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Design and development of hydraulic controlled tractor front mounted twin conveyor onion (*Allium cepa*) digger

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ABSTRACT

In India and many developing countries harvesting of onion (*Allium cepa* L.) crop is done manually which is cumbersome and time-consuming. The tractor-operated front-mounted twin conveyor onion digger was designed and developed during 2019 in Divisional Workshop (Farm Machinery and Power Engineering) at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. It had five blades made of mild steel (320 mm × 150 mm × 12 mm size) bolted to the base plate instead of one single share to strengthen the share. Onion and soil were separated over conveying unit. Power from the rear PTO (Power take-off) of a tractor to the front-mounted digging unit was conveyed through a power transmission unit which consisted of a gear reduction unit, V-belt and pulley arrangement, and 40 mm diameter of the propeller shaft. The lifting, lowering, and depth were controlled with the help of two single-acting hydraulic cylinders. The biometric and physical properties of onion bulbs (Agri found light red) were found average with equatorial and polar diameter, plant height, neck thickness, and weight of onion dry leaves as 36.19 and 37.19 mm, 284.05 mm, 6.80 mm and 30.19 g respectively. The average soil cone index, moisture content, and bulk density (before transplanting and harvesting) of soil were observed to be 1 kg/cm^2, 17.22,12.58%, and 1.50, 1.38 g/cm^3 respectively. The performance evaluation in the field found a maximum percentage of exposed and minimum damaged bulbs as 82.55% and 13.51% respectively, at a forwarding speed of 1.5 kmph and conveyor speed of 2 kmph. The field efficiency of the machine was 87.46%.

Keywords: Conveyor, Hydraulic cylinder, Onion, Power-transmission

Mechanization plays a pivotal role in the development of agriculture. Reform in agriculture is required to achieve food security, reduce labour hours and increase rural income. It aids in boosting labour and land productivity, lowering production costs, and encouraging young people to return to agriculture to advance and promote mechanization (FAO 2019). The level of mechanization in India (40–45%) as compared to world scenario countries such as the U S (95%), Brazil (75%), and China (57%) is still low (Tiwari *et al.* 2019). Farm power availability in India was about 2.761 kW/ha in 2020–2021 (Singh and Singh 2021).

In India, harvesting of onion (*Allium cepa* L.) crop is done by pulling out plants by hand. The harvested crop is left in shade again for curing for about a week. Both operations, i.e. digging and top removal are done manually which is very time-consuming, tedious, and costly. Harvesting of one-acre onion includes digging, top removal and grading and requires 10–14 laboures, which costs ₹4200 as per the ministry of labour and employment in 2017. Besides, it is necessary to complete the harvesting operation within a specified time for reduced harvest losses. Labour scarcity delays the harvesting operation, which may cause damage to bulbs in adverse conditions.

Most of the studies are confined to tractor-drawn rear-operated diggers. With these diggers crop is dug, picking, and foliage removal is performed manually. These tractor-drawn rear-operated onion diggers dug the onion crop sown with the appropriate agronomical practice of plant-to-plant distance and row-to-row distance; otherwise, the losses may be significant. Being a rear-mounted machine, the visibility of crops is poor. Keeping the above facts in view, to develop a front-mounted onion digger for mechanizing onion harvesting. The developed machine will have the advantages of better visibility of crops during field operation. It will have higher flexibility because of the hydraulic system for lifting, lowering, and depth control as per the requirement of the onion bulb, it will reduce onion damage in terms of cut, slicing and bruising. Therefore, the present study was undertaken to design and develop a tractor front-mounted hydraulically controlled twin

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conveyor onion digger and to evaluate the performance of the machine in field conditions.

MATERIALS AND METHODS

The basic soil, crop and machine parameters were considered for the design of a hydraulic-controlled tractor front-mounted twin conveyor onion digger. The soil parameters played an important role in designing the machine. Type of soil, mechanical composition of soil, soil moisture content (before transplanting and harvesting), bulk density of soil (before transplanting and harvesting), and soil cone index were considered to determine the volume of material passed to conveyor kilogram per second and it affected the maximum exposed onion bulbs and minimum damaged bulbs of onion digger (Lalit 2011). Crop parameters namely, name of variety, row-to-row and plant-to-plant spacing, plant density and height, the thickness, neck, depth of the bulb, moisture content of onion bulb and onion distribution in a vertical plane (Khura *et al.* 2010, Mehta and Yadav 2015) were used for optimum setting of digging blade as well as maximum exposed bulbs of onion. The average equatorial diameter and a polar diameter of the onion were most important parameters used for deciding the sieve opening of soil separation unit. The weight of the onion bulb with leaves and soil onion bulb ratio was used for the volume of the material passed to the conveyor unit and for deciding the handling capacity of the soil separation unit. The machine parameters such as the forward speed of the tractor, conveyor speed of the machine and forward speed to conveyor speed ratio played an important role in designing of onion digger (Khura *et al.* 2010, Mehta and Yadav 2015, Nisha and Sridhar 2018).

