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Design, Development and Performance Evaluation of Animal-Drawn Onion Digger

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ABSTRACT

Background: Mechanizing small-scale farming enhances productivity and reduces labor dependency for resource-limited farmers. To address these needs, an animal-operated onion digger was developed at IIHR, Bangalore, for rose onion varieties Arka Bindu and Arka Kalyan. Designed for digging, soil separation and windrowing in one pass, it offers a cost-effective, sustainable solution to reduce labor costs and worker fatigue in onion harvesting.

Methods: The onion digger features a robust design with two digging blades, a 430 mm diameter main beam, hitch rods for yoke attachment, depth control wheels, lift rods and windrows. It was evaluated using two blade designs (flat and V-shaped) at rake angles of 16°, 23° and 30°, across twelve experimental plots. The key performance indicators assessed included harvesting efficiency, draft requirements, power consumption and field capacity.

Result: The V-shaped blade at a 23° rake angle achieved the highest harvesting efficiency (93.82%), closely followed by the flat blade (93.65%) at the same angle. The draft requirements ranged from 510 to 550 N, with power requirements of 0.21 to 0.25 hp. Field capacities were 0.10 ha/h and 0.11 ha/h for flat and V-shaped blades, respectively. Statistical analysis confirmed that the V-shaped blade at a 23° rake angle provided optimal draft values and maximum digging efficiency. The total cost of the digger is ₹ 6240, offering a practical and affordable solution for small-scale farmers. The animal-operated onion digger represents a transformative advancement in onion harvesting technology by significantly reducing labor costs, improving harvesting efficiency and alleviating worker fatigue.

Key words: Animal-operated onion digger, Draft requirements, Field capacity, Harvesting efficiency, Rose onion varieties.

INTRODUCTION

Onions (*Allium cepa* L.) are among the most widely cultivated and consumed vegetables worldwide, with India being a significant producer. As of the 2022-2023 period, India ranks as the second-largest onion producer globally, after China, contributing about 13% to the world's total onion production (Rathore and Chaturvedi, 2018; Aruna *et al*., 2023). During this period, India produced approximately 31.7 million tonnes of onions from around 1.64 million hectares, achieving an average yield of 19.34 tonnes per hectare (National Horticulture Board, 2023; Deepa and Aanchal, 2024).

The primary onion-producing states in India are Maharashtra, Karnataka and Madhya Pradesh, which together account for nearly 75% of the country's total onion output (NHB, 2023). The cultivation and harvesting of onions in India are largely labour-intensive, especially in regions where traditional farming methods prevail. The manual harvesting process involves several laborious tasks such as digging, soil separation, windrowing and topping leaves. Manual harvesting requires approximately 200-280 man-hours per hectare and incurs an estimated cost of ₹ 4200 per hectare (Naik *et al*. 2022, Kumawat and Raheman, 2022).

Recent advancements in mechanization have shown potential in alleviating these challenges. Studies indicate that mechanized onion diggers can significantly reduce labour requirements, decrease post-harvest losses and enhance overall efficiency (Sharma *et al*., 2020). Despite these benefits, the adoption of such machinery remains limited among small-scale farmers due to the high costs and limited availability of advanced equipment.

To address this issue, an animal-operated onion digger was developed at IIHR, Bangalore. This digger is specifically designed for the rose onion varieties Arka Bindu and Arka Kalyan, which are prevalent in the Karnataka

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region. The development of this animal-drawn digger aims to offer a cost-effective and efficient solution for small-scale farmers who rely on animal labor. This study examines the design, development and performance of the animal-operated onion digger, emphasizing its potential to transform onion harvesting practices for small-scale farmers in India.

MATERIALS AND METHODS

Study area

An animal-drawn onion digger was developed and fabricated during the year 2020-2021 by the Agricultural Engineering Section of the Indian Institute of Horticultural Research (IIHR), Bengaluru. The development focused on creating an efficient and farmer-friendly implement for onion harvesting. Key considerations in the design included the suitability of the implement for effective digging and conveying of onions, ease of operation and maintenance, low cost of operation and minimal damage to the harvested bulbs. Additionally, the digger was designed to reduce the time required for harvesting, thereby improving overall efficiency. The aim was to provide a simple, low-cost solution that could help reduce post-harvest losses and improve the productivity of small and marginal farmers.

