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RESEARCH ARTICLE

Design and performance of mini tractor-operated onion detopping and harvesting unit

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Abstract

Onion (*Allium cepa* var. *aggregatum*) is a widely cultivated crop in Tamil Nadu, India, for domestic and export purposes. It is used as an essential ingredient in all food preparations. Onion, as an indispensable vegetable, the demand for its bulbs has remained relatively consistent irrespective of wide fluctuations in the market prices. Manual onion harvesting is a tiresome, time-consuming, labour- and cost -intensive operation that necessitates mechanized harvesting. Mechanization, which is adopted presently in onion harvesting, is a traditional practice performed with a hand shovel (khurpa). This process alone consumes 21.4 % of the total cost of onion cultivation. Developing a power-operated detopper that can detop the onions after uprooting the onion leaves is essential. Hence, a research study has been taken up for the "Development and evaluation of mini tractor operated onion harvester with detopping unit" to perform both detopping and harvesting simultaneously. The onion harvester attached to the detopping unit was evaluated for harvesting CO (On)5 variety at farmers fields. The performance of the developed prototype onion harvester and detopping unit was evaluated for detopping and harvesting of onion crops in the farmer's field at Nahar village and cost economics was worked out. The cost of the onion harvester, along with the detopping unit, was Rs. 22300. The adequate field capacity of the onion harvester with a detopping unit was found to be 0.052 ha/h. The cost of harvesting and detopping with an onion harvester was 8337 Rs./ha. The savings in cost and time were 81.4 and 92.2 %, respectively. The onion harvester's break-even point (BEP) with the detopping unit was found to be 25.12 h per annum and the payback period was determined to be 1 year and 5 days.

Keywords: detopping efficiency; harvesting mechanization; onion harvesting; small tractor

Introduction

Agriculture plays an essential role in the Indian economy. Among the horticultural crops, onions (*Allium cepa* var. *aggregatum*) are a crucial underground bulbous, commercial vegetable and spice crop grown in a relatively large area. Globally, India holds the second-largest position next to China. Onions from India are famous for their pungency and are available 365 days a year. The onion belongs to the genus Allium, which contains about 300 species widely distributed in Northern temperate regions as biennials and perennials. It is widely cultivated for domestic consumption and export purposes and is an essential ingredient in all food preparations. According to the Ministry of Agriculture, for 2022-23 in India, the area of onion cultivation is 1740000 ha with 17.4 MT production.

Central onion-producing states in the country are Maharashtra, Karnataka, Madhya Pradesh, Rajasthan, Bihar, etc. The area of onion cultivation in Tamil Nadu is 43980 ha, with production of 301140 T in 2022-23. In Tamil Nadu, the onion crop is grown mainly in Perambalur, Trichy, Dindigul, Namakkal, Tirunelveli, Erode and Coimbatore districts. Onion in India is grown in three seasons Rabi (March to June), Kharif (October to December) and late Kharif (January to March). Kharif produce is available in the market from October to December, which is estimated to be 15-20 % of the total produce per annum.

Onions can be harvested using two methods, i.e., manually and mechanically. Manual harvest is carried out by pulling out plants when plant tops are drooping but still green. The height of the onion crop during harvesting is 15 to 40 cm. When soil is hard in summer, bulbs are pulled out with a hand hoe. Manual harvesting of onions is tiresome, time-consuming, labour-intensive and costlier, necessitating mechanization. Mechanization adopted for onion harvesting as a traditional practice was with the help of a hand shovel (khurpa). This requires 21.4 % of the total cost of onion cultivation (1). This traditional practice is assisted within specified time limits to reduce harvest losses and increase storage life. Early harvest affects the onions' keeping quality adversely and reduces the yield, whereas delayed harvesting results in infection caused by microorganisms

(2). The available mechanical onion harvesters involve only digging the onions and conveying them. After harvesting the onions, i.e., separating the onions along with leaves from the soil either manually or mechanically, separate labour was adopted to detop the onion leaves. The conventional practice for detopping onion leaves is detopping the leaves manually with the help of a sickle and primarily by thread cutter scissors. Manual detopping of the onions is a laborious, tedious, time-consuming operation demanding numerous labourers to 12.5 man-h for 1 MT of onion bulbs (3).

Onion harvesting is labour-intensive, involving undercutting, lifting, windrowing and collection. Manual harvesting requires significant labour, which is becoming increasingly scarce and expensive due to rural migration to urban areas. Mechanization reduces dependency on labour, ensuring timely harvesting without excessive costs. Mechanized harvesters significantly reduce harvesting time, allowing farmers to complete the process efficiently and minimize post-harvest losses. Small and medium-scale farmers often cultivate onions on fragmented landholdings (1-5 ha), where large machinery is practically impossible. The harvester can be designed as an attachment, reducing machinery costs and making it an economical choice for farmers.

Some researchers have developed stationary power-operated detoppers for detopping the onions. The onions were fed into the unit manually by labourers and it will detop the onion leaves up to 25 mm onion neck length, which is recommended for storage (4). The developed power-operated detoppers will detop the onions after the uprooting of onion leaves. The detopping of onion before uprooting the crop from the soil is conceived for mechanization of the onion crop to reduce machinery and labour costs. Developing a machine that can do both detopping and harvesting simultaneously will be more economical. So, a research study has been taken up for the "Development of mini tractor operated onion harvester with detopping unit" with the following objectives.

The current study investigates agronomical parameters, crop parameters and suitable mechanisms for detopping and harvesting onions. Next is to develop a prototype onion harvester with a detopping unit based on optimized parameters. And to evaluate the performance of the prototype unit under the actual field conditions.

Material and Methods

Crop variety

Around 90 % of the country's onion production is from Tamil Nadu and 10 % from the adjacent state Karnataka (5). CO (On) 5 a high-yielding variety of Country onion or '*chinnavengayam*' with attractive pink and bold bulbs, commonly preferred by farmers, was selected for the study (6). About 12.5 kg onion was collected after maturity (90 days).

Sowing pattern and spacing

The cultivation of onion crops in the field is practiced in three ways: (i) By raising seedlings in a nursery and then transplanting them in the main field. (ii) By planting bulbs in raised beds and (iii) By broadcasting or drilling the onion seeds in the field. The recommended crop spacing for country onions in conventional practice is 150 mm row to row and 150 mm plant to plant, whereas for CO (On) 5 variety, 200 mm row to row and 120 mm plant to plant has been followed in this study.

Physical properties of crop

The physical properties of the crop that influence the mechanical harvesting along with detopping of onions before uprooting the crop were identified as plant population, plant height, bulb diameter *viz*., polar diameter and equatorial bulb diameter, bulb depth, plant height, number of bulbs hill, bulb weight, bulk density, number of leaves, crop moisture, coefficient of static friction and bulbs per plant (4, 7, 8). For the investigation of crop parameters of CO (On)5 variety, the onion crop was grown in the Central Farm of Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy and the following crop parameters were studied for fifty samples which were selected randomly.

Plant population

The plant population is a parameter used in measuring the crop volume handled by the machine per unit width of the blade per unit time and unit speed. It was calculated by counting the number of plants in one square meter area in fifty different areas and taking the average value of the crop population.

Plant height

The maximum plant height of the leaves above the soil surface was significant regarding the detopping height. The height of the leaves above the ground surface was measured for different plants selected at random using a scale of 1 m with a resolution of 1 mm and the mean value was calculated.

Polar diameter

The space between the onion crown and the root attachment point is considered polar diameter (9). The onion neck length after detopping was calculated based on the polar diameter. The polar diameter was measured by a digital vernier calliper of 0.01 mm least count. The polar diameter for onion bulbs was recorded and the mean value was determined.

Equatorial diameter

The equatorial bulb diameter is the maximum width of the onion in a plane perpendicular to the vertical plane. The spacing between the bars in the grader depends on the diameter of the onion bulb. It was measured by a digital vernier calliper (0.01 mm least count) (9). The equatorial diameter for onion bulbs was measured and the mean value was determined.

Bulb depth

The depth of the onion bulb below the soil surface was measured by removing the soil beside the plant. The reading was taken from the soil surface to the point of root attachment. It was measured using a 30 cm scale having a 1 mm pitch. The depth was randomly measured for samples, the values were recorded and the mean value was calculated.

Number of bulbs per hill

The number of bulbs per hill was considered an essential parameter for measuring the crop volume handled by the unit. The number of bulbs per hill was counted. The mean value was calculated.

Bulb weight

The bulb weight is an important physical property for measuring the weight of the crop handled per unit width of operation per unit of time. The bulbs were removed from the soil and weighed with electronic balance. The values were recorded and means values were calculated.

Bulk density of the bulb

The bulb density measures the volume and quantity of the crop handled by the machine. A container of known volume, having an inner size of 50 × 50 × 50 cm, was taken and weighed in a balance. Then, it was filled freely with freshly harvested CO (On) 5 plants and weighed again. The bulk density of the bulb was calculated and the mean value was calculated and tabulated.

Coefficient of static friction

The coefficient of static friction (μ_s) of onion bulbs is required for designing a shaker cum conveyor unit for giving inclination to the unit. The coefficient of static friction was measured by using incline plate apparatus consisting of a feed trough, screw shaft and angle indicator mounted on a trapezoidal frame. The onion bulb was placed in the feed trough and the angle at which the bulb started falling from the feed trough was measured using the inclination angle. The coefficient of static friction was calculated, the experiment was repeated and the mean value was determined.

Diameter of the onion neck

The diameter of the onion neck is an essential physical parameter considered for detopping the onion leaves. The diameter of the onion neck length was measured using a standard one-inch micrometre with a resolution of 0.01 mm.

Conventional practice of harvesting and detopping operations

Harvesting of onions starts when the leaves fall by 25 - 50 % (8), within 70 to 90 days of planting. Manual harvest is carried out by pulling onion plants from the land when plant tops drooping but still greenish. A hand hoe pulls the bulbs on hot days when soil is hard. The field capacity, cost of harvesting and harvesting efficiency were calculated using the manual method.

The efficiency of manual harvesting can be calculated using the following formula.

$$\eta_h = W_p / 〚W_s + W〛_p \times 100 \qquad \text{(Eqn. 1)}$$

Where, η_h = Harvesting efficiency, %

W_p = weight of onion bulbs collected from the harvested plants in unit, kg

W_s = weight of left-out onion bulbs collected from the soil in unit area, kg

After the harvesting, the traditional detopping was carried out using cutting tools, like sickle and thread cutter scissors. The detopping labour requirement per unit weight was recorded.