The design and developed machine was fabricated at the Department of Farm Machinery and Power Engineering (College of Technology) at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand in 2019. It consisted of a mainly rectangular frame, digging unit, soil-separation unit, power transmission unit, tractor front mounting assembly, lifting or lowering and depth control unit.

The design of rectangular frame length and width was selected based on the spacing between the front and rear axle of tractors. The frame of 1600 mm × 450 mm size was fabricated by using angle iron 50 mm × 50 mm × 6 mm and two angle irons jointed with the help of welding. This frame was provided with a hitch assembly to mount the onion digger in front of the tractor. Mild steel (MS) sheet of 450 mm × 152 mm × 3 mm size was fixed by nuts and bolts mounted on both sides of the frame to cover the machine so that the onion does not fall side of the frame. This frame had a provision for mounting digging unit, conveying unit, gear reduction unit and depth control wheels. The digging unit consisted of a share or blade to lift or dug up the onion plants along with soil, partially or completely breaking up the soil layer and passing the volume of soil and plants to the subsequent working components**.** The share width was decided on the basis of spacing between the front and rear axle of the tractor and thickness on the basis of load. The average soil resistance of the shovel act at a distance of 0.2 measured from the cutting edge. The center of resistance would act at a distance of 14 mm from the cutting edge on the central axis of the width of the share (Lalit 2011). The digging share made of high carbon steel (Singh 2014) was 1600 mm × 150 mm × 12 mm in size and was mounted on a 1515 mm × 65 mm × 17 mm size base plate using nuts and bolts. The five shares of 320 mm × 150 mm ×12 mm size were bolted to the base plate instead of one single share to strengthen the share and ease of replacement of worn-out share. The shares were fixed to the base plate at a distance of 100 mm from its cutting-edge using nuts and bolts. The rake angle of the share could be changed by the lock bolt arrangement provided on the frame which could be adjusted between 15–30° with horizontal. On both ends of the share, a 3 mm thick MS sheet was welded. The dugout material by the share does not fall outside and moves up on the separating unit and tip angle of share was kept at 16°. The twin conveyor was designed based on parameters such as volume of the material dug out by blade, average weight of onion bulb, equatorial and polar diameter of the onion bulb. The main function of twin conveyors is to separate the soil and onion. Soil and onion dug out by the share move up and separation takes place on the conveyor. It consists of a 5-ply rubber belt, rollers, shafts, MS flats, bush bearings, and nuts and bolts. The conveyor roller diameter was selected such that the belt does not touch the ground surface and ply of the belt based on the volume of material dugout from the blade is passed on the conveyor during digging. The four rollers made of galvanized iron pipe (90 mm outside diameter and length 500 mm) were mounted on the frame using a 25 mm diameter MS shaft on a bush bearing. The spacing between two MS flats was fixed on the belt by using nuts and bolts as 30 mm based on the polar and equatorial diameter of the onion. The MS flats of 20 mm × 3 mm size and length 500 mm were bolted perpendicular to the belt mounted on over rollers, which formed two conveying units. The twin conveyors rotated in a rearward direction drive from the gear unit and finally, the material was collected at the center of the tractor.

The main function of the power transmission unit was to transmit power from the rear PTO to conveying unit of the digger. It consists of a propeller shaft, gears, belt, pulley, and the design of different components of the power transmission unit. The belt and pulley system are used to transmit power from the PTO of a tractor to the propeller shaft. V-belt is used to transmit a great amount of power from one pulley to another because the distance between two pulleys is very near to each other (Khurmi and Gupta 2005).

