Design and preliminary evaluation of an onion harvester hand tractor implement

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Abstract: Onions are manually harvested in the Philippines due to the unavailability of mechanical harvesters adaptable to local field conditions. Further, imported onion harvesters are not only expensive, but it is beyond the reach of local farmers. Hence, this study design and preliminary evaluation of onion harvester hand tractor implement conceptualized to adapt the local field conditions and increase profitability in onion production. The design combines digging, cleaning, and collecting onion bulbs simultaneously in one operation. The main assemblies of the implement include the frame, digger blade, soil-onion separation device, power transmission, and discharge cart. The implement has a total weight of 68 kg; an overall dimension of 1 230 mm × 570 mm × 500 mm ($l \times w \times h$); and a power requirement of 2.08 hp. The machine was fabricated by a local manufacturer using available standard materials. The treatments were the rotary speed of soil-onion separation device; 100 rpm, 208 rpm and 333 rpm. The data were analyzed using Completely Randomized Design (CRD) and Tukey's Honest Significant Difference (THSD) to further test the level of significance. Results revealed that the actual field capacity, harvesting capacity, and harvesting efficiency were 0.027 ha h^{-1}, 299.05 kg hr^{-1}, and 70.93%, respectively. Hence, this study paved a way for mechanizing onion harvesting at a lower cost and further use of the machine to other root crops can be explored.

Keywords: agricultural machinery, hand tractor implement, onion harvester, soil-onion separation device, digger blade

Citation: Abad, R. L., Z. J. Tam-awen, J. A. Pagaduan, H. C. Buccat, D. P. Dal-uyen, R. N. Laquidan, and D. J. Valmores. 2023. Design and preliminary evaluation of an onion harvester hand tractor implement. Agricultural Engineering International: CIGR Journal, 25(1): 88-98.

1 Introduction

Onions are one of the most ancient food sources on the planet; and are one of the most important vegetable crops cultivated worldwide since the beginning of civilization (Mehta, 2017). It is an indispensable crop found in almost every kitchen in the world. Aside from its use as a spice, it possesses the greatest concentration of health-promoting phytochemicals used for health disease treatment. The National Cancer Institute has reported that onions contain antioxidants that help block cancer and appear to lower cholesterol which can be helpful in the prevention of cardiovascular diseases, diminishing blood clot risk, and improving lung function in asthmatics (Etana et al., 2019).

This inevitable importance of onion boosts the increasing demand every year. In 1996, the worldwide total onion production was 40,695,848 MT, which increased by 128.94% of 93,168,548 MT in 2016. Out of 170 onion-producing countries, the top three countries are China with 18,190,997 MT, India with 11,057,657 MT, and the United States of America with 3,255,948 MT (Hanci, 2018).

In the Philippines, the production is 222,100 MT with a production value of Php 6.7 Billion planted at

Received date: 2021-12-15 **Accepted date:** 2022-04-29

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18,000 ha. The top five (5) producing regions are Region 3 with 138, 875.26 MT, Region 1 with 38, 827.62 MT, Region IV-B with 35, 055.30 MT, Region II with 8,880.36MT, and Region VI with 419.00 MT (Department of Agriculture [DA], 2020). The most common onion varieties planted are red creole, yellow granex, and shallot or multipliers.

The farm gate price of onion has an increasing trend of 2% to 7% from 2015 to 2019 (DA, 2020). This price increase should lift onion production; however, the local production supply cannot meet the demand as the importation of onion is consistent every year. It could be the high production investment cost of Php 141,745.00 ha^{-1}. Out of this cost, Php 49,750 ha^{-1} was spent for manual planting, crop management, and harvesting operations. Out of these operations, harvesting is one of the highest costs requiring 20 to 25 mandays ha^{-1} with a total cost of Php 6,000 to Php 7,500 ha^{-1} (Php 300/mandays) (DA, 2020). The introduction of mechanical onion harvesters lowers the cost of operations. However, the unavailability of commercialized onion harvester adaptable to local field conditions hinders mechanization (Gavino et al., 2018).

