹ for a travel speed of 3.0 km h⁻¹. Singh (2014) tested the performance of a fabricated onion digger and discovered that operating at a depth of 76.20 mm resulted in no harm to the onion bulbs. Digging efficiency of the developed onion digger was found 89.80% with harvesting capacity of 2.77 t h⁻¹, which also saves 58% of labour and 49% of the cost. Mehta and Yadav (2015) invented an onion harvester that saved 87.64% of the time, 46.23% of the energy and 78.86% of the cost of operation as compared to hand harvesting. According to prior

research, the blade rake angle has a substantial impact on digging efficiency. Ibrahim *et al.* (2008) sets the multi-purpose digger to the test for potatoes at 12°, 18°, and 24° blade rake angles, and best results were coming from 18°. Similarly, the effectiveness of Massah *et al.* (2012) onion harvester was tested at 12°, 15°, and 20° rake angles, with the 20° rake angle proving to be the most effective and significant effect due to forward speed also observed. It also investigated the root crop harvester's forward speed and found that it was extremely effective at around 2 km h⁻¹ (Mehta and Yadav, 2015). It was reported that the Raipur, Durg, Raigarh, Kanker and Surajpur were five top onion producer district of Chhattisgarh, India in 2019-20 (Anon. 2020). Purposive sampling (Singh and Masuku 2014, Yamane 1967) at 2020-21 was conducted to perform a survey in the Chhattisgarh plain, namely in several blocks in the districts Raipur, Durg, Dhamtari, and Mahasamund, to learn about the region's adopted harvesting methods. Uprooting onion bulbs and using simple conventional tools were the most common methods of onion harvesting in this region. It was revealed from the survey that the usage of machinery was quite limited, and that there was not a single tractor-driven onion harvester in Chhattisgarh. Because the available digger isn't adequate to the task, it's probable that the soil conditions in other regions of India are different. As a result, research was carried out to develop, construct, and test a tractor-drawn onion digger.

2. MATERIALS AND METHODS

An onion digger was designed and developed at engineering workshop of Indira Gandhi Krishi Vishwavidyalya, Raipur (C.G.) and shown in Fig. 2. 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, Kaveri and Thirupathi 2015, Dabhi *et al.* 2017), agronomical characteristics of onion crop (Mahala *et al.* 2019), soil parameters (Punamia and Jain 2005) and various machine components.

2.1 Development of onion digger

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 and

Yadav (2015). The required power to operate the onion digger was calculated as 14.04 kW (Singh, 2007, Rotz and Muhtar 1992, Alhaseen *et al.* 2015). 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 2005), 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). 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 as shown in Fig. 3 (in which 1. Gear box input shaft 2. Gear box 3. Sprocket-56 teeth 4. Bars 5. Sprocket-17 teeth 6. Separator input shaft 7. Separator 8. Link attachment chain 9. Dual 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.