The length of the belt is 942 mm for 127 mm driving pulley and 90 mm for the driven pulley and the velocity of belt was 12.92 kmph. Based on the design requirement of power transmitted to the machine, B35-size belt was considered. The main function of the propeller shaft is to transmit power from the PTO of a tractor to the gearbox of the root crop digger. As per the design requirement, propeller shaft of 40 mm diameter is considered and mounted at the lower side of the tractor chassis by three bush bearings. The reduction gears are fitted as per the design requirements at different positions. All the gears are made of cast iron. Two gears were fitted, one pinion gear and the other crown gear. Pinion gear had 12 teeth fitted to the propeller shaft with the help of two ball bearings and crown gear had 24 teeth fitted to the conveyor shaft with the help of bush bearings. According to the conveyor unit, design requirements power was transmitted in 1:2 ratio. The tractor front mounting assembly is designed according to the root crop digger and front axle of the tractor. It consists of two frames front mounting frame and another top mounting frame. The top mounting frame is made of mild steel 800 mm × 40 mm × 10 mm. The tractor front mounting frame is made of mild steel 460 mm × 75 mm × 5 mm. Two single-acting hydraulic cylinders were mounted in this frame to convert fluid power to linear mechanical force and motion for lifting, lowering, and depth control of a machine. The proper selection of hydraulic cylinders requires numerous factors influenced by the expected application. The design factors include a selection of hydraulic cylinder, the required amount of force 26340 N, weight of the machine 190 kg, weight of soil and onion 336 kg, stroke length 100 mm, operating pressure 2.47×10^8 Pa, direction force and means of stopping the workload during the motion. According to these design requirements, hydraulic cylinder of diameter 50 mm and piston rod diameter 32 mm was selected as per the standard (BIS Test code, IS 11146:1999). Two depth wheels are supported at the rear end of the frame which controls the depth of the machine as well as conveyor does not touch the ground during operation.

Working description: The developed machine was fixed in front of the tractor with the help of tractor front mounting frame and hydraulic cylinders. The power was transmitted from PTO of tractor to onion digger machine with the help of pulleys, V-belt, propeller shaft, and universal joint. This power was transmitted to gear box of onion digger and its supply to the conveyor unit with the help of bevel gear and shaft of roller. The shaft of rear mounted two rollers are rotated in reverse direction (rear side), in the same way front mounted two rollers also rotate in same direction. Two single acting hydraulic cylinders are mounted on the tractor front frame and hydraulic fluid is supplied to cylinders with the help of hose pipe in reservoir of tractor hydraulic control system. During operation, lifting, lowering and precise depth of machine was controlled by lever with the help of two hydraulic cylinders.

Before digging of onion, the machine should be adjusted for forward speed of tractor and conveyor speed as per requirement of operation. Otherwise, it will increase onion bulb damage as well as decrease the harvesting efficiency of machine and other factors like fuel consumption, and damaged onions like cut and bruised onions will be more. The machine was operated in the onion field and soil dug out by the digging blade moves up to the conveyor unit. These onion plants and soil got separated with the help of MS flats over the conveyor because the spacing between two flats was kept as 30 mm based on polar and equatorial diameter of onion. The soil would fall down and remaining onion plants passed to center of tractor in a line. The onion plants and onions would be collected manually.

RESULTS AND DISCUSSION

The performance evaluation of developed machine was carried under field conditions (Fig 1a,b). Onion (Agri found light red) seeds were sown in the nursery on raised bed 15th November 2018 at vegetable research center, Pantnagar. Before testing the machine, observations regarding onion crop parameters were such that the average plant height, neck thickness of onion crop and weight of dry bulbs with leaves was found to be 284.05 mm, 6.80 mm and 30.19 g respectively. The average depth of onion bulb was 30.5 mm and percentage of vertical distribution onion bulbs per m^2 was found that 50% of onion bulbs had depth of soil in the range of 0–30 mm, 40% had depth of soil in the range 0–50 mm where as 10% had ranged from 0–70 mm. The equatorial diameter of onion bulbs ranged from 26.29–49.45 mm. It was observed that 10% of onion bulbs have an equatorial diameter in the range from 20–30 mm, 70% of onion bulbs in the range from 30–40 mm, and 20% of equatorial diameter onion bulbs in the range from 40–50 mm. The polar diameter of onion bulbs ranged from 28.36–46.86 mm. The polar diameter of onion bulbs ranged from 20–30, 30–40 and 40–50 mm and percentage of vertical distribution onion bulbs per m^2 was found to be 6.67, 66.67 and 26.67%, respectively. For the shape of onion bulbs, it was observed that 36.66% of bulbs were found to

Fig 1a Field evaluation of developed machine.