In the province of Nueva Ecija, one of the top producers of onion, the mechanization level of onion production is 1.02 hp ha^{-1} with a labor productivity of 71.5% (Gavino et al., 2020). Only land preparation, spraying, and irrigation utilize mechanical power; transplanting, crop establishment, and harvesting are human power. According to Benke et al. (2017), a mechanical harvester with a capacity of 0.107 ha hr^{-1} and a field efficiency of 77.06% saves manual labor of 21.5 mandays ha^{-1}. The self-propelled onion digger, designed to dig and pile onion bulbs into the field plots by Khura et al. (2011) with a capacity of 0.32 ha hr^{-1}, and digging efficiency, separation index, bulb damage, fuel consumption, a draft requirement of 97.7%, 79.1%, 3.5%, 12.81 li ha^{-1}, and 10.87 kN, respectively, reduces the manual digging cost by 44%. The adoption of mechanical onion harvesters commercially available abroad could be one intervention to solve the high cost of manual labor; however, the high cost of investment and complexity of the design may not be adaptable in the Philippines' small fragmented farms. On average, the size of onion farms in the country is 0.71 ha. Farm areas ranged from 0.26 ha in Ilocos Norte to 1.48 ha in Mindoro Occidental (Philippine Statistics Authority [PSA], 2014). Thus, adopting big-size machines for small parcels of land contradicts the economies of scale, contributing to lower profitability and non-utilization of machinery (Paras et al., 2011).

Since 2013, 51.23% of farmers use hand tractors, 43.29% use four-wheel tractors, and 10.96% use draft animals (PSA, 2014). It is time to mechanize onion harvesting operation and economically optimize hand tractors, not only for land preparation and transportation. Mechanizing onion harvesting operation increases the output timeliness and reduces risks caused by unpredictable weather and the non-availability of labor (Benke et al., 2017). Thus, to reduce both the labor and cost of manual operation, the study aimed to design and evaluate the preliminary performance of an onion harvester hand tractor implement. Specifically, design an onion harvester hand tractor implement adaptable to local field conditions; fabricate using locally available materials; and evaluate the performance in terms of actual field capacity (AFC), harvesting capacity, and harvesting efficiency.

2 Materials and methods

2.1 Design consideration

Based on the Reference Model for the Agricultural Machinery Development Process (RM-AMDP) (Romano et al., 2005), the designing phase must consider the informational design comprising the design considerations of the onion harvester prototype as follows:

a) The onion harvester should be fabricated using locally available materials. The strength and rigidity of materials based on standards;

b) The working width of the machine is 500 mm, based on the actual farm plot sizes of farmers;

c) The maximum harvesting depth of the machine is 100 mm; the depth of onion tubers upon maturity or when it is ready for harvest;

d) The soil-onion separation device should have an amplitude of vibration of 25 mm; this is to break soil clods and deposit foreign materials into the ground;

e) The digging blade and the soil-onion separation device be inclined at 18 °, the rolling angle of repose of onions; and

f) The onion harvester implement is driven by a locally developed hand tractor with a power requirement of a 7 to 12 hp diesel engine. There should be no alteration in the design of the hand tractor; all parts are assembled using bolts for easy disassembly.

2.2 Design of machine components

The onion harvester implement was driven by a hand tractor shown in Figure 1. As the machine moves forward, the digger blade is pulled through the soil underneath one row of onions, lifting the mass of soil and bulbs onto the soil-onion separation device. The soil-onion separation device serves as cleaning mechanism allowing the separation of onions from the soil mass and as a conveyor delivering the separated onions into the discharge cart. Once the discharge cart is full, it is replaced with another cart.