Selection of prime mower

Based on the agronomical and physical properties of the onion crop, a prime mower was selected to develop an onion harvester with a detopping unit, which was finalized as a mini tractor. The specifications of the mini tractor and mini tractor implement system were selected by considering the crop geometry and track width adjustment.

The following machine units are essential for a machine to perform harvesting operations.

Detopping unit - detopping the onion leaves using rotary impact

Digging unit - digging the onion bulbs after detopping and lifting

Shaker cum conveying unit - lifted and conveyed onion bulbs were shacked to remove the soil or dust attached to the bulbs and to windrow them in furrows between the beds in the direction of travel for easy collecting.

Identification of relevant parameters for optimization of detopping unit

The onion detopping unit was conceptualized to perform detopping operations in the field. Shear impact cutting attached with a thread was used to cut various crops, particularly for low-dense crops. The rotary-type impact cutter is mainly adopted because of its simplicity in construction and low maintenance (10). Hence, the type impact cutter was selected as the detopping unit. The performance of the detopping unit mainly depends on the crop and operational parameters. The crop and operational parameters were classified as independent and dependent parameters for optimization of the detopping unit.

In the development of the detopping unit attached to the onion harvester, the parameters that independently affect the performance of the detopping unit were selected as forward speed of the machine (S), peripheral speed of the detopping unit (N), type of cutting string (T) and number of cutting edges (H).

Forward speed

Detopping operation is closely affected by the forward speed of the machine. The increase in forward speed reduces the work per unit area per unit time, resulting in the change of onion neck length (11). Hence, optimum forward speed should be maintained to increase the detopping efficiency. The laboratory investigation was conducted by selecting three different levels of the machine's forward speed based on the power source attached to the machine (mini tractor) and evaluated for the optimization of the detopping unit.

Peripheral speed

The quality of the detopping of onion leaves is highly influenced by the peripheral speed of the detopping unit. The effect of peripheral speed is mainly concerned by the rotary impact cutting of the onion leaves. The peripheral speeds of the cutter were chosen based on the speed at which the leaf was cut, i.e., 5.05 m/s (950 rpm) for the laboratory investigation.

Type of cutting string

The type of cutting string is an essential parameter for detopping the onion leaves. The material chosen for cutting the onion leaves should resist breakage and have extra strength for cutting the onion leaves directly in the field condition. Hence, reinforced composite nylon material was considered for cutting the onion leaves. The detopping of onion leaves varies by the speed at which the nylon string applies the impact force on the onion leaf. Hence, the shape of the surface of the nylon string which touches the onion leaf for detopping also plays an important role in the operation. The specifications of the nylon strings are mentioned in Table 1. Among three types of nylon strings, the string which efficiently detops the onion leaves was selected under laboratory investigation.

Number of cutting strings

The number of strings is essential for attaining effectiveness in the detopping. As the cutting strings increase, the number of cuts increases and thereby, the quality of cut increases. So, three different alignments of the nylon string were considered for optimizing the best treatment i.e., that detops the onion leaves effectively. The alignment of nylon strings considered for the study is shown in Fig. 1.

Dependant parameters

In developing onion harvester and detopping unit, the dependent parameter considered in evaluating the detopping unit was onion neck length (3, 4).

Onion neck length

Neck length is defined as the space between the onion bulb and the top cut segment of the onion bulb. It was measured with the help of a vernier calliper of 0 - 150 mm (least count of 0.01 mm).

Treatments involved in the investigation of the performance of the detopping unit

Based on the selected levels of the variables, the treatment combinations are detailed in Table 2.

Development of prototype onion harvester with detopping unit

Based on agronomical, crop and machine parameters, the optimized values of the selected variables were utilized to develop the prototype. The prototype of a mini tractor-operated onion harvester with a detopping unit consists of the following components: i. Main Frame, ii. Detopping unit, iii. Digging unit, iv. Shaker cum Conveyor and v. Transporting wheels.

Table 1. Specifications of nylon strings considered for laboratory investigation

S.No	Cross section	Size	Pictorial view
1.	Square	3 mm	
2.	Round	3.2 mm	
3.	Flat with one side serrated	2 mm	

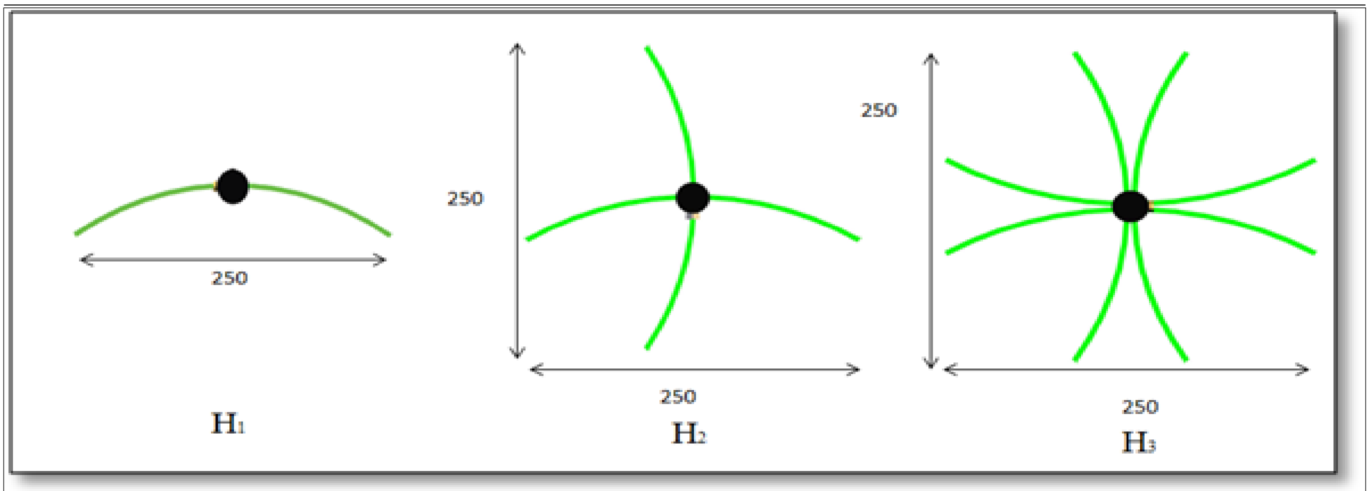

Fig. 1. Indicating the alignment of the nylon string.

Table 2. Treatment combinations

Sl.No	Variables		Levels
1	Number of forward speeds (km/h)	-	3 levels (1, 1.5 and 3.5)
2	Number of peripheral speeds (m/s)	-	3 levels (5.31, 6.64 and 7.97)
3	Shape of cutting strings	-	3 levels (Square, Round and Flat surface with serrations on one side)
4	Number of cutting strings	-	3 levels (2,4 and 8)
5	Replications	-	3
6	Total number of experiments	-	243

The main frame consisted of a rectangular section of 1500 × 1000× 600 mm for mounting the power transmission unit and detopping unit, digging blade and shaker cum conveyor. It comprised an M.S. rectangular hollow tube of cross section 76.2 × 38.1 mm. Mild steel was selected based on the strength offered by the material, easy availability and machinability. The power transmission system was chosen with a gear system to avoid losses and slippage and gear ratios were calculated and implemented according to the conversion required from tractor PTO. In the front portion of the frame, a gearbox was mounted at the top with a gear ratio of 11:18 ratio. The drive to the mounted gearbox was transmitted from the mini-tractor PTO through a telescopic shaft with universal joint. The power from the mini-tractor PTO was diverted perpendicularly using a gearbox having an 11:18 gear ratio. The gearbox's output was connected to an extension shaft of 25.4 mm in diameter and a length of 700 mm. The power to the detopping unit, digging unit and shaker cum conveyor unit was taken from this extension shaft with belt and pulley, chain and sprocket and a set of bevel gears, respectively. The main purpose of the frame is to provide durable support to different parts of the harvester.

The detopping unit was mounted in the front portion of the main frame. Two detopping units were mounted at a distance of 300 mm, two mid-ways of four rows of onion crop, each covering two rows. Two "L" angle bars of length 1000 mm with a cross-section of 40 × 40 mm were fixed horizontally in the front portion of the main frame with a distance of 100 mm between them in a vertical plane. The detopping string was the central part of the detopping unit fixed in the horizontal plane to a 20 mm vertical rod at a distance of 5 mm from the bottom. This vertical rod was inserted vertically at the bottom of an M. S. shaft of 25.4 mm diameter to a length of 100mm. The length of the round shaft was 400 mm. It was fixed on two "L" angles of cross-section 40 × 40 mm and a thickness of 8 mm by pillow block bearings. To adjust the depth of the cut to 50 mm, slots were given at 10 mm intervals at the top of the vertical rod attached with a detopping string.

The power to the detopping unit was given from the extension shaft by attaching a drive pulley of 200 mm diameter. The power from the driven shaft is transferred to the detopping unit with the help of bevel gears of 24 teeth having an outer diameter of 80 mm attached at the position of the two detopping units. Similar bevel gears were fixed at the top of the two vertical shafts of the detopping units (Fig. 2).