Determination of physical and mechanical properties of onion bulbs

To design an animal-drawn onion digger, key physical and mechanical properties such as linear dimensions, geometric mean diameter, sphericity, bulb weight, bulk density, true density, angle of repose and coefficient of static friction were measured (Kumawat and Raheman, 2022; Jahanbakhshi *et al*., 2018). Linear dimensions (polar diameter, equatorial diameter and thickness) were measured using a digital vernier caliper with an accuracy of ±0.01 mm. Bulk and true densities were determined as fundamental physical properties of the onion bulbs (Pagare *et al*., 2024). Mechanical properties such as the angle of repose and coefficient of static friction were measured using the tank emptying and inclined plane methods, respectively (Kumawat and Raheman, 2023). These physical and mechanical properties guided the design of the digger components, including the inclination and spacing of the lifting rods, while material selection for fabrication was based on general engineering standards and strength requirements suitable for field operations.

Design and development of animal-drawn onion digger

An animal-drawn onion digger was designed and developed [Fig 1 and 2 (A)] considering relevant physical and mechanical properties. Key components include a flat or 'V'-shaped digger blade (700×100×10 mm), lifting rods, windrowers, a handle, a main beam and depth control wheels. The blade, made of M.S. flat material, is attached to the main beam *via* a 'J'-shaped digger supporter (620×50×10 mm) to prevent damage during operation. The rear handle, adjustable in height, is fabricated from G.I. pipe and M.S. square tube. Two 200 mm diameter wheels control the digging depth, supported by M.S. square tube wheel supporters and additional angles. Lifting rods (10 mm diameter, 350 mm length) convey the harvested crop, with windrowers guiding it to the center to prevent damage from animal movement. All components are attached to the main beam and yoke beams for efficient digging. Different adjustment provisions in the developed machine are shown in Fig 3.

Working principle of an animal-drawn onion digger

The animal-drawn onion digger operates by utilizing animal traction to pull the implement through the soil. As the animal moves forward, the front-mounted blade cuts beneath the

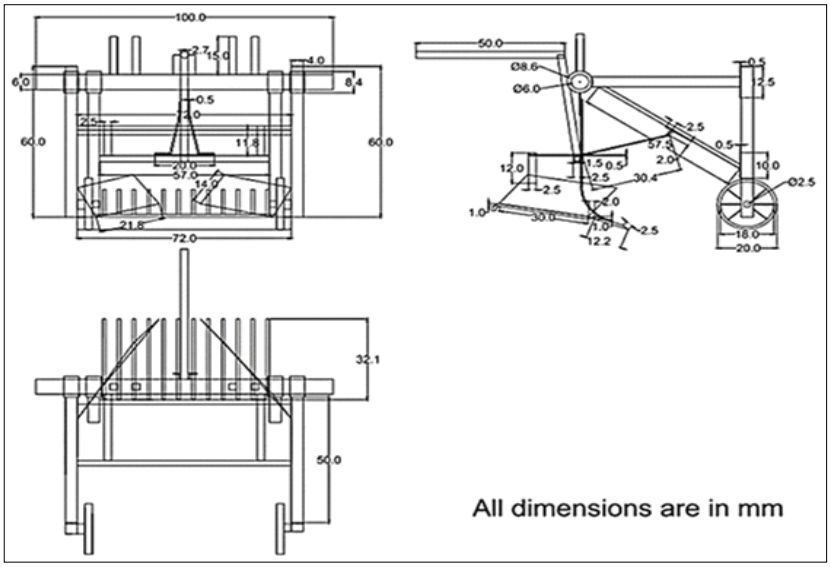


Fig 1: 2 D diagram for developed onion digger in different views.

onion bulbs. The soil and onions are then lifted onto the lifting rods, which separate the onions from the soil while minimizing crop damage. The lifting rods guide the onions to the rear of the digger, where they are windrowed on the surface for manual collection. The adjustable rear handle allows the operator to control force and depth, aided by the attached wheels. This system, powered by the animal's movement, provides an efficient and cost-effective solution for small-scale farming.