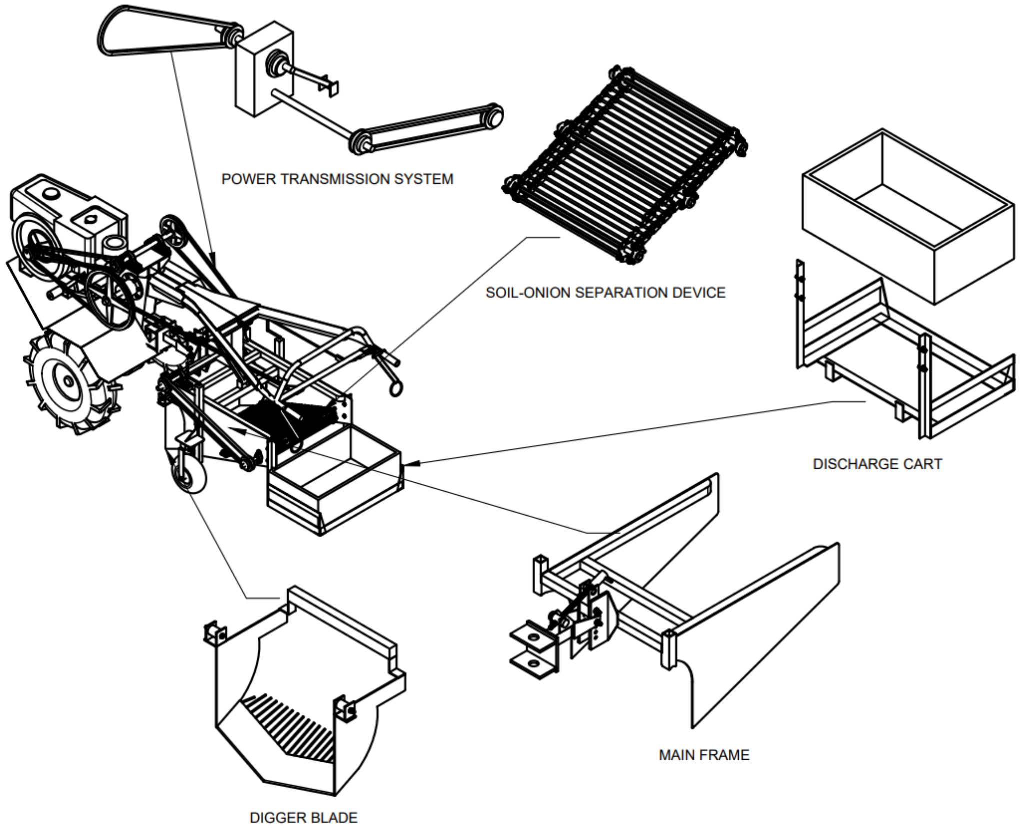

Figure 1 Perspective view of hand tractor driven onion harvester

2.2.1 Frame assembly

The mainframe (Figure 1) serves as the foundation of the onion harvester implement supporting the machine for stability during operation. It serves as the mounting structure supporting the digger blade, soil-onion separation device, power transmission system, and discharge cart. The mainframe also serves as the structure for the hitching system of the implement.

The hitching system of the onion harvester implement was based on the standard one-hole hitch specified in PNS/PAES107 (2000); where the pin sleeve and hitch frame were adaptable to the hand tractor.

2.2.2 Digger blade assembly

The digger blade (Figure 1) is the penetrating medium lifting the onion bulbs from the field plots. It was designed with reciprocating motion reducing the soil compressibility for ease of penetration. And to reduce the pulling force or draft requirement of the implement (Khura et al., 2011). The working width of the digger blade of 500 mm adapted to the local practice of onion farmers. The digger blade was inclined 18 ° to the horizontal. As mentioned by Singh (2014), the onion rolling angle of repose facilitates penetration and delivery of onion to the soil-onion separation device.

The calculation of traction resistance with a free-body diagram (FBD) shown in Figure 2 is based on the method used by Liu et al. (2014). The Equation 1 was used in calculating digging blade traction resistance.

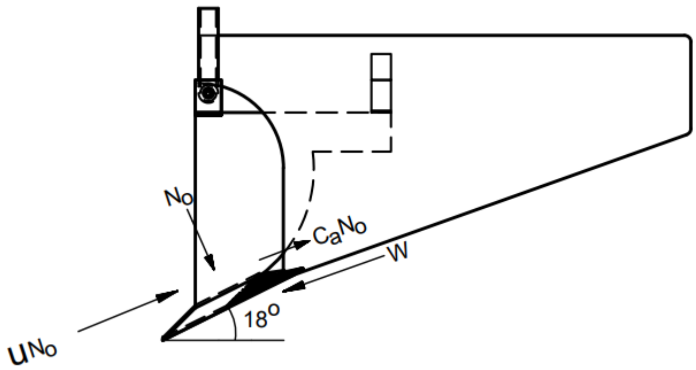

Figure 2 FBD of digging blade considering soil mechanics

$$W = [N_o \times \text{[illegible]}(\alpha)] + [M \times N_o \times cos(\alpha)] + [C_a \times N_o \times cos(\alpha)] \quad (1)$$

where: W-digging blade traction resistance, N

α-digging blade tilt angle, °

M-soil to metal friction factor, 0.675

C_a-soil adhesion coefficient, 25kN cm-2

N_o-blade surface area, cm^2

2.2.4 Soil-onion separation device assembly

The soil-onion separation device (Figure 1) is used to separate the onion from the soil mass and convey the onions to the discharge cart. The spacing of the separation device, which is 15 mm, was based on the non-marketable size of the onion (Del Carmen et al., 2016). It means that onion lifted below 15 mm discharged with the soil mass. The device with a set of cams in the rotating shafts oscillating at an amplitude of 25 mm. It was inclined at an angle of 18 ° to the horizontal to enhance the cleaning and transport of cleaned onions to the discharge cart (Budhale et al., 2019).