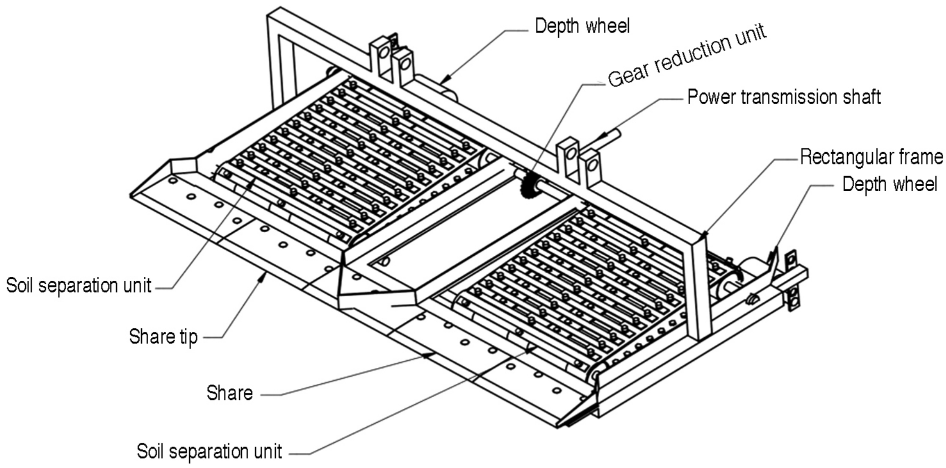

Fig 1b Schematic view of tractor front mounted twin conveyor onion digger.

be oblate and 63.34% of onion bulbs were prolate in shape. The average moisture content of soil before transplanting and harvesting in terms of dry basis was found as 17.22 and 12.58%, respectively. The average bulk density of soil found before transplanting and harvesting was 1.50 and 1.38 g/cm^3, respectively.

The performance of developed machine was affected by forward speed of tractor and conveyor speed of machine was studied at experimental field of onion crop at vegetable research center, Pantnagar, Uttarakhand in 2019. The forward speeds of tractor, i.e. 1, 1.5 and 2 kmph and conveyor speeds of machine, i.e. 1.5, 2, 2.5 kmph was evaluated each dependent variable. The percentage of exposed onion bulbs was obtained during field evaluation at various levels of forward and conveyor speeds. At forward speeds of 1, 1.5 and 2 kmph, the average percentage of exposed onion bulbs was 79.03, 77.41 and 76.35%, respectively (Fig 2a). The maximum average onion exposed of 79.03% was observed at forward speed of 1 kmph, which decreased by 1.62 and 2.68% at forward speeds of 1.5 and 2 kmph, respectively. As forward speed of tractor increased up to 2 kmph the average percentage exposed onion bulbs was decreased to 76.35%. This may be reason due to greater volume of soil and onion bulbs was passed over the soil separation unit, which caused less time to separate onion from the soil and drop down to the conveyor. When conveyor speed of onion digger was 1.5, 2 and 2.5 kmph, the average percentage of exposed onion bulbs was observed 76.62, 80.16 and 76.01% (Fig 2a) and effect of conveyor speed on percentage of exposed onion bulbs was significant ($P<0.01$). At the lowest average percentage exposed onion bulbs was observed 76.01% at highest conveyor speed 2.5 kmph of onion digger. But in case of conveyor speed 2 kmph, the average percentage exposed onion bulbs was observed maximum 80.16%.This may be reason due to the ratio of conveyor speed of onion digger and forward speed of tractor at particular combination the percentage exposed onion bulbs was maximum (Khura and Mani 2011).

The percentage of damaged onion bulbs obtained during field evaluation at forward speeds of 1, 1.5 and 2 kmph the average percentage of damaged onion bulbs was 16.19, 16.52 and 16.41%, respectively (Fig 2b). The average minimum percentage damaged onion of 16.19% was observed at forward speed of 1 kmph which increased by 0.33 and 0.22% at forward speeds of 1.5 and 2 kmph, respectively. At the lowest forward speed of tractor 1 kmph, observed minimum average percentage of damaged onion bulbs was found as 16.19%. As forward speed of tractor increased up to 2 kmph, the average percentage exposed onion bulbs was increased to 16.41%. This may be due to higher forward speeds of tractor larger volume of material passed to over the conveyor per unit time, which causes spillage of onions to the sides of digging share. These spilled onions may chance to fall down to front and rear axle of tractor. Moreover, at