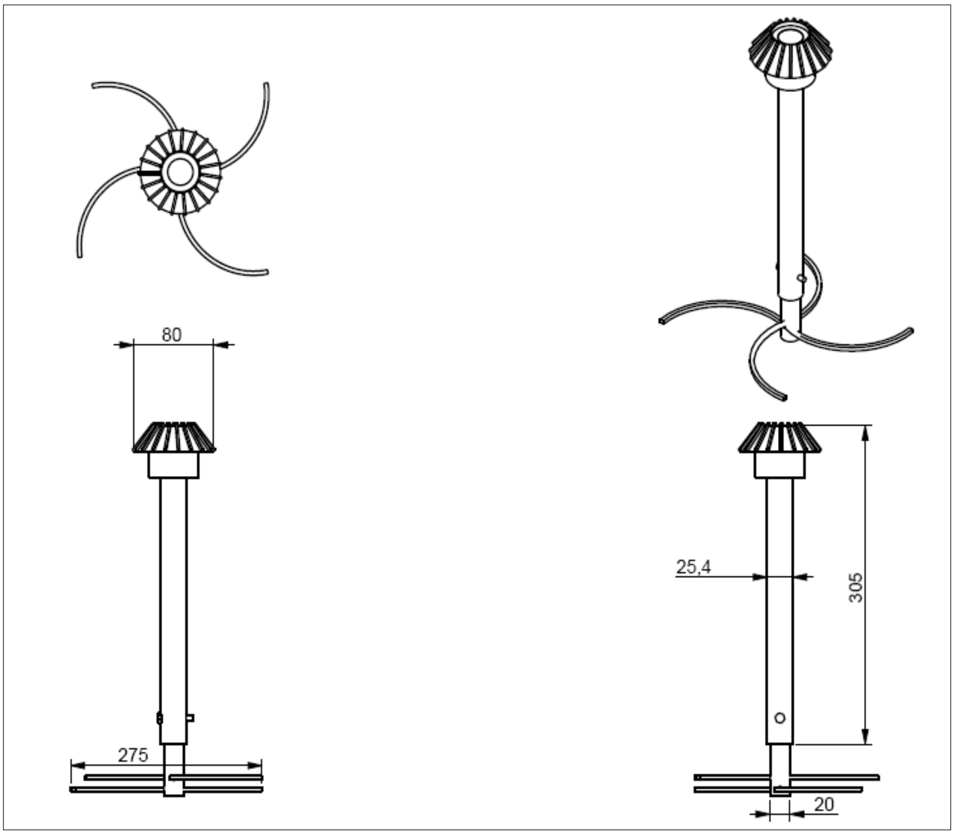

Fig. 2. Detopping unit.

The digging unit consists of two main components: a digging blade to dig the onion bulbs and a roller to convey the digged onion bulbs. The portion that enters the soil was made into a series of three consecutive triangular cross sections with a separation of 100 mm between each of the triangles and having triangle dimensions as 70 ×100 mm for easy penetration of the blade into the soil. On the surface of the blade, four rectangular cuts of dimensions 250 ×100 mm were made and a square mesh of 1 × 1 inch was attached at the back side of the blade, covering the rectangular cut portions so that the weight of the blade was reduced and also the loose soil which was on the surface of the blade after digging can fall through the square mesh (Fig. 3).

The overall dimensions of the shaker cum conveyor unit were 1050 × 400 × 500 mm. One end of the shaker cum conveyor unit was connected to the crankshaft and the other end of the unit was connected to the mainframe support with the help of nylon belts of dimensions 100 × 50 × 7 mm by bolt and nuts. The purpose of the nylon belt was to provide an easy reciprocating motion to the unit while moving with the harvested produce. The shaker cum conveyor unit was fabricated with M.S flats of 100 × 10 mm with a thickness of 6 mm. Based on the bulb diameter, the spacing between the two consecutive M.S flats was fixed at 20 mm. The sides of the unit were closed with a square mesh of 10 × 10 mm apart from the blade width on one side and throughout the length of the unit on the other side to a height of 420 mm to restrict the jumping of the onions out of the unit. Two cranks were taken on both ends of the conveyor unit across its cross-section to get equal oscillations. The cranks were connected by a round shaft of 25.4 mm diameter of length 500 mm and two M.S. flats of thickness 5 mm and having dimensions 550 × 50 mm were used to connect the shaker cum conveyor unit and the crankshaft. One end of the M.S. flat was welded to the surface of the shaker cum conveyor unit and the other end of the flat was welded with M.S. rings of 26 mm inner diameter so the crankshaft was inserted into the ring and gave power to the shaker cum conveyor unit through the M.S flat. The number of revolutions made by the crank shaft is equal to the number of reciprocating motions of the shaker cum conveyor unit. No gear reduction was provided to reduce the unit's speed, but the unit's stroke length depends on the degree of eccentricity. The stroke was nil when set at the crank's centre (0°) and 40 mm and 65 mm lengths were observed at 0.5 ° and 1° eccentricity, respectively.

The four corner vertical posts of the main frame were attached with transporting wheels to provide forward motion to the unit in the field while operating and for transporting purposes.

Performance evaluation of the onion harvester in field operation

The onion harvester attached to the detopping unit was evaluated for harvesting CO (On) 5 variety at the farmers' field at Nahar village. The following tests were carried out in the field to study the performance of the onion harvester in terms of fuel consumption, field capacity and draft.

Theoretical field capacity

The width and speed of the digging blade were considered and the theoretical field capacity was calculated.

Effective field capacity

The adequate field capacity of the onion harvester with a detopping unit was calculated.

Field efficiency

The field efficiency of the onion harvester with a detopping unit was calculated.

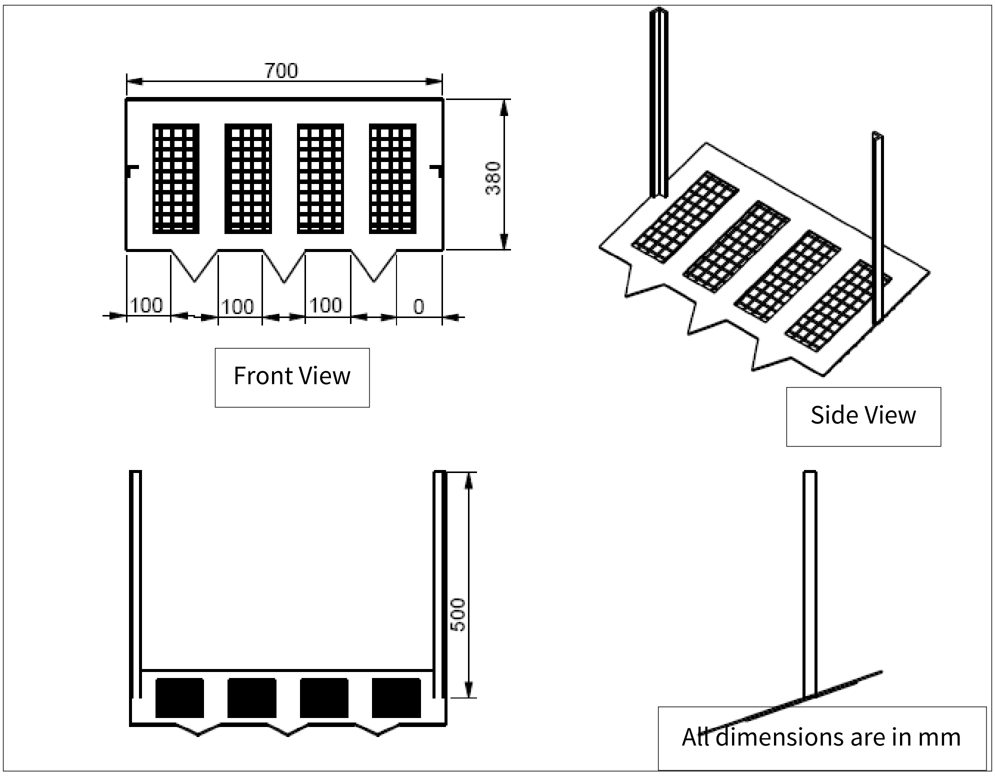

Fig. 3. Digging blade.

Digging efficiency

The digging efficiency of the unit is the ratio of harvested bulbs to total bulbs in the field.

$$\text{Digging efficiency (\%)} = \frac{\text{Harvested bulbs}}{\text{Total bulbs in the field}} \times 100 \qquad \text{(Eqn. 2)}$$

Percentage of damaged bulbs

The damage to the onion should be minimal while harvesting. The damage during the operation of the prototype onion harvester with a detopping unit was calculated using the following formula.

$$\text{Percentage of damaged bulbs (\%)} = \frac{\text{Damaged bulbs}}{\text{Total har. bulbs in the field}} \times 100 \qquad \text{(Eqn. 3)}$$

Conveying efficiency

Conveying efficiency is the ratio of harvested bulbs windrowed to the total bulbs in the field.

$$\text{Conveying efficiency (\%)} = \frac{\text{Windrowed bulbs}}{\text{Total harvested bulbs in the field}} \times 100 \qquad \text{(Eqn. 4)}$$

Output capacity

The amount of onions windrowed from the shaker cum conveyor unit per unit of time is known as the output capacity.

$$\text{Output capacity (kg/hr)} = \frac{\text{Weight of onions windrowed (kg)}}{\text{Time (hr)}} \times 100 \qquad \text{(Eqn. 5)}$$

Fuel consumption

The fuel tank was filled to the full capacity before and after the tests. The fuel consumption for the particular test was the amount of fuel refilled after the tests. It was calculated by using the formula.

$$\text{Fuel consumption (L/hr)} = \frac{\text{Fuel consumed (1)}}{\text{Time of operation (hr)}} \qquad \text{(Eqn. 6)}$$

Draft measurement

A draft of the onion harvester with a detopping unit was measured in the field following the standard procedure of RNAM. Attach a load cell with a chain between the front portion of the mini-tractor, which is attached to an onion harvester with a detopping unit and the back hitch point of the auxiliary tractor.

Firstly, the draft was calculated in no load condition, i.e., by keeping the harvester in the raised portion and the mini tractor in neutral gear. The auxiliary tractor was operated in first gear to pull the mini tractor-attached onion harvester. The reading was recorded from a digital dynamometer attached to the load cell and placed on the auxiliary tractor. Then, the harvester was lowered to the proper depth and the draft for pulling the mini tractor and harvester with the detopping unit (lowered position) was recorded. The draft was measured by considering the difference between the average draft value at load and no load conditions.

$$\text{Draft} = P_2 - P_1$$

Where,

P_1 - Draft recorded in strain gauge dynamometer when prototype in lifted condition, kN.

P_2 - Draft recorded in strain gauge dynamometer when prototype in operating condition, kN.

Cost economics

The total cost of a mini tractor-operated onion harvester with a detopping unit was calculated. The fixed and variable costs of the developed unit per hour were assessed as per the procedure enumerated by RNAM (12). Based on the developed unit's field capacity, the operation cost per ha was estimated. The performance was compared with the conventional method of onion harvesting in terms of cost savings and improvement in overall efficiency. The Break Even Point (BEP) for the developed mini tractor-operated onion harvester with a detopping unit was found.

Results and Discussion

The agronomical parameters, crop parameters and effects of the independent and dependent parameters on the performance of the detopping unit were statistically analyzed and discussed. Fig. 20 shows the field evaluation of the detopping unit.

Agronomical parameters

The physical properties of onion variety Co(On)5 were studied and the physical parameters are presented in Table 3.

Selection of prime mower

The prime mower was selected as a tractor and three tractors with different power ranges and track widths were considered. The tractor specifications, the distance between the inner edges of the front and the rear wheels and the track width of the tractor are presented in Table 4.