Table 1 Philippine National Standard size classification of onions (mm)

Size classification	Red creole	Yellow granex
Small	15-30	25-45
Medium	31-50	46-65
Large	>51	>66

The rotating shaft in the soil-onion separation device is the main element transmitting power from one shaft to another. The diameter of the rotating shaft is calculated using the volume of the soil in a particular moment of stillness. The calculation includes the weight of the gears, the weight of the chain, the weight of round bar spindles, and the rotating shaft subjected to combine and bending moments. The bending moment acting on the shaft was computed considering the vertical and horizontal loads shown in Figure 3. The vertical load is the tension load; while the horizontal loads are the mass of the soil, chain and sprocket, and round bar spindles.

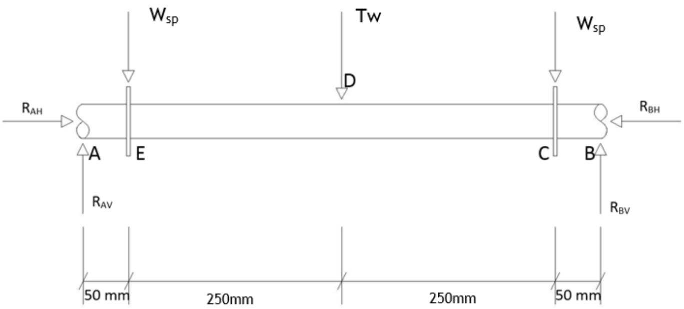

Figure 3 FBD of rotating shaft for soil-onion separation device

The Equations 2-9 were used in the calculation of shaft diameter adopted from Alhaseen et al. (2015).

$$Z = 0.57H - 0.01 \quad (2)$$

$$V_s = L_{cmd} + W_{cmd} + Z \quad (3)$$

$$m_s = V_s \times \rho \quad (4)$$

$$W_{sp} = W_{stansp} \times g \quad (5)$$

$$W_{ch} = W_{stanch} \times t_l \times g \quad (6)$$

$$W_{rb} = W_{stanrb} \times w_c \times g \quad (7)$$

$$T_w = W_{sl} + W_{sp} + W_{ch} + W_{rb} \quad (8)$$

$$\sqrt{M_{kb}^2} + T_{kt}^2 = \frac{\pi}{16} \times \tau_{max} \times d^3 \quad (9)$$

where: Z-thickness of the soil in the cleaning device, m

H-depth of cut, m

Vs-volume of soil, m^3

Lcmd-length of cleaning device, m

Wcmd -width of cleaning device, m

ms-Mass of soil, kg

ρ-soil density, kg m-3

Wsp-weight of sprocket, N

Wstansp-standard weight of sprocket, kg

g-acceleration due to gravity, m s-2

Wch-weight of chain, N

Wstanch-standard weight of chain, kg

tl-pitch diameter

Wrb-weight of round bar, N

Wstanrb-standard weight of round bar, kg

wc-cut width, m

Tw-total weight of soil, chain, sprocket, round bar spindles carried by the shaft, N

Mkb-bending moment acting on the shaft (combined shaft and fatigue), N·m

Tkt-torsion on solid shaft, N·m

τmax-allowable stress for carbon steel for shaft with keyway, kg m-3

d-diameter of shaft, mm

The power requirement was calculated considering the total weight acting on the shaft and the speed of the device. Equation 10 was used computing the power requirement of the soil-onion separation device adopted from Alhaseen et al. (2015).

$P_{STD} = T_w \times V$ (10)

Where:

P_{STD}: power requirement, hp

T_w: total weight carried by the shaft, kN

V: speed of the device, m s^{-1}

2.2.5 Power transmission system

The power transmission system (Figure 1) provides controlled application of power into the onion harvester. From the engine power, it uses a gearbox composed of sets of gears providing speed and torque conversions, rotating and oscillating the soil-onion separation device and digger blade. The size of pulleys and length of belts were calculated using Equations 11-12 adopted to PNS/PAES301:2000 and PNS.PAES303:2000.

$$N_1 D_1 = N_2 D_2 \quad (11)$$

Where:

D_1: pitch diameter of drive pulley, cm

D_2:pitch diameter of driven pulley, cm

N_1:number of revolutions of driver pulley, rpm

N_2:number of revolutions of driven pulley, rpm

$$L_c = 2C_p + \frac{T}{2} + \frac{t}{2} + \left(\frac{T-t}{2\pi}\right)^2 \left(\frac{1}{C_p}\right) \quad (12)$$

Where:

Lc: length of chain, pitches;