Experimental design and procedure for performance evaluation of developed Machine

The study utilized a complete randomized block design (CRBD) to evaluate the performance of the animal-drawn onion digger. The experimental setup involved two onion varieties, Arka Bindu (V_1) and Arka Kalyan (V_2) and two blade types, flat (B_1) and V-shaped (B_2), tested across three rake angles, 16°(A_1), 23° (A_2) and 30° (A_3). Each combination was replicated twice to ensure the robustness of the data. The total number of replications (R) is calculated by using equation (T-1) (R-1) ≤12, which accounts for all treatment combinations. The total treatment combinations are shown in Table 1. Blade types were selected based on recommendations from local farmers and onion varieties were chosen for optimal digging efficiency and minimal damage (Sharma *et al*., 2020). The lower rake angle was preferred for its reduced soil upheaval and draft requirements (Naik *et al*., 2022; Bosoi, 1990).

The developed machine (Fig 1 and 2A) was evaluated under field conditions at IIHR Farm, Bangalore, India. Field preparation involved setting up twelve experimental plots, each 7 meters long and 0.7 meters wide. These plots were allocated to two onion varieties: Arka Bindu (V_1) and Arka Kalyan (V_2). The digger was tested across these treatments in each plot, ensuring operation at the specified rake angles for both blade types on plots (Fig 2c with the two onion varieties 2B). Data collection focused on digging efficiency [the ratio of onions dug to total onions (both dug and undug)], damage efficiency (the ratio of damaged onions to total onions), operational speed (measured in kmph) and field capacity (determined in ha.h^{-1} based on the area covered) (Naik *et al*., 2022).

Statistical analysis

The field data were analyzed using Fisher's factorial, completely randomized block design to evaluate the impact



Fig 2: (A) Animal-drawn onion digger (B) Experimental plot with two onion varieties and (C) Rake angle adjustment to the digger during harvesting.

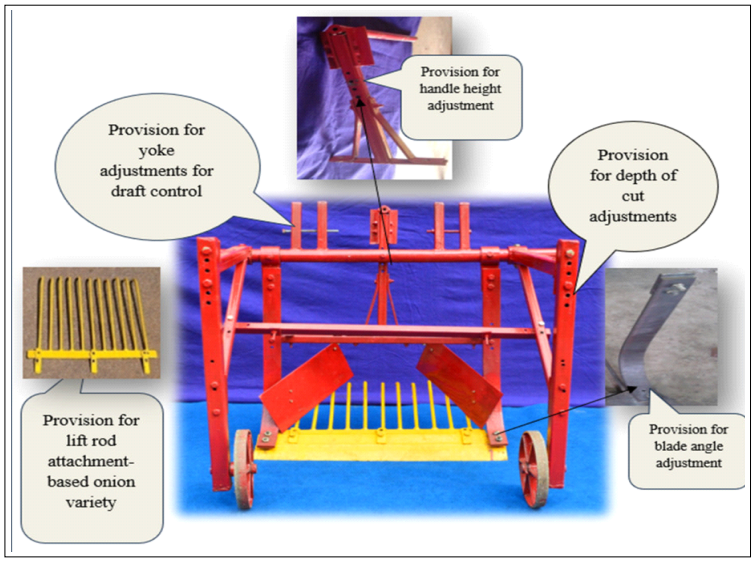


Fig 3: Different adjustment provisions in developed machine.

of variety, blade type and rake angle on these performance metrics using Ager's software.

Cost economics

The cost economics of an animal-drawn onion digger was determined taking into account the fixed and variable costs (labor, raw materials, *etc*.) as per the procedures described by IS: 9164-1979.