Fig. 2: Developed prototype of onion digger

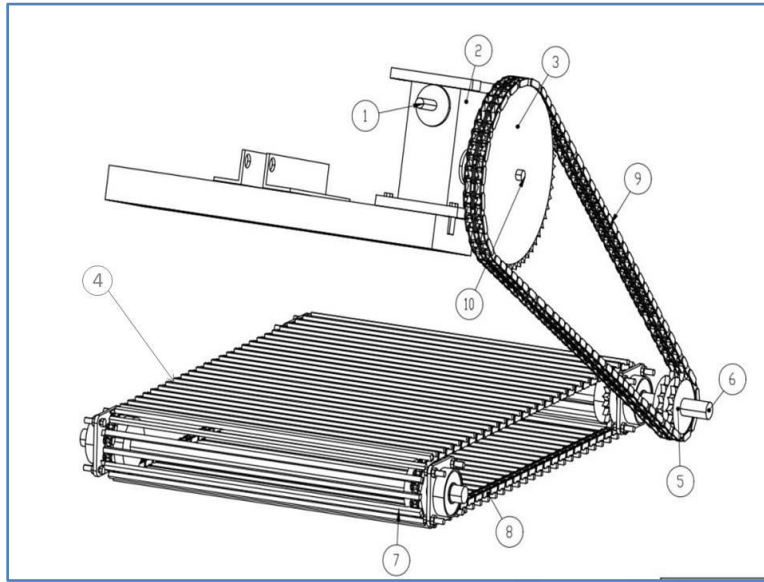


Fig. 3: Layout of transmission system

2.2 Experimental design

An experiment was conducted to assess the influence of different rake angle (A) of blade and forward speed (S) on harvesting parameter (i.e. damage per cent, harvesting efficiency and separation index) of developed onion digger with three level of each factors (i.e. rake angle 15° (A_1), 20° (A_2) and 25° (A_3) and forward speed 2.0 km h^{-1} (S_1), 2.5 km h^{-1} (S_2) and 3.0 km h^{-1} (S_3)). Split-plot design (Gomez and Gomez, 1984; Patel and Naik, 2022) was used to analyze the observed data with utilization of OPSTAT statistical package developed by CCS Haryana Agricultural University, Hisar, India. Rake angle was taken for main plot and forward speed was chosen for the sub-main plot. Forward speed was taken for sub-main plot because it was easy to change the forward speed of operation than the rake angle of blade. Total of 9 treatment combinations (A_1S_1 , A_1S_2 , A_1S_3 , A_2S_1 , A_2S_2 , A_2S_3 , A_3S_1 , A_3S_2 and A_3S_3) were observed with five replications of each. Total number of plots 45 ($3 \times 3 \times 5$) of size $10 \text{ m} \times 1.2 \text{ m}$ were prepared in a total 750 m^2 plot. Developed onion digger was prepared for field evaluation with V-shape blade and 0.7 m s^{-1} separator velocity. Some crop parameters before harvesting the onion bulb is displayed in Table 1.

2.3 Performance evaluation

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).

$$\text{Soil separation index} = \left(1 - \frac{W_a}{W_t}\right) \times 100 \quad \dots 1$$

Where,

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

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

Table 1: Crop parameters before digging operation

S.No.	Parameters	Values
1	Variety	N-53
2	Period of crop, days	110-130
3	Sowing method	Transplanting
4	Row spacing, mm	150.40±2.43
5	Plant spacing, mm	100.70±3.61
6	Height of plant (90 DAT), mm	583.90±26.79
7	No. of leaves per plant (90 DAT)	10.20±0.76
8	Plant population (90 DAT)	49.20±0.87
9	Depth of onion bulb, mm	57.60±3.63
10	pH	6.74±0.17
11	Temperature, °C	41.30±1.01

2.4 Cost analysis

Cost of operation of developed onion digger was calculated using IS: 9164. The developed onion harvester operational cost was divided into fixed and variable cost. The depreciation, interest on the capital cost, shelter, insurance and taxes were taken under

fixed cost and variable cost include fuel, lubricants, repair-maintenance cost and wages of labour (Kamboj 2012; Diwan *et al.* 2022). Cost of developed onion digger was calculated ₹ 28,120/- based on the cost of components and fabrication charges. Breakeven point (Reddy 2003) and payback period (Sabaji *et al.* 2012) also measured of the developed machine. 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.

3. RESULTS AND DISCUSSION

There was a considerable variation in damage as a result of factors A and S, as well as their interaction. As shown in Table 2 most effective result observed due to A2 and S1 on damage per cent, and their interaction was also observed minimum of about 2.74% as depicted in Table 3. When the angle of cut was changed from 15° to 20°, the damage percentage fell by 90.43 percent. There was a further increase of 61.17 percent when the angle was adjusted from 20° to 25°. It might be caused by a short depth of cut of around 50 mm at A1, causing bigger onion bulbs to come into touch with the blade before being entirely dug out, As a result, the lower section of the onion bulb stayed in the soil, and the blade did not reach the bottom of the onion bulb and cut it. In the case of A3, the digging depth was greater, resulting in uneven digging depth over the length of the cultivated strip, and bigger soil clods with larger volume caused damage to the onion bulbs. Due to forward speed better performance observed at lower speed S1 with average digging efficiency of 4.14%, and it was observed that as the forward speed increased damage also increased. The volume of soil and onion bulb to be handled increased as the digger's forward speed increased, it caused friction between soil clods and the bulb that's increase the digger's damage percentage.

Table 2: Mean value of the harvesting parameters of developed onion digger

Factors	Damage, %	Harvesting efficiency, %	Separation index, %
Rake angle (main-plot)			

A1	6.92±0.57	92.82±0.58	57.21±1.71
A2	3.16±0.30	96.60±0.29	56.22±1.87
A3	4.40±0.69	95.39±0.69	52.26±1.77
SE(m)	0.149	0.146	0.299
CD	0.492	0.483	0.989
Forward speed (sub-plot)			
S1	4.14±0.80	95.62±0.80	58.26±1.88
S2	4.22±0.78	95.57±0.78	55.24±1.38
S3	6.11±0.99	93.63±1.00	52.19±1.69
SE(m)	0.052	0.052	0.517
CD	0.154	0.153	2.183

SE(m) = Standard error of the mean, CD= Critical Difference

It was observed that harvesting efficiency was found maximum due to A2 (96.60%) and S1 (95.62%) as depicted in Table 2, and their interaction effect also showing significant effect on harvesting efficiency as shown in Table 3. It was mainly affected by the damage per cent thus as bulb damage decreased, harvesting efficiency improved so it was easy to correlate harvesting efficiency with damage per cent.