C_p: center to center distance, pitches

T: number of teeth of driver sprocket

t: number of teeth of driven sprocket

2.2.6 Discharge cart assembly

The discharge cart (Figure 1) attached at the rear end of the implement served as the collection chamber of cleaned onion bulbs from the soil-onion separation device. The dimension capacity was calculated using the length of the plot of 10 000 mm, the width of 500 mm, and the yield of onions of 15.33 tons ha^{-1} (Galindez et al., 2017)

2.2.7 Draft requirements

Draft force is the energy used to overcome the soil resistance and cut and invert the soil during tillage operation (Almaliki, 2018). The impact of draft force to the implement depends on the type of soil, implement width, harvesting depth, and running speed. The calculation of draft requirements of the onion harvester implement is assumed to be similar to the moldboard plow. The Equations 13-16 (American

Society of Agricultural Engineers [ASAE] Standards 2000; Coates, 2002) were used.

$$D = Fi \times [A + B(S) + C(S^2)] \times W \quad (13)$$

Where:

D:implement draft, kN

Fi:a dimensionless soil texture adjustment parameter

A, B & C:machine-specific parameters

S:forward speed of the hand tractor, km h^{-1}

W:machine working width, m

To consider the specific draft as affected by the forward speed shown, the calculated draft was adjusted respective to the specific forward speed (Resurreccion, 2010).

$$D = SD \times W \times d \quad (14)$$

$$D_a = D \times adjusted\ draft\ due\ to\ speed \quad (15)$$

$$HP_{draft} = \frac{D_a \times S}{C} \quad (16)$$

Where:

D:implement draft, kN

SD:specific draft, kg cm^{-2}

W:width of cut, cm

d:depth of cut, cm

D_a:adjusted draft value, kg

HP_{draft}:horsepower due to adjusted draft caused by speed, hp

S:forward speed of hand tractor, km h^{-1}

C:conversion factor for hp

The power requirement is the total power needed for the hand tractor and the implement to fully operate. This was calculated considering the power requirement for the digging blade and the soil-onion separation device. Equations 17 and 18 were used to compute the total power requirement of the implement adopted from Alhaseen et al. (2015).

$$P_{TDB} = \frac{D \times S}{C} \quad (17)$$

$$T_{HP} = P_{DB} + P_{STD} \quad (18)$$

Where:

P_{TDB}:total drawbar power, hp

D: draft, kN

S:speed of operation, m s^{-1}

C:conversion factor for hp

T_{HP}:total power requirement of the harvester, hp

P_{DB}:power requirement of digging blade, hp

P_{STD}:power requirement of soil-onion separation device, hp

2.3 Research design

This study utilized Complete Randomized Design (CRD) as an experimental design using the three (3) levels of speed of the soil-onion separation device as treatments. These are 100 rpm, 208 rpm, and 333 rpm. The evaluative technical parameters evaluated are the AFC, harvesting capacity, and harvesting efficiency. The analysis data was in Statistical Software for Social Sciences (SPSS) and Tukey's Honest Significant Difference (THSD) to test further the significance between treatments.

2.4 Evaluation performance parameters

AFC is the actual area harvested per unit operation time. The total area covered was measured per plot before the start of the test. The turning time was measured from the end of plot to the start of the next plot. The total operation time includes the unproductive time (i.e., adjustment and turning time) and the productive time (time during simultaneous harvest without failure). The data gathered were recorded for analysis. The AFC was computed using Equation 19 adopted from PNS/PAES160 (2011).

$$AFC = Ah / (Tp + Tn) \quad (19)$$

Where:

AFC: actual field harvesting capacity, ha hr^{-1}

Ah: area harvested, ha

Tp: productive time, hr

Tn; non-productive time, hr

HC is the actual weight of onion conveyed in the discharge cart per unit operation time. The total operation time includes the unproductive time (i.e. adjustment and turning time) and the productive time (time during simultaneous harvest without failure). The data gathered were recorded for analysis. The harvesting capacity was computed using Equation 20 adopted from PNS/PAES160 (2011).

$$HC = O_c / (T_p + T_n) \quad (20)$$

Where:

HC: Harvesting capacity, kg hr^{-1}

O_c: Total weight of onion collected in the discharge cart, kg

HE is the mass ratio of the harvested onions collected in the discharge cart over the unharvested/unlifted onions in the plot. After harvesting in each plot, unharvested onion bulbs were manually collected and weighed. The harvesting efficiency was determined using Equation 21, adopted from Ibrahim et al. (2008).

$$HE = (Rt - D)/ Rt \tag{21}$$

Where:

HE: harvesting efficiency, %

R_t: total weight of onions harvested in the area, kg

D: unharvested onions by the machine, kg

3 Results and discussion

3.1 Description of the hand tractor driven onion harvester

The onion harvester is a hand tractor implement capable of digging, lifting, cleaning, and collecting onion bulbs in one operation. It is a single row harvester that can be hitched to a locally designed hand tractor with a single forward speed and has no reverse. The parts were made of locally available materials and fabricated by a local manufacturer. It has five (5) main assemblies shown in Figure 4: mainframe, digger blade, soil-onion separation device, power transmission system, and discharge cart. The specifications of the machine are in Table 2.