Hence, the mini tractor VST SHAKTHI VT 224 -1D was chosen as a prime mower for operating the onion harvester with a detopping unit (Fig. 4). The specifications of the selected prime mower are mentioned in Table 4.

Effect of selected variables on onion neck length

Using the experimental test rig, a total of 243 experiments were conducted to investigate the influence of selected levels of variables. The impact of variables on onion neck length was analyzed and detailed in the further sections.

Table 3. Physical properties of onion

Sl. No	Statistical inference	Plant population per square meter, numbers	Plant height, mm	Polar diameter, mm	Equatorial diameter, mm	Bulb depth, mm	Number of bulbs per hill	Bulb weight, g	Bulk density of onion bulb, kgm^{-3}	Onion neck diameter, mm
1	Maximum value	37	450	50.48	40.56	100	8	40	580.00	9.22
2	Minimum value	31	248	28.45	24.32	75	3	25	515.00	5.20
3	Mean	35	315	40.63	32.96	88	5	32	535.40	6.66
4	Median	33.5	300	40.07	33.54	88	4.5	31	534.50	6.51
5	SD	1.73	54.59	6.98	5.74	8.69	1.85	5.65	15.45	1.30
6	SE	0.54	17.26	2.20	1.81	2.74	0.58	1.78	4.88	0.41

Table 4. Various prime movers and its details

S. No	Tractor Name	Distance between inner edges of the Front wheels (mm)	Distance between inner edges of the Rear wheels (mm)	Track width of the tractor (mm)
1.	VST SHAKTHI VT 224 -1D	680	710	1140
2.	SWARAJ 724XM Orchard	900	995	1630
3.	SWARAJ 735XT	1020	1180	1680

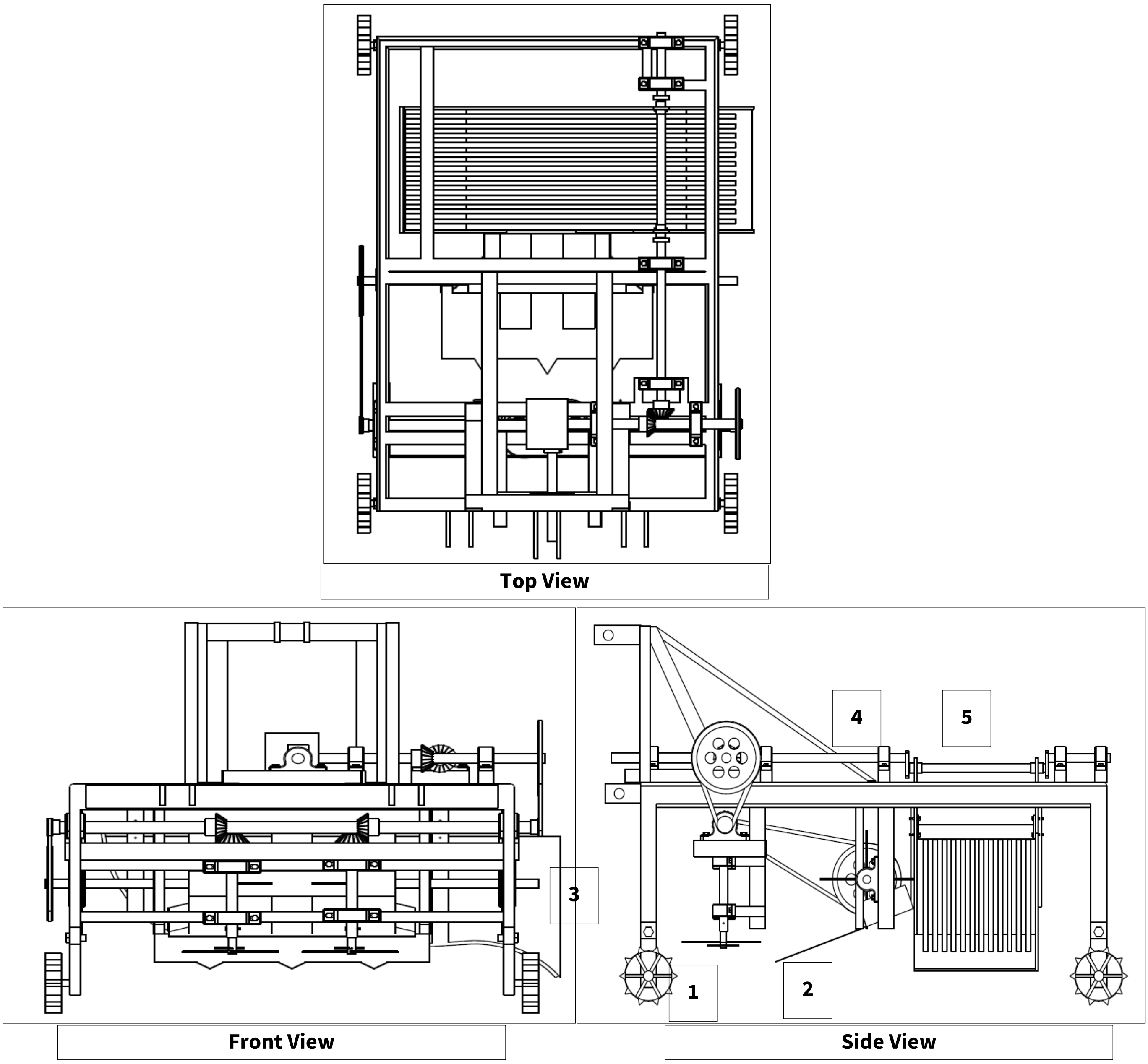

Fig. 4. Onion harvester with detopping unit. 1. Detopping unit 2. Digging blade 3. Main frame 4. Roller 5. Shaker cum conveying unit.

Effect of forward speed and peripheral speed on onion neck length

The influence of forward speed (km/h) and peripheral speed (m/s) on the onion neck length was studied using the experimental test rig. The mean values of onion neck length for selected levels of forward speed (km/h) and peripheral speed (m/s) were recorded.

Square type of nylon string (T_1)

The effect of forward speed (S) of detopping unit on onion neck length at 1 (S_1), 1.5 (S_2) and 3.4 (S_3) km/h forward speed for square type string with two strings (H_1), four strings (H_2) and eight strings (H_3) is depicted in Fig. 5-7, respectively. It is inferred from Fig. 5, that the increase in forward speed increased onion neck length. An increase of 7.8, 14.2 and 9.5 % were recorded with an increase in forward speed from 1 (S_1) to 1.5 (S_2) km/h at 5.31 (N_1), 6.64 (N_2) and 7.97 (N_3) m/s.

Further increase in forward speed from 1.5 (S_2) to 3.4 (S_3) km/h resulted in a drastic increase of the onion neck length by 73.77, 79.65 and 88.22 % at three peripheral speeds, 5.31 (N_1), 6.64 (N_2) and 7.97 (N_3) m/s respectively. The same trend was observed for four strings at an incremental increase of 5.2, 28.5 and 21.8 % with increase in forward speed from 1 (S_1) to 1.5 (S_2) km/h at 5.31 (N_1), 6.64 (N_2) and 7.97 (N_3) m/s respectively (Fig. 6). Further increase in forward speed from 1.5 (S_2) to 3.4 (S_3) km/h resulted in a sudden increase of 83.2, 86 and 35.1 % respectively.

With the increase in forward speed from 1 (S_1) to 1.5 (S_2) km/h, the time to cut the crop was reduced, increasing onion neck length. Further increase in forward speed from 1.5 (S_2) to 3.4 (S_3) km/h resulted in a sudden rise in onion neck length. After detopping at 3.4 (S_3) km/h, the onion neck length was almost equal to the plant height, indicating no cut happening at 3.4 (S_3) km/h. The trend is evident from the fact that at the lower forward speed of the crop conveyor, more time was available for detopping, resulting in the pure cutting of onion leaves. At higher forward speed, it was found that the time taken by the conveyor assembly to convey the onion crop to the detopping unit was less and all levels of several nylon strings were not coming in contact with onion leaves for a clean detopping. The above results were in close agreement with the findings of (13-16). A similar trend was depicted in the incremental increase of forward speed when eight strings were used for detopping operation in the laboratory investigation (Fig. 7).

The effect of peripheral speed (N) on onion neck length for the square string type with two, four and eight strings can be observed in Fig. 5-7, respectively.

It is observed from Fig. 5 that the onion neck length decreased with the detopping unit's peripheral speed. It was observed from Fig. 5 that there was a 23.1 and 26.3 % decrease, 17. 9 and 30.4 % when the peripheral speed was increased from 5.31 to 6.64 m/s and 6.64 to 7.97 m/s, at 1 (S_1) km/h and 1.5 (S_2) km/h respectively. The decrease in onion neck length with an increase in peripheral speed could be due to more shear cuts on the onion leaves at higher peripheral speeds, resulting in the required uniform neck length of the onion. Researchers reported similar results (7, 10, 13, 15, 17-19).

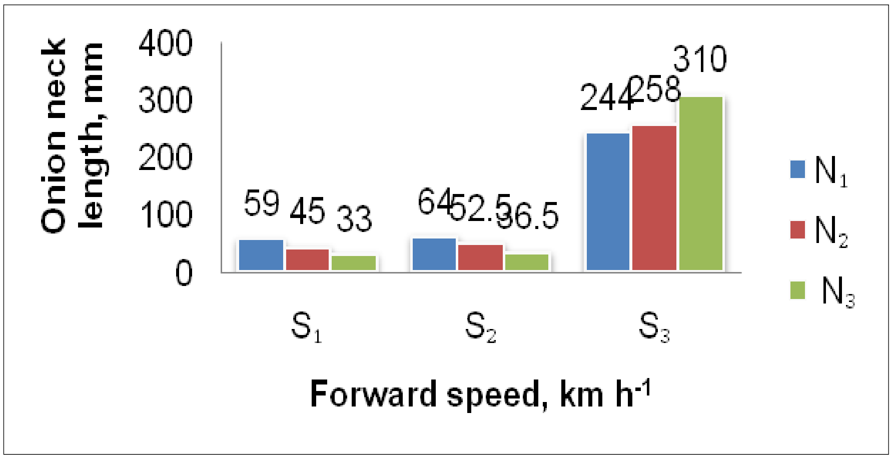

Fig. 5. Effect of forward speed (km/h) and peripheral speed (m/s) on onion neck length with square-type string and two cutting strings.