RESULTS AND DISCUSSION

Optimization of design parameters of digger based on physical and mechanical properties

The results on the physical and mechanical properties of the selected onion bulbs, as shown in Table 2, provide key insights for designing the animal-drawn digger. The linear dimensions of the bulbs ranged from 19.36 to 49.14 mm in polar diameter, 15.13 to 47.26 mm in equatorial diameter and 15.44 to 40.93 mm in thickness. The geometric mean diameter was 25.67 mm and the sphericity was 0.95. These measurements informed the spacing between the lifting rods, set at 40 mm. The weight of 100 onion bulbs was 718.2 g, which helped in analyzing the draft requirements. Additionally, the blade's conveying capacity was assessed based on bulk density (0.51 kg/m^3) and true density (1.09 kg/m^3). The mean angle of repose was 48.69°, guiding the angle of cut for the digging blades. Similar results were found in other onion varieties (Gayathri *et al*., 2016; Dabhi and Patel, 2017; Shoba *et al*., 2017; Devojee *et al*., 2021). The mean coefficient of static friction for various materials was as follows: mild steel sheet (0.2886), GI sheet (0.2448), SS sheet (0.304), plywood sheet (0.242) and aluminum sheet (0.364). Given mild steel's optimal coefficient of friction, strength and cost-effectiveness, it was selected for the digger's fabrication.

Optimization of operational parameters on digging efficiency, field capacity and operational speed

After harvesting the onions with a developed onion digger, dugged and un-dugged onions were collected manually. Analysis of the results obtained from digging the two varieties of onion bulbs is shown in Fig 4. The highest digging efficiency was observed in treatment T4 ($V_1 B_2 A_2$) at 93.82%, closely followed by T3 ($V_1 B_1 A_2$) at 93.65%. These results indicate that using the V-shaped blade (B_2) or the flat blade (B_1) with a 23° angle of cut (A_2) for the Arka Bindu variety (V_1) offers the best performance. Conversely, the lowest efficiency was recorded in treatment T12 ($V_2 B_2 A_3$)

Table 1: Total treatments for performance evaluation of the digger and their description.

Treatments		Treatments description
T_1	$V_1B_1A_1$	Arka Bindu (V1), flat blade (B1) rake angle16° (A1)
T_2	$V_1B_2A_1$	Arka Bindu (V1), V-shaped (B2), rake angle16° (A1)
T_3	$V_1B_1A_2$	Arka Bindu (V1) flat blade (B1), rake angle23° (A2)
T_4	$V_1B_2A_2$	Arka Bindu (V1), V-shaped (B2), rake angle23° (A2)
T_5	$V_1B_1A_3$	Arka Bindu (V1), flat blade (B1), rake angle 30° (A3).
T_6	$V_1B_2A_3$	Arka Bindu (V1), V-shaped (B2), rake angle 30° (A3).
T_7	$V_2B_1A_1$	Arka Kalyan (V2), flat blade (B1) rake angle16° (A1)
T_8	$V_2B_2A_1$	Arka Kalyan (V2), V-shaped (B2), rake angle 16° (A1)
T_9	$V_2B_1A_2$	Arka Kalyan (V2), flat blade (B1) rake angle 23° (A2)
T_{10}	$V_2B_2A_2$	Arka Kalyan (V2), V-shaped (B2), rake angle 23° (A2)
T_{11}	$V_2B_1A_3$	Arka Kalyan (V2), flat blade (B1) rake angle 30° (A3).
T_{12}	$V_2B_2A_3$	Arka Kalyan (V2), V-shaped (B2), rake angle 30° (A3)

Table 2: Physical and mechanical properties of onion bulbs.

Properties	Material type		
	Onion bulbs		
	Mean	SD (%)	95% CL
Moisture content (db.)	8.90	0.11	8.90±0.20
Equatorial diameter, mm	29.86	0.55	29.86±1.07
Polar diameter, mm	25.36	0.54	25.36±1.06
Thickness, mm	25.11	0.51	25.11±1.01
Geometric mean diameter, mm	25.67	0.41	25.67±0.80
Sphericity	0.95	0.01	0.95±0.18
Weight, g	718.2	227.13	718.26±445.18
Bulk density, kg/m^3	0.51	0.02	0.51±0.03
True density, kg/m^3	1.09	0.04	1.09±0.06
Angle of repose (°)	48.69	1.19	48.69±2.33
Coefficient of static friction	0.29	0.04	0.21±0.37