Table 2 Specifications of onion harvester hand tractor implement

Component	Specification
Machine overall dimension and weight	
Length, mm	1,230
Width, mm	570
Height ,mm	500
Weight, kg	68
Prime mover	
Model	RK70-s
Rated power, hp	7.0
Rated speed, rpm	1750
Types of power transmission	
Engine to the gearbox	V-belt and pulley
Gearbox to the harvester components	Chain and sprocket
Transmission system accessories	
Transmission gearbox	Speed ratio at 1:3
Drive and driven sprocket	13 T, bore at 19 mm diameter
Shafts	Stainless steel at 19 mm
Chain	254 mm pitch diameter, 25 mm bore
Sprocket	19 mm bore, 13 T
Main Frame	
Length, mm	880
Width, mm	570
Height, mm	410
Material	Tubular bar, 38.1 mm
Digger blade	
Type	Shovel-shaped sharpened at edges
Material	Mild steel
Dimension: l x w x h, mm	$300 \times 500 \times 41$
Angle of inclination	18^0
Soil-onion separation device	
Conveyor type	Chain
Material	plain round bar, 8 mm
Spacing, mm	15
Cam shaft (triangular and circular)	Mild steel, 76 mm Ø , 13 mm thick
Angle of Inclination	18^0
Discharge cart	
Capacity, kg	10

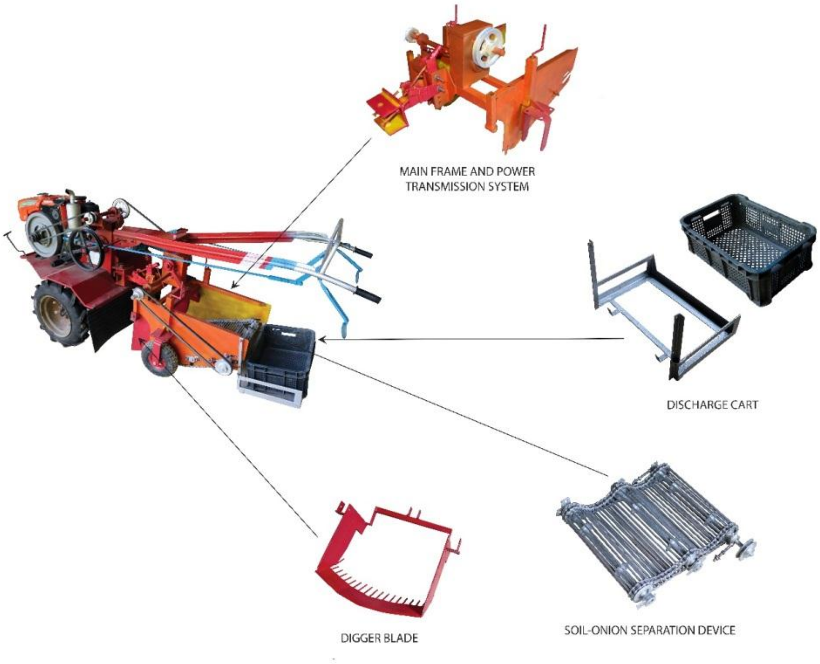

Figure 4 Onion harvester hand tractor implement

3.2 Description of different machine assemblies

3.2.1 Main frame assembly

The mainframe of the onion-harvester is of a tubular bar welded together to form a trapezoidal shape frame with a dimension of 880 mm × 570 mm × 410 mm ($l \times w \times h$) shown in Figure 4. The onion harvester implement has a one-hole hitch system mounted to the mainframe with a pin sleeve diameter of 32 mm. The pin sleeve is adaptable to the hitch pin diameter of the hand tractor of 21 mm.

3.2.2 Digger blade assembly

The overall dimension of the shovel-shaped blade shown in Figure 4 is 300 mm × 500 mm × 0.5 mm ($l \times w \times h$). It is made with a 5 mm thick flat bar counteracting digging blade traction resistance of 489.27 N during operation. It oscillates at 25 mm separating the onion bulb from the soil mass and reducing the draft requirement of the implement. It was oriented 18 °to the horizontal lifting of the onion bulbs to the soil-onion separation device without rolling back. The digger blade assembly was bolted into the frame for easy assembly and disassembly during repair and maintenance.