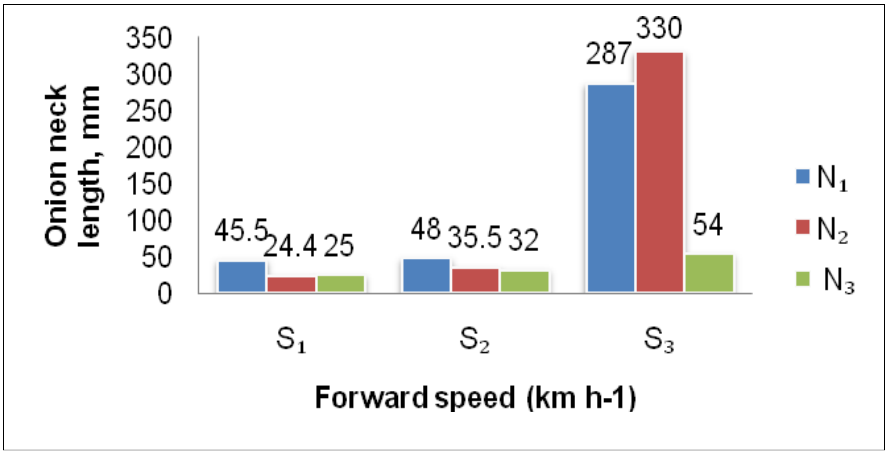

Fig. 6. Effect of forward speed (km h^{-1})and peripheral speed (m s^{-1}) on onion neck length with square-type string and four cutting strings.

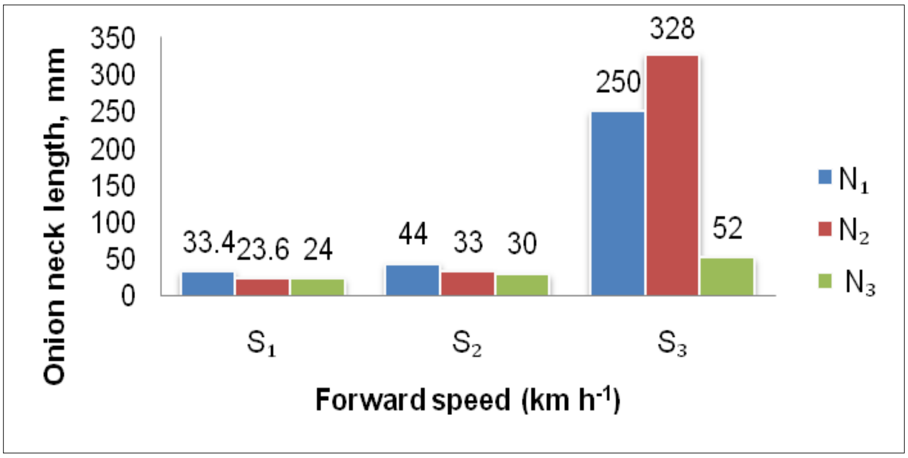

Fig. 7. Effect of forward speed (km h^{-1}) and peripheral speed (m s^{-1}) on onion neck length with square type string and eight cutting strings.

From Fig. 6, it was observed that a decrease of 44.3 % in onion neck length with an increase in peripheral speed from 5.31 (N_1) to 6.64 (N_2), m s^{-1} at 1 (S_1) km/h. A negligible effect was depicted in the change of onion neck length when the peripheral speed was increased from 6.64 (N_2) to 7.97 (N_3) m/s, indicating that the peripheral speed required to detop the onions was sufficient. The above results were in close agreement with the earlier studies (4, 7). It is revealed from Fig. 7 that a similar trend was observed for eight strings. The optimum onion neck length observed after detopping was 23.6 mm at 1 km/h (S_1) and 6.64 m/s (N_2) when eight strings were used by operating with the square type of thread.

Round type of nylon string (T_2)

The effect of forward speed (S) of detopping unit on onion neck length at 1 (S_1), 1.5 (S_2) and 3.4 (S_3) km/h forward speed for round type string with two strings (H_1), four strings (H_2) and eight strings (H_3) is presented in Fig. 8-10, respectively.

It is inferred from Fig. 8 that the increase in forward speed increased onion neck length. An increase of 4.4, 15.2 and 6.6 % were recorded with an increase in forward speed from 1 (S_1) to 1.5 (S_2) km/h at 5.31 (N_1), 6.64 (N_2) and 7.97 (N_3) m/s. Further increase in forward speed from 1.5 (S_2) to 3.4 (S_3) km h^{-1} resulted in a sudden increase of the onion neck length by 75.09, 80.9 and 85.48 % at three peripheral speeds 5.31 (N_1), 6.64 (N_2) and 7.97 (N_3) m s^{-1} respectively. A similar trend was obtained for four strings at an incremental increase of 8.3, 31.17 and 21.3 % with increase in forward speed from 1 (S_1) to 1.5 (S_2) km h^{-1} at 5.31 (N_1), 6.64 (N_2) and 7.97 (N_3) m/s respectively (Fig. 9). Further increase in forward speed from 1.5 (S_2) to 3.4 (S_3) km/h resulted in a sharp rise by 81.9, 83.3 and 84.6 % respectively. The above results were closely related with previous studies (13). A similar trend was observed in the incremental increase of forward speed, when eight strings were used for detopping operation in the laboratory investigation (Fig. 10).

The effect of peripheral speed (N) on onion neck length for round type of string with two, four and eight strings can be observed in Fig. 8-10, respectively.

It is observed from Fig. 8 that the onion neck length was decreased with increased peripheral speed. It was observed from Fig. 7 that there was a decrease of 31.5 and 22.7 percent, 5.6 and 14.2 % when the peripheral speed was increased from 5.31 (N_1) to 6.64 (N_2) m/s and 6.64 (N_2) to 7.97 (N_3) m/s at 1 (S_1) km/h and 1.5 (S_2) km/h respectively. Various researchers reported similar results (7, 13, 15, 17-19).

It is inferred from Fig. 9 that the decrease in onion neck length of 31.8 and 8.9 % when the peripheral speed was increased from 5.31 (N_1) to 6.64 (N_2) m s^{-1} at 1 (S_1) km/h. But a negligible change was observed in the onion neck length when the peripheral speed increased from 6.64 (N_2) to 7.97 (N_3) m/s indicating that it was the optimum peripheral speed for detopping the onion leaves. This result was in close agreement with previous findings (3, 7). At 1.5 (S_2) km h^{-1} forward speed, the decrease in onion neck length was observed at 10.1 % when the peripheral speed was increased from 6.64 (N_2) to 7.97 (N_3) m s^{-1}. A similar trend was observed in Fig. 9-10 with a decrease in onion neck length when peripheral speed was increased from 5.31 (N_1) to 6.64 (N_2) m/s and a negligible change in the further increase of peripheral speed.

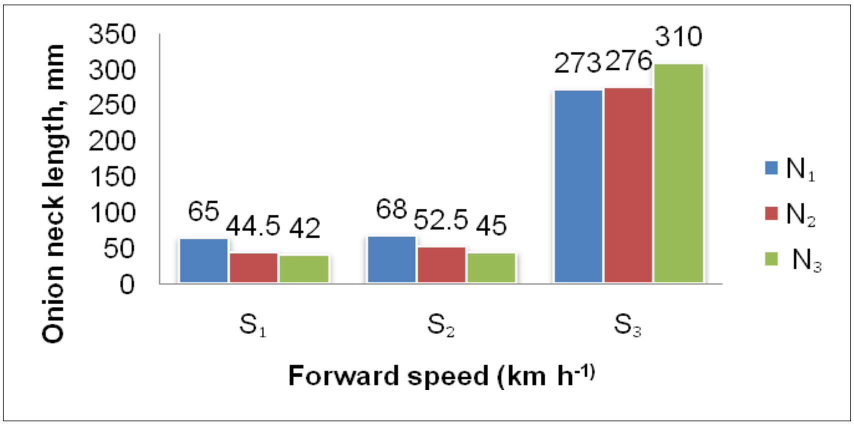

Fig. 8. Effect of forward speed (km h^{-1})and peripheral speed (m s^{-1}) on onion neck length with round type string and two cutting strings.

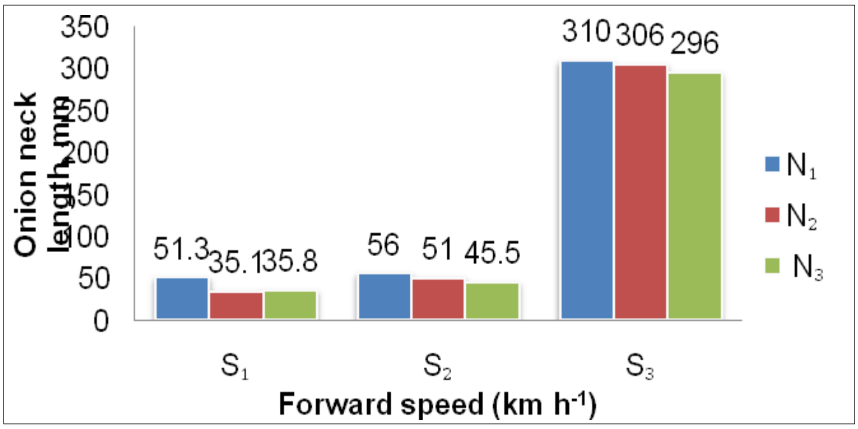

Fig. 9. Effect of forward speed (km h^{-1})and peripheral speed (m s^{-1}) on onion neck length with round type string and four cutting strings.

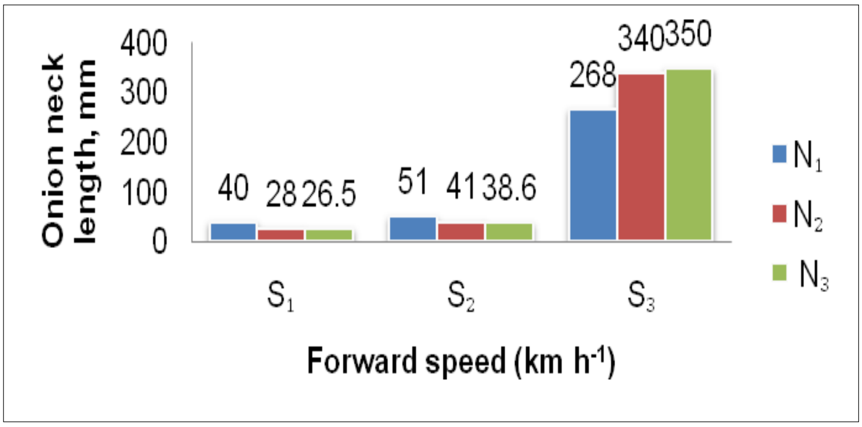

Fig. 10. Effect of forward speed (km h^{-1}) and peripheral speed (m s^{-1}) on onion neck length with round type string and eight cutting strings.