Among the different rake angles maximum separation Index was observed to be 57.21% at A1, and due to forward speed it was observed to be 58.26% at S1. It happened because higher soil mass was handled at a higher rake angle because of deep penetration, which made separation difficult. And also the removal of material from the separator to the rear end was quick at higher speeds, so the separation was not done properly at higher speeds. As a result, the separator worked effectively at a lower speed of 2.0 km h⁻¹.

Capital cost of the machine was evaluated by considering price of different components and fabrication charges. Cost of one unit of prototype of onion digger was calculated ₹ 28,120/-. Cost of operation was calculated ₹ 3,346.72/- per hectare with average effective field capacity of 0.12 ha h⁻¹ at 2.0 km h⁻¹ forward speed. Breakeven point and payback period of the developed onion digger were calculated to be 95 h year⁻¹ and 0.54 year, respectively as shown in Fig. 4, and total energy required to operate the developed digger was found to be 329.24 kWh ha⁻¹. It was conclude that a small power

tractor operated onion digger cum separator successfully developed, and best outcome was observed with V-shape blade at rake angle 20° and forward speed of onion digger 2.0 km h⁻¹ with 97.02% harvesting efficiency.

Table 3: Effect of rake angle of blade and forward speed on damage, harvesting efficiency and separation index of the developed onion digger

Treatments	Damage, %	Harvesting efficiency, %	Separation index, %
A1S1	6.71±0.40	93.55±0.39	60.41±1.88
A1S2	5.84±0.41	93.54±0.40	56.91±2.25
A1S3	8.31±0.49	91.37±0.48	54.32±2.04
A2S1	2.57±0.30	97.02±0.29	60.11±2.54
A2S2	2.60±0.31	96.85±0.30	54.95±2.09
A2S3	3.55±0.32	95.94±0.31	53.61±1.86
A3S1	3.98±0.31	96.29±0.30	54.26±2.01
A3S2	3.73±0.21	96.32±0.19	53.87±2.46
A3S3	6.69±0.40	93.57±0.38	48.64±1.96
SE(m) (S at same level of A)	0.257	0.253	0.517
SE(m) (A at same level of S)	0.166	0.163	0.663
CD (S at same level of A)	0.294	0.291	2.183
CD (A at same level of S)	0.537	0.528	1.996

SE(m) = Standard error of the mean, CD= Critical Difference

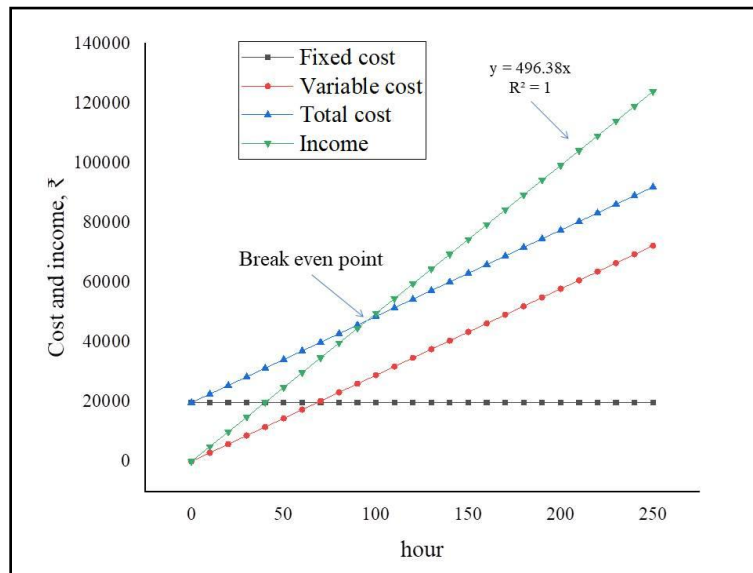


Fig. 4: Break even point of developed onion digger

4. CONCLUSION

Various design parameters like agronomical parameters, soil properties and machine components were determined in field and laboratory condition and applied to the design of onion digger. A tractor drawn onion digger was designed and developed successfully in the Department of Farm Machinery and Power Engineering, IGKV, Raipur. The best result was found with rack angle 20° at forward speed was 2.0 km h^{-1} . The developed onion digger could harvest maximum 3.11 t h^{-1} . The cost of machine and cost of operation were found to be ₹ 28,120/- and ₹ 3,346.72/-, respectively.

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