3.2.3 Soil-onion separation device assembly

The soil-onion separation device shown in Figure 4 has an overall dimension of 520 mm × 500 mm × 400 mm ($l \times w \times h$). It includes a series of round bars arranged to each other having distal ends attached to an endless chain and connected to the sprockets. The rotating shaft has a carried load of 587.36 N resulting in a diameter of 19 mm.

The soil-onion separation device rotates at a rotational speed of 100 rpm. The rotating shafts equipped with 76.2 mm diameter triangular and circular cams create oscillation movement of the device at 25 mm. It was inclined 18 ° to the horizontal to prevent the rolling back of onions. Rotating shafts were inclinedly mounted to the mainframe using flange bearings and rotatably connected to the gearbox for power supply.

Gb h: The soil-onion separation device has attached rubber wheels maintaining stability and digging depth of the digger blade. It was bolted to the frame for easy assembly and disassembly during repair and maintenance.

3.2.4 Power transmission system

The power transmission system shown in Figure 4 is a combination of belts and pulleys, gearbox, and chains and sprockets. From the hand tractor engine with a rotational speed of 1650 rpm (with load), speed reducer using a gearbox of 1:3 ratio, providing a digger blade speed of 500 rpm and soil-onion separation device of 100 rpm.

The draft requirement for the hand tractor to pull the implement with a forward speed of 1.93 km hr^{-1} is 1 962.92 N. Using the 80% power transmission efficiency, the total power requirement pulling the onion harvester implement is 2.08 hp.

3.2.5 Discharge cart assembly

The discharge cart shown in Figure 4 consists of a metal holder bolted to the frame assembly and a replaceable standard plastic crate, which serves as the collection box, with dimensions 520 mm × 350 mm × 200 mm (l × w × h). During the operation of the machine, when the plastic crate with 10 kg capacity was loaded, it was immediately replaced with another plastic crate continuing the harvesting operation.

3.3 The performance parameters of the onion harvester implement

3.3.1 Actual field capacity (AFC)

The mean AFC of the machine as affected by different speed levels of the soil-onion separation device is in Table 3. Analysis of Variance (ANOVA) revealed no significant difference between treatment means at a 5% level of significance. It implies that the speed of the soil-onion separation device does not affect the AFC of the machine. According to Nasr et al. (2019), the AFC of the machine is directly affected by the tractor's forward speed where the capacity increases as the forward speed increases.

Table 3 Mean AFC affected by different speed levels of the soil-onion separation device of the machine

Treatment	AFC (ha hr^{-1})
100 rpm	0.027
208 rpm	0.023
333 rpm	0.022

The hand tractor has only one (1) forward speed; the AFC is almost the same. The hand tractor was designed to adapt to the operators walking speed. Thus, the forward speed of the hand tractor does not vary with the operator's walking speed. Nasr et al. (2019) also stated that AFC is inversely proportional with the digging depth, wherein AFC decreases as the digging depth increases or vice versa due to a change in exerted force. During operation, the digging depth of the machine is 100 mm, digging blade load-bearing is almost the same. Thus, there is no significant decrease in the AFC.

3.3.2 Harvesting capacity

The mean harvesting capacity of the machine affected by different speed levels of the soil-onion separation device is in Table 4. Using ANOVA, it revealed that there is no significant difference among treatment means at a 5% level of significance. It implies that the speed of the soil-onion separation device does not affect the harvesting capacity of the machine. Since the hand tractor has only one (1) forward speed utilized during the operation, the harvesting capacity does not vary significantly in all treatments.

Table 4 Mean harvesting capacity (kg hr^{-1}) affected by different speed levels of the soil-onion separation device of the machine

Treatment	Harvesting capacity (kg hr^{-1})
100 rpm	299.05
208 rpm	246.66
333 rpm	240.11

3.3.3 Harvesting efficiency

The mean harvesting efficiency of the machine affected by different speed levels of the soil-onion separation device is in Table 5. Using ANOVA, it revealed that there is no significant difference among treatment means at a 5% level of significance. The digger blade has only one (1) digging depth at 100 mm and no variable depth penetration addressing the unevenness of field plots. It causes a high percentage of unlifted/unharvested onion bulbs conveyed into the discharge cart.

Table 5 Mean harvesting efficiency (%) affected as affected by different speed levels of the soil-onion separation device of the machine

Treatment	Harvesting efficiency (%)
100 rpm	70.93
208 rpm	67.54
333 rpm	62.10

The digging depth of the onion harvester designed by Gavino et al. (2018) of 66 to 76 mm that served as the basis of the study adjusted to 100 mm should be variable up to 200 mm.