at 79.09%, highlighting the impact of onion variety and blade type on efficiency. Damage efficiency varied significantly, with the lowest value of 3.74% observed in T3 (V_1 B_1 A_2). This suggests that the combination of the flat blade (B_1) with a 23° angle of cut (A_2) for the Arka Bindu variety (V1) minimizes onion damage. In contrast, T8 (V_2 B_2 A_1) showed the highest damage efficiency at 16.38%, indicating that the blade type and angle of cut can significantly affect the extent of damage to the onions. The fastest operational speed of 2.16 km/h was achieved in T1 (V_1 B_1 A_1). This speed decreases with less efficient treatments, such as T11 (V_2 B_1 A_3) at 0.14 km/h. The data indicates that the type of blade and angle of cut impact the operational speed, with the flat blade (B1) and the 16° angle (A1) generally providing higher speeds. The highest field capacity of 0.15 ha/h was recorded for T1 (V_1 B_1 A_1). This is significantly higher compared to the lowest field capacity of 0.07 ha/h in T12 (V_2 B_2 A_3). This variation emphasizes that field capacity is greatly influenced by the type of blade and angle of cut, with the flat blade (B1) and the 16° angle (A1) being the most effective. The optimal configuration for maximum digging efficiency, minimal damage and higher operational speed and field capacity is the combination of the V-shaped blade (B_2) with a 23° angle of cut (A_2) for the Arka Bindu variety (V_1).

The ANOVA table (Table 3) summarizes the statistical analysis of the effects of different treatments on effective harvesting efficiency, operational speed and field capacity of the developed animal-drawn onion digger. The treatments considered include onion varieties (V_1: Arka Bindu and V_2: Arka Kalyan), blade types (B_1: Flat and B_2: V-shaped) and angles of cut (A_1: 16°, A_2: 23° and A_3: 30°). The analysis indicates significant effects of onion variety (V) and angle of cut (A) on the harvesting efficiency. Onion variety V_1 achieved a higher efficiency (89.06%) compared to V_2 (84.6%). This variation can be attributed to differences in onion size and characteristics, which align with findings from Sharma *et al*. (2020). Among the angles of cut, A_2 (23°) resulted in the highest efficiency (88.02%), significantly

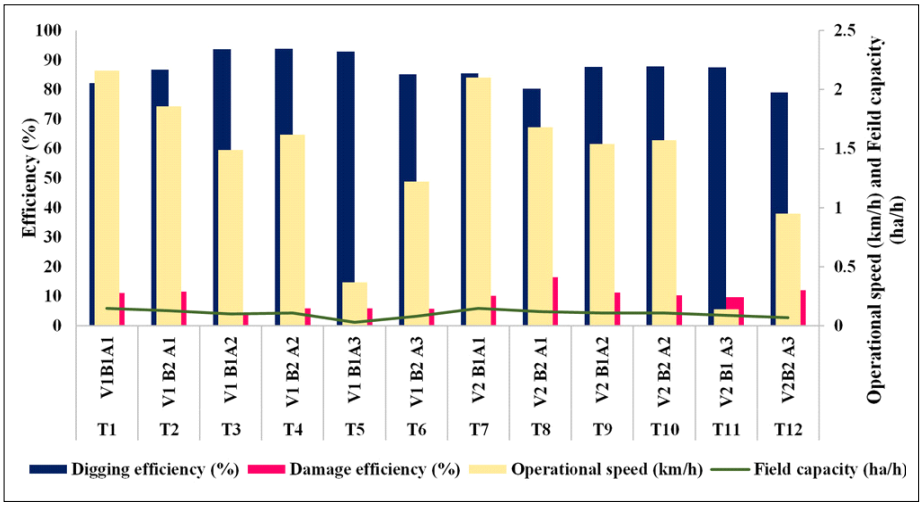


Fig 4: Effect of variety, type of blade and angle of cut on digging efficiency, operational speed and field capacity.

Table 3: ANOVA table for effect of standardized parameters on effective harvesting efficiency, operational speed and field capacity.