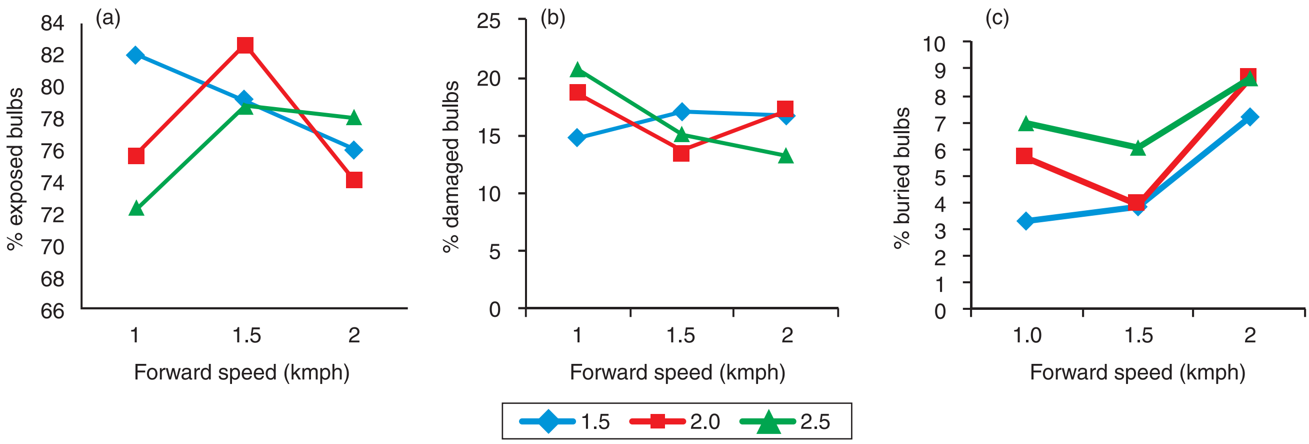

Fig 2 Effect of forward speed of tractor and conveyor speeds (machine) on percentage of a) exposed onion bulbs b) damaged bulbs and c) buried onion bulbs. Significant at $P<0.01$.

higher forward speeds, the depth of operation of share has fair chance to be sliced of onions. The conveyor speed of onion digger 1.5, 2 and 2.5 kmph, the average percentage of damaged onion bulbs was observed 18.06, 15.24 and 15.82%. At the lowest average percentage damaged onion bulbs was observed 15.24% at conveyor speed 2 kmph of onion digger. But in case of conveyor speed 1.5 kmph, the average percentage damaged onion bulbs were observed maximum 18.06%. This may be reason due to the ratio between conveyor speed of onion digger and forward speed of tractor. The percentage of buried onion bulbs obtained during field evaluation at forward speeds of 1,1.5 and 2 kmph the percentage of buried onion bulbs was 4.78, 6.08 and 7.24%, respectively (Fig 2c). The maximum buried onions of 7.24% were observed at forward speed of 2 kmph which decreased by 2.46 and 1.16% at forward speeds of 1 and 1.5 kmph, respectively. At the lowest forward speed of the tractor 1 kmph, observed minimum average percentage of buried onion bulbs was found as 4.78%. As the forward speed of the tractor increased up to 2 kmph the average percentage of damaged onion bulbs was increased to 7.24%. This may be the reason due to higher forward speeds of tractor larger volume of material passed to over the conveyor per unit time, which causes poor separation of onion bulbs from the soil through soil separation unit and it will drop down along with soil. The average values percentages of buried bulbs were 5.32, 4.60 and 8.17% for conveyor speeds of 1.5, 2 and 2.5 kmph, respectively. The maximum onion buried of 8.17% was observed at conveyor speed of 2.5 kmph which increased by 2.85 and 3.57% at conveyor speeds of 1.5 and 2 kmph, respectively and the effect of conveyor speed on percentage of buried onion bulbs was significant ($P<0.01$).

The design and developed machine have the following advantages over other available machines. The machine should dig root crop from the field of 1.5 m width because, the digger was front mounted and spacing between overall widths of maximum tractor is 2.4 m. It can be operated by a tractor in the 40–60 hp range as this was the common size of tractor available on Indian farms. Since the machine is front-mounted, there is provision for lifting, lowering, and depth control as per requirement. The average forward speed of operation of the digger was 1.41 kmph. and the theoretical field capacity of the machine was worked out as 0.24 ha/h. The overall actual field capacity of the machine was found as 0.21 ha/h and overall field efficiency was found as high 87.46% compared to rear mounted tractor operated onion harvester (Mehta and Yadav 2015). It is simple in design and efficient for digging the onions, potatoes and it's suitable for other root crops like garlic, turmeric, carrot with some minor modifications in design of machine.

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