The optimum onion neck length observed after detopping was 26.5 mm at 1 km/h (S_1) and 7.97 m/s (N_3) when eight strings were used by operating with square type of thread.

Flat type with one side serrated (T_3)

The effect of forward speed (S) of detopping unit on onion neck length at 1 (S_1), 1.5 (S_2) and 3.4 (S_3) km/h forward speed for flat type string with two strings (H_1), four strings (H_2) and eight strings (H_3) is presented in Fig. 11-13 respectively.

From the Fig. 11-13, it is inferred that the values of the onion neck length were similar to the average plant height of the CO (On) 5 variety at three levels of forward speeds and three levels of peripheral speeds. The graphs depicted that no detopping happened for the flat type thread, indicating that the flat type was not suitable for the detopping operation because of its cross- section.

Effect of shape of string on onion neck length

The influence of shape of string (T) on the onion neck length after detopping was studied using the experimental test rig. The mean values of the onion neck length after detopping with selected levels of shape of string (T) were recorded.

The effect of shape of string (T) on the onion neck length after detopping at 1 (S_1), 1.5 (S_2) and 3.4 (S_3) km/h forward speeds with two strings for three levels of peripheral speeds was depicted in Fig. 14-16 respectively.

At 1 (S_1) km/h forward speed

It is inferred from the Fig. 14, that there was increase in the onion neck length when the shape of string was altered from square (T_1) to round (T_2). A rise of 9 % was depicted at 5.31 (N_1) m/s and there was a negligible effect depicted at 6.64 (N_2) m/s and a rise of 21 % was observed at 7.97 (N_3) m/s.

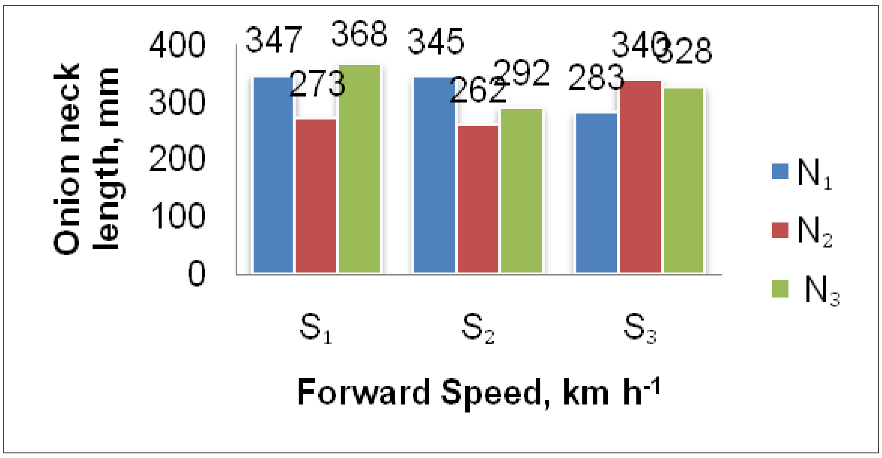

Fig. 11. Effect of forward speed (km h^{-1}) and peripheral speed (m s^{-1}) on onion neck length with flat type string and two cutting strings.

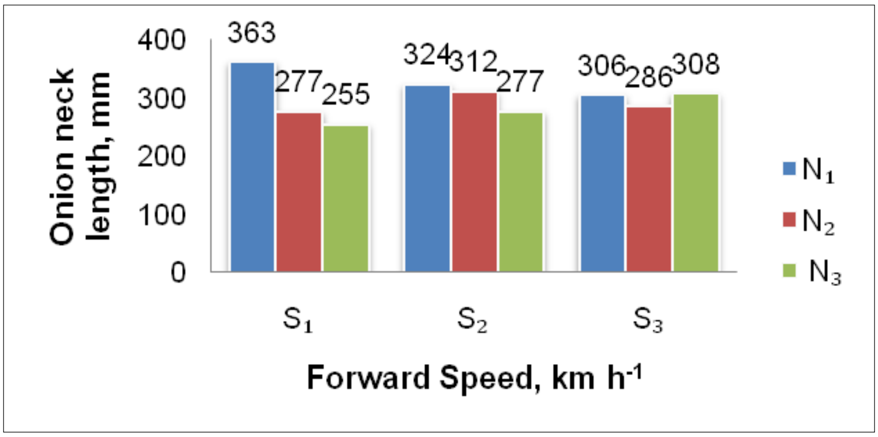

Fig. 12. Effect of forward speed (km h^{-1}) and peripheral speed (m s^{-1}) on onion neck length with flat type string and four cutting strings.

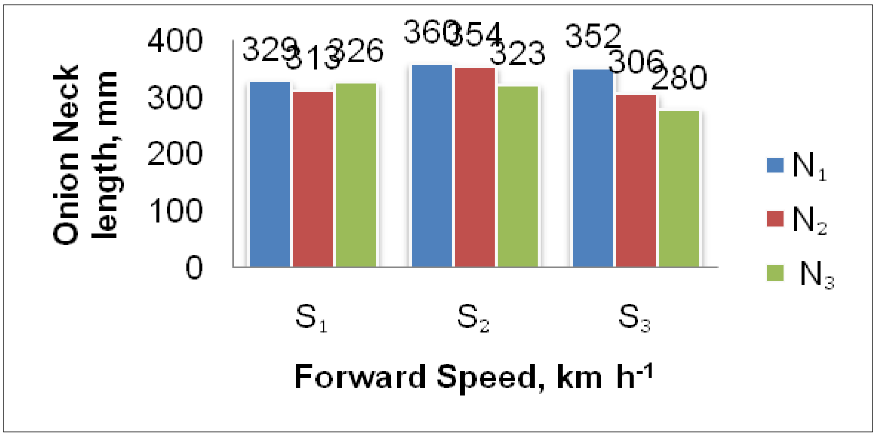

Fig. 13. Effect of forward speed (km h^{-1}) and peripheral speed (m s^{-1}) onion neck length with flat type string and eight cutting strings.

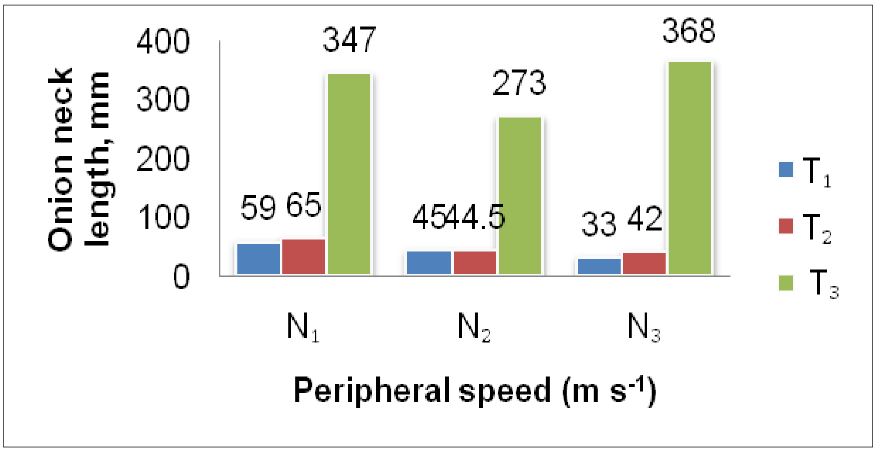

Fig. 14. Effect of shape of string on onion neck length at 1 (S_1) km h^{-1} forward speed with two strings.

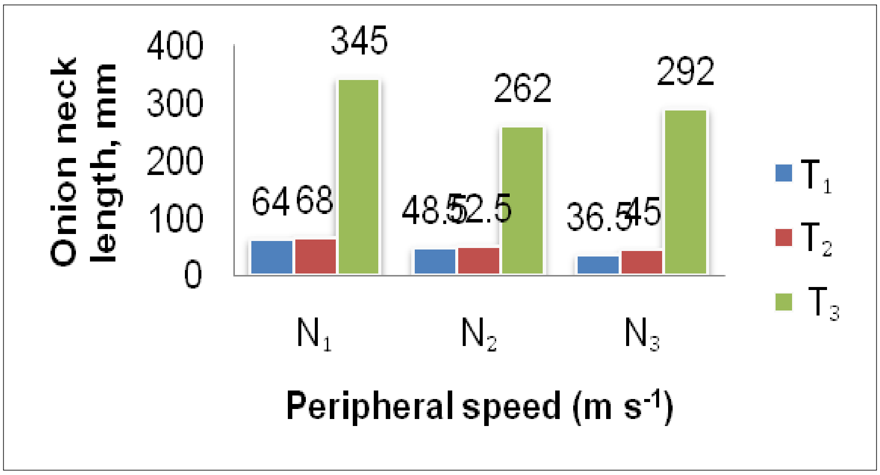

Fig. 15. Effect of shape of string on onion neck length at 1.5 (S_2) km h^{-1} forward speed with two strings.

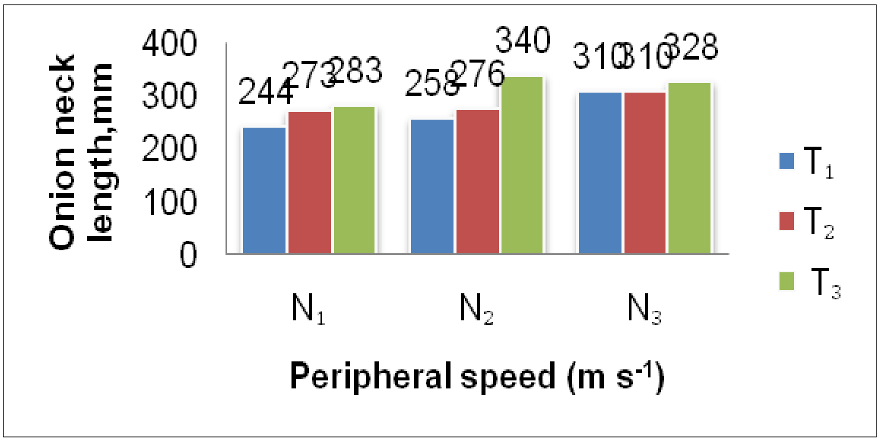

Fig. 16. Effect of shape of string on onion neck length at 3.4 (S_3) km h^{-1} forward speed with two strings.