Treatment	Effective harvesting eficiency (%)			Operational speed, kmph			Field capacity (ha/h)		
Variety	V_1 (89.06)		V_2 (84.6)	V_1 (1.45)		V_2 (1.33)	V_1 (0.26)		V_2 (0.09)
Blade type	B_1 (88.2)		B_2 (85.4)	B_1 (1.3)		B_2 (1.48)	B_1 (0.12)		B_2 (0.23)
Angle of cut	A_1 (84.18)	A_2 (88.02)	A_3 (88.3)	A_1 (1.78)	A_2 (0.95)	A_3 (1.44)	A_1 (0.12)	A_2 (0.12)	A_3 (0.29)
Source	F-value	SED	CD(P=0.05)	F	SED	CD(P=0.05)	F	SED	CD(P=0.050)
V	**	1.29	2.82	**	0	0	**	0	0
B	NS	1.29	2.82	**	0	0	**	0	0
A	**	1.58	3.45	**	0	0	**	0	0
VB	NS	1.83	3.99	**	0	0	**	0	0
BA	*	2.24	4.89	**	0	0	**	0	0
VA	NS	2.24	4.89	**	0	0	**	0	0
VBA	NS	3.17	6.91	**	0	0	**	0	0

(NS = Not significant, * = Significant at P≤0.05, ** = Highly significant at P≤0.05).

better than angles A_1 (16°, 84.18%) and A3 (30°, 88.3%). The significant effect of angle A_2 is consistent with its optimal balance between soil engagement and operational efficiency. Blade type (B) did not significantly affect harvesting efficiency, suggesting that blade design might be less critical compared to other factors.

The operational speed was notably influenced by the angle of the cut. The angle of cut A_1 (16°) resulted in the highest operational speed (1.78 km/h), while angles A_2 (23°, 0.95 km/h) and A_3 (30°, 1.44 km/h) had slower speeds. The slower speed at angle A_2 can be attributed to increased soil disturbance at this angle. The blade type also showed a significant impact on operational speed, with B_2 (V-shaped blade) performing better (1.48 km/h) compared to B1 (flat blade, 1.3 km/h). This suggests that the V-shaped blade may facilitate smoother operation through the soil. Field capacity was significantly affected by the angle of cut, with A_3 (30°) having the highest field capacity (0.29 ha/h) compared to A_1 (0.12 ha/h) and A_2 (0.12 ha/h). This indicates that a steeper angle of cut can enhance the area covered per hour, potentially due to improved soil penetration. Blade type did not significantly influence field capacity, consistent with the finding that blade design has a less pronounced impact on this parameter. Interactions between treatments were also analyzed. The interactions between blade type and angle of cut (BA) and variety and angle of cut (VA) were significant, affecting both efficiency and operational metrics. Notably, the combination of the V-shaped blade with a 23° angle of cut yielded the best results in terms of harvesting efficiency and operational metrics, indicating its optimal performance for the developed digger.

Cost analysis

The cost economics of an animal-drawn onion digger were calculated using the Straight-line method, considering both variable and fixed costs. The machine's initial cost was Rs. 6200, with a salvage value of 10% of the initial cost. The machine's life was assumed to be 10 years, with an annual usage of 480 hours. The total fixed cost (including depreciation, interest and maintenance) was Rs. 2.046 per hour, while the total variable cost (labor and bullock) was Rs. 183 per hour, resulting in a total operational cost of Rs. 185.046 per hour. Factoring in the machine's field capacity, the total operating cost was Rs. 1850.46 per hectare. In comparison, the traditional manual harvesting method, which includes harvesting, topping leaves and collecting onions, costs Rs. 4000 per hectare (Kumawat and Raheman, 2022). The animal-drawn digger offers a 46.25% cost saving over the traditional method and is 7.8% higher than a tractor-operated onion digger, which costs Rs. 1716.29 per hectare (Khura *et al*., 2011, Naik *et al*., 2022).

CONCLUSION

The development and evaluation of the animal-drawn onion digger demonstrate its effectiveness as a cost-efficient alternative to traditional and tractor-operated harvesting methods. The optimized design, particularly with the V-shaped blade at a 23° angle, provides high digging efficiency (93.82%), field capacity (0.1 ha/h) and operational speed (1.49 kmph), making it suitable for small-scale farmers. The economic analysis reveals significant cost savings, reducing operational expenses by 46.25% compared to manual methods. This innovation not only enhances productivity but also offers an affordable solution that alleviates labor demands in onion harvesting.

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Conflict of interest

The authors declare that they have no financial interests or personal relationships that could be perceived as influencing the work presented in this paper.

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