A sudden increase in the onion neck length was observed when the shape of the string altered from the round (T_2) to flat type with serrated edge on one side (T_3). The onion neck length at flat type string was almost equal to the plant height, indicating that there was no cut happened at the flat string at all three levels of peripheral speeds. The increase in onion neck length when the shape of string altered from square (T_1) to round (T_2) is because of the cross section of the strings. The square type string having sharp edges detops the onion leaves effectively at lower neck length when compared with round string. There was no detopping happened at flat type of string because of its cross section. The results were in close agreement with earlier studies (20). The optimum neck length obtained in this treatment was 33 mm at square string (T_1) and at peripheral velocity 7.97 (N_3) m/s.

Effect of number of strings on onion neck length

The influence of the number of strings (H) on the onion neck length after detopping was studied using the experimental test rig. After detopping with selected levels of the number of strings (H), the mean values of the onion neck length were recorded. The effect of a number of strings (H) on the onion neck length after detopping at 1 (S_1), 1.5 (S_2) and 3.4 (S_3) km/h forward speeds with two, four and eight strings for three levels of peripheral speeds was depicted in Fig. 17-19 respectively.

At 1 (S_1) km/h forward speed

It is inferred from Fig. 17, that a decrease in the onion neck length of 22.8 and 26.5 % was observed when the number of strings altered from two (H_1) to four (H_2) and four (H_2) to eight (H_3) respectively at 5.31 (N_1) m/s peripheral speed. At 6.64 (N_2) m/s and 7.97 (N_3) m/speripheral speeds by changing the

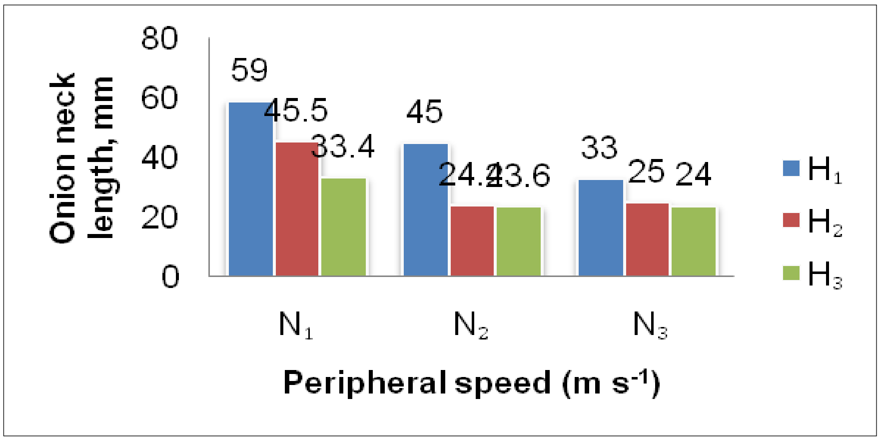

Fig. 17. Effect of number of strings on onion neck length at 1 (S_1) km h^{-1} forward speed at square type string.

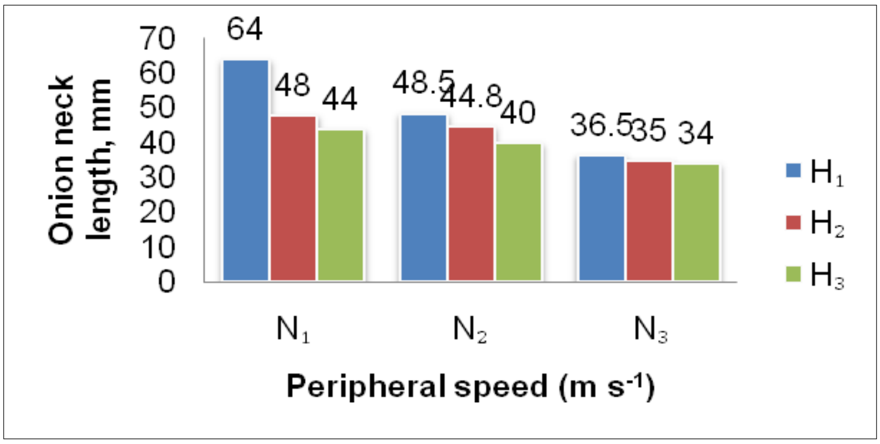

Fig. 18. Effect of number of strings on onion neck length 1.5 (S_2) km h^{-1} forward speed at square-type string.

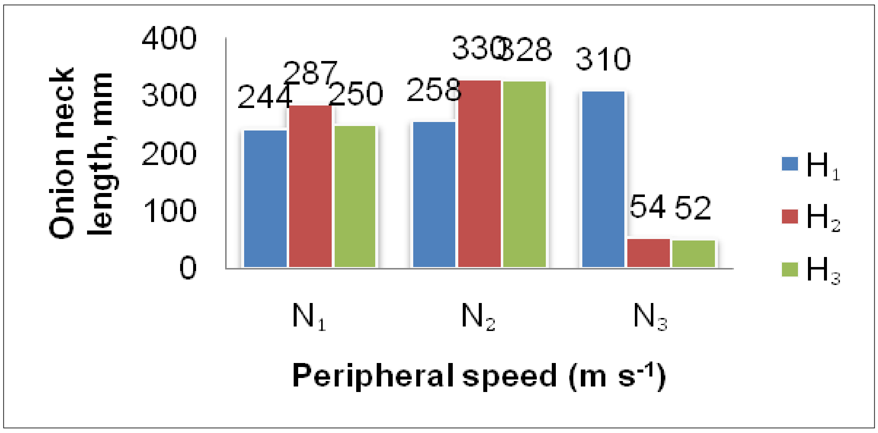

Fig. 19. Effect of number of strings on onion neck length at 3.4 (S_3) km h^{-1} forward speed at square type string.

Fig. 20. Field evaluation of mini-tractor operated onion detopper and digger.

number of strings from two (H_1) to four (H_2) there was a decrease of 45.7 and 4.2 % in the onion neck length and there was a negligible change of onion neck length obtained when the number of strings altered from four (H_2) to eight (H_3) at both the peripheral speeds. The optimum onion neck length observed in these treatments was 23.6 mm at 6.64 (N_2) m/s peripheral speed and square thread with eight strings.

At 1.5 (S_2) km/h forward speed

It is observed from Fig. 18, that a decrease in the onion neck length of 25 and 8 % was observed when the number of strings altered from two (H_1) to four (H_2) and four (H_2) to eight (H_3), respectively at 5.31 (N_1) m s^{-1} peripheral speed. At 6.64 (N_2) m s^{-1} the change in number of strings from two (H_1) to four (H_2) and four (H_2) to eight (H_3) resulted in decrease of 7.6 and 10.7 % in the onion neck length. There was a negligible change of onion neck length obtained by altering the number of strings from four (H_2) to eight (H_3) at 7.97 (N_3) m/s peripheral speed. The optimum onion neck length observed in these treatments was 34 mm at 7.97 (N_3) m/s peripheral speed and square thread with eight strings.

At 3.4 (S_3) km/h forward speed

It is inferred from Fig. 19 & 20, the obtained values of onion neck length were similar to the average onion plant height, indicating that there was no detopping occurred at 6.64 (N_2) m s^{-1} and 7.97 (N_3) m s^{-1} peripheral speeds.

At 7.97 (N_3) m s^{-1} peripheral speed the value of onion neck length decreased by 82 % when the number of strings altered from two (H_1) to four (H_2) and there was a negligible change in the onion neck length by altering the number of strings from four (H_2) to eight (H_3).

Statistical analysis

The statistical analysis of the data collected in the laboratory investigation was performed to assess the significance of the variables as well as mathematical modelling of the variables.

The analysis of variance (ANOVA) for onion neck length is furnished in Table 5. The order of significance was highest for shape of string (T) followed by forward speed (S), peripheral speed (N) and number of strings (H).

The results of ANOVA indicated that there was a significant difference among the treatments. From the Table 5, the shape of string (T), forward speed of the unit (S) and peripheral speed (N) were individual operational parameters significantly affecting the onion neck length (mm) at 1 % probability level. In addition to this, the interaction effects of the pairs shape of thread with peripheral speed and forward speed were significant at 1 % and with number of strings at 5 % probability levels. Similarly, the shape of string is considerable with interactions of number of strings and forward speed, peripheral speed and forward speed were also significant at 1 % probability level. The interaction effects of peripheral speed with number of strings and forward speed were significant at 1 % probability level and the effect with combination of these three factors was also significant at 1 % probability level. Number of strings (H) individually does not have any effect significantly in varying neck length (mm).

The interaction effect of this with shape of string has effect significantly of 5 % probability level whereas, with forward speed was not significant. The combination effect of shape of string number of strings and peripheral speed was not significant. S×N×T×H was significant affecting the

Table 5. ANOVA for onion neck length

Source	df	Sum of squares	Means squares	F	PROB
Forward speed of unit (S)	2	1194417.850	597208.925	425.5705	0.0000**
Peripheral Speed of detopping unit (N)	2	28285.262	14142.631	10.0780	0.0001**
Shape of string (T)	2	2123153.896	1061576.948	756.4786	0.0000**
Number of strings (H)	2	6183.746	3091.873	2.2033	0.1138(ns)
S × N	4	31432.610	7858.152	5.5997	0.0003**
S×H	4	4256.806	1064.201	0.7583	0.5539 (NS)
S×T	4	690071.172	172517.793	122.9360	0.0000**
N×T	4	46145.793	11536.448	8.2209	0.0000**
N×H	4	32625.071	8156.267	5.8121	0.0002**
T×H	4	17336.458	4334.114	3.0885	0.0175*
S×N×T	8	61365.354	7670.669	5.4661	0.0000**
S×N×H	8	34486.793	4310.849	3.0719	0.0030**
S×H×T	8	16313.775	2039.221	1.4531	0.1785(ns)
N×H×T	8	16620.729	2077.591	1.4805	0.1681(ns)
S×N×T×H	16	89457.387	5591.086	3.9842	0.0000**
ERR	160	224530.213	1403.313	1.0000	

(**) significant at 1 % level, (*) significant at 5 % level and (ns) not significant

onion neck length (mm) at 1 % probability level.

This shows that the different operational parameters levels have effect on height of cut either combine or individua. Though a number of strings (H) is non-significant individually for height of cut but it has significant effect in combination with shape of thread (T).

Mathematical modeling and different variables in onion detopping unit

The multiple linear regression equation was determined for the variation of onion neck length with forward speed, peripheral speed and the number of strings of the detopping unit using SPSS software. The equations were furnished in Table 6. Table 6 shows that the R square value of 0.745 was significant at 5 % probability level for square type string. The equation for a square-type string showed that a unit increase in X_1 (forward speed) *cetaris paribus* would increase to 98.24 units of Y. A unit increase in X_2 (peripheral speed) *cetaris paribus* effect in decrease of 26.319 units of Y and a unit increase in X_3 (number of strings) *cetaris paribus* would result in decrease of 15.185 units of Y.

The R square value of 0.638 was significant for round type string at 5 % probability level. The equation for round type string showed that a unit increase in X_1 (forward speed) *cetaris paribus* would result in an increase of 130.933 units of Y. A unit increase in X_2 (peripheral speed) *cetaris paribus* result in an increase of 1.442 units of Y and a unit increase in X_3 (number of strings) *cetaris paribus* would increase 1.394 units of Y. Similarly for flat type string, the R square value of 0.156 was not significant. The equation for flat type string showed that a unit increase in X_1 (forward speed) *cetaris paribus* would result in decrease of 3.128 units of Y. A unit increase in X_2 (peripheral speed) *cetaris paribus* results in a decrease of 14.179 units of Y and a unit increase in X_3 (number of strings) *cetaris paribus* would result in an increase of 5.938 units of Y.

Optimization of variable for detopping unit

The selected levels of variables were optimized for achieving the best performance of detopping unit in terms of optimum onion neck length. The lowest values of onion neck length for different combinations of the selected levels of variables are furnished in Table 7.

The optimum level of onion neck length suggested by the previous researchers for the storage of onions was 20 -25 mm and it was obtained using the above-mentioned treatment combinations. The best treatment combination of the selected variables was observed at 1 km/h forward

Table 6. Multiple regression equations for three shapes of strings

S. No	Shape of string	Equation	R^2
1.	Square	$Y = 98.246 X_1 - 26.319 X_2 - 15.185 X_3 + 46.580$	0.745*
2.	Round	$Y = 130.933 X_1 + 1.442 X_2 + 1.394 X_3 - 2.794$	0.638*
3.	Flat with serrated on one side	$Y = -3.128 X_1 - 14.179 X_2 + 5.938 X_3 + 325.975$	0.156

**significant at 1 % level. *significant at 5 % level.

Where, Y: Onion Neck length (mm); X_1: Forward speed (km/h); X_2:Peripheral speed, (m/s); X_3: Number of strings

Table 7. Optimized value of onion neck length obtained at different combinations

S.No	Treatment combination level of selected variables	Value
1.	$S_1N_3T_1H_3$	23.6
2.	$S_1N_2T_1H_3$	24
3.	$S_1N_2T_1H_2$	24.4

speed with a peripheral speed of 6.64 (N_2) m/s with square type string (T_1) with both four and eight strings (H_2 and H_3).

Further, detopping on various other varities of onion, as well as wear and tear of machine is excluded, which may be future work to optimize the detopper more effectively.

Performance evaluation of prototype onion harvester with detopping unit

The performance evaluation of the prototype onion harvester with a detopping unit was carried out in the farmers field at Nahar village in Tamil Nadu. The parameters determined in the performance evaluation are soil parameters i.e., soil type, soil moisture, bulk density cone index and operational parameters such as theoretical field capacity, effective field capacity, digging efficiency, conveying efficiency, soil separation efficiency, percentage of damaged bulbs, output capacity, fuel consumption and draft of the implement.

The results of the performance evaluation of the tractor-operated onion harvester with a detopping unit are furnished in Table 8.

Cost economics

An onion detopper was developed and evaluated. The best treatment combination of the selected variables was observed at 1 km/h forward speed with a peripheral speed of 6.64 (N_2) m/s with square type string (T_1) with both four and eight strings (H_2 and H_3). The cost economics were tabulated in Table 9. The cost of harvesting and detopping with an onion harvester was Rs. 8337 ha^{-1}. The savings in cost and time were 81.4 and 92.2 %, respectively. The onion harvester's break-even point (BEP) with the detopping unit was found to be 25.12 h per annum and the payback period was determined to be 1 year and 5 days.

Conclusion

A research study has been taken up for the "Development and evaluation of mini tractor operated onion harvester with detopping unit" to perform both detopping and harvesting simultaneously. The developed prototype onion harvester and detopping unit's performance was evaluated for detopping and harvesting onion crops in the farmer's field. The cost of the onion harvester, along with the detopping unit, was Rs. 22300. The adequate field capacity of the onion harvester with a detopping unit was found to be 0.052 ha/h. The cost of harvesting and detopping with an onion harvester was Rs. 8337 ha^{-1}. The savings in cost and time were 81.4 and 92.2 %, respectively. The onion harvester's break-even point (BEP) with the detopping unit was found to be 25.12 h per annum and the payback period was determined to be 1 year and 5 days. Further research may focus on reducing cost of operation and increasing the efficiency with commercial aspects.

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Authors' contributions

PKP was involved in investigation and writing of the manuscript. VAA and RS were involved in analysis and supported in drafting of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Jadhav RV, Turbatmath PA, Gharte LV. Design, development and performance evaluation of onion digger windrower. AMA-Agric Mech Asia, Africa Latin America, 1995;26(3):35–38.
2. Maw BW, Hung YO, Tollner EW, Smittle DA, Mullinese BG. Physical and mechanical properties of fresh and stored sweet onion. Trans ASAE, 1996; 39(2):633–37. https://doi.org/10.13031/2013.27545
3. Rani V, Srivastava AP, Design and development of onion de-topper, AMA-Agric Mech Asia, Africa Latin America, 2012;43(3):69.

Table 8. Performance evaluation of prototype onion harvester with detopping unit

Sl.No.	Evaluation Parameters	Results
1	Theoretical field capacity, ha/h	0.06
2	Effective field capacity, ha/h	0.052
3	Field efficiency (%)	86.1
4	Detopping efficiency (%)	74.58
5	Digging efficiency (%)	94.17
6	Conveying efficiency (%)	88.7
7	Percentage of damaged bulbs	27
8	Output capacity (kg/h)	582.92
9	Fuel consumption (L/h)	2.5
10	Draft (kg/m)	298.68

Table 9. Cost economics

S.No.	Parameter	Value
1	Effective field capacity	0.052 ha/h
2	Costs of operating the unit per hour	433.54 h^{-1}
3	Cost of the onion harvester	Rs. 22300
4	Cost of operation per ha	Rs.8337 /-
5	Break-even point	25.12 h
6	Payback period	1 year and 5 days

4. Bhanage G, Deshmukh VD, Thokale PJ, Wandka SV. Development of Power Operated Onion Detopper, Bioved J. 2016;27(1):73–78.
5. Saraswathi T, Sathiyamurthy VA, Tamilselvi NA, Harish S. Review on Aggregatum Onion (*Allium cepa* L. var. *aggregatum* Don.), Int J Curr Microbiol App Sci. 2017;6(4):1649–67. https://doi.org/10.20546/ijcmas.2017.604.201
6. Pandiselvam R, MM Pragalyaashree, R Kailappan, V Thirupathi, P Krishnakumar. Moisture dependent engineering properties of onion seeds, J Agric Eng, 2014; 51(2):36–43.
7. Chittappa B. Design and development of motorized onion detopper cum grader. [Thesis] Bengaluru: University of Agricultural Sciences; 2016.
8. Kamaraj P. Design, Development and evaluation of self-propelled onion digger [Thesis] Coimbatore: Tamil Nadu Agricultural University; 2002.
9. Bahnasawy AH, El-Haddad ZA, El-Ansary MY, Sorour HM. Physical and mechanical properties of some Egyptian onion cultivars, J Food Eng, 2004;62(3):255–61. https://doi.org/10.1016/S0260-8774(03)00238-3
10. Dauda SM, Ahmad D, Khalina A, Jamarei O. Effect of cutting speed on cutting torque and cutting power of varying kenaf stem diameters at different moisture contents, Trop Agric Sci. 2015;38(4):54961. https://doi.org/10.5555/20153366460
11. Randal DM, Mcnulty PB. Impact cutting behaviour of forage crops-I Mathematical model and laboratory tests. J Agr Eng Res., 1978;23:816–21. https://doi.org/10.1016/0021-8634(78)90104-X
12. Anon. Test code and procedures for harvesting machines, ESCAPE-RNAM, Pasay City, Philippines; 1983.
13. Randal DM, McNulty PB. Cutting behaviour of forage crops. The British Society Res Agric Engg 1978;23(8634):329–38. https://doi.org/10.1016/0021-8634(78)90105-1
14. Dange AR, Thakare SK, Bhaskarrao I. Cutting energy and force as required for pigeon pea stems, J Agric Tech. 2012;7(6):1485–93.
15. Jyothi B. Development and evaluation of cassava stem harvester as influenced by machine and operational parameters, [thesis]. Coimbatore: Tamil Nadu Agricultural University; 2013.
16. Budhale KC, Patil AG, Shirole VS, Patil SS, Desai RS, Salavi SB. Design and development of digging and conveying system for self-propelled onion Harvester, Int Res J Eng Tech. 2019;6(4):3304–07.
17. Chattopadhyay P, Pandey KP. Effect of knife and operational parameters on energy requirement in flail forage harvesting, J Agr Eng Res. 1999;73:3–12. https://doi.org/10.1006/jaer.1998.0395
18. Yiljep YD, Mohammed US. Effect of knife velocity on cutting energy and efficiency during impact cutting of sorghum stalk, Agric Eng Int CIGR J. 2005;1–7.
19. Bello RS, Baruwa A, Orisamuko. Development and performance evaluation of a prototype electrically powered brush cutter, Int Lett Chem Phy Astron 2015; 58:26–32. https://doi.org/10.18052/www.scipress.com/ILCPA.58.26
20. Langton MI. Design of brush cutter and its Integration into a semi-mechanised sugarcane harvesting machine, [thesis], School of Bioresources Engineering and Environmental Hydrology, South Africa: University of KwaZulu-Natal; 2007.

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