This is to address the unevenness of manually prepared plots.

4 Conclusion and recommendations

The designed onion harvester implement is adaptable to a hand tractor with a power requirement of 2.08 hp. The onion harvester implement has a simple design that a local manufacturer could fabricate using standard available materials. The field performance of the machine having AFC of 0.027 ha hr^{-1}, harvesting capacity of 299.05 kg ha^{-1}, and 70.93% harvesting efficiency prove that manual harvesting operation could be mechanically done using the implement. The labor and cost requirement associated with manual harvesting could be reduced potentially, thereby increasing profit for farmers. However, further, improvements to increase the harvesting efficiency to minimize the unlifted/unharvested onions in the field plot during operation. Another is decreasing the implement weight for ease of turning on the headlands. Similarly, an inclusive performance test using the different speeds of the digger blade to standardize the operation of the implement for commercialization. Further, using the onion harvester implement to harvest potatoes, sweet potatoes, and peanuts could be explored.

Acknowledgements

The researchers acknowledge the Department of Science and Technology- Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD), the funding agency, for giving importance to improving the onion production in the country; the onion farmers in Bauang, La Union, for committing their farms as field test area in the actual evaluation of the hand tractor driven harvester; and to the Lord our God, for letting His blessings overflow.

References

Alhaseen, I. A. A., A. M. S. Sharif, Z. M. A. Ali, and A. A. M. A. Alamein. 2015. Design of a one-row potato digger harvester. Available at: http://api.uofk.edu:8080/api/core/bitstreams/6d366667-c68d-4ed8-9cec-6dc28234ce33/content. Accessed 9 January 2022.

Almaliki, S. 2018. Simulation of draft force for three types of plow using response surface method under various field conditions. *Iraqi Journal of Agricultural Sciences*, 49(6): 1123-1124.

American Society of Agricultural Engineers. 2000. *ASAE EP496.2 DEC99: Agricultural machinery management*. Available at: https://www.academia.edu/41779575/STANDARDASAE_EP4962DEC99_Agricultural Machinery Management. Accessed 9 January 2022.

Benke, A., S. Gadge, Y. Bhagat, V. Mahajan, and M. Singh. 2017. Mechanization in onion and garlic cultivation brainstorming on challenges in mechanization of onion and garlic production in India organized by ICAR - Directorate of Onion and Garlic Research (DOGR) in collaboration with Indian Society of Alliums-Way Forward. *ICAR-DOGR*. Available at: https://www.researchgate.net/publication/335690988_Mechanization_ in_Onion_and_Garlic_. Accessed 3 February 2022.

Budhale, K. C., A. G. Patil, V. S. Shirole, S. S. Patil, R. S. Desai, and S. B. Salavi. 2019. Design and development of digging and conveyor system for self-propelled onion harvester. *International Research Journal of Engineering and Technology*, 6(4): 3304-3307.

Coates, W. 2002. *Agricultural Machinery Management*. The University of Arizona Cooperative Extension. Available at: https://cals.arizona.edu/crop/equipment/agmachinerymgt.html. Accessed 18 January 2022.

Del Carmen, D. R., A. M. D. Espigol, P. A. Nuevo, and G. D. Masilungan. 2016. Morphological and physico-chemical characteristics of "red creole" *Allium cepa* L. in three production areas in the Philippines. *Philippine Journal of Crop Science (PJCS)*, 41(3): 13-19.

Department of Agriculture (DA). 2020. Investment guide for onion. Available at: https://www.da.gov.ph/wp-content/uploads/2021/04/Investment -Guide-for-Onion.pdf. Accessed 8 May 2022.

Etana, M. B., M. C. Aga, and B. O. Fufa. 2019. Major onion (*Allium cepa* L.) production challenges in Ethiopia: A review. *Food Science and Quality Management*, 86: 1-5.

Galindez, J., P. Pascua, F. Porcuincula, and L. L. M. Lopez. 2017. Performance of red onion (Bulb Type) in fully converted organic area as affected by frequency of organic fertilizer application combined with *Trichoderma* spp. *Journal of Agricultural Science and Technology*, 6(1): 10-17.

Gavino, H. F., W. C. Mateo, and C. R. C. De Vera. 2018. Development of a locally made power tiller driven onion

harvester.
Available at: https://www.researchgate.net/publication/326542972Development of a Locally Made Powe Tiller Driven Onion Harvester 1. Accessed 13 June 2022.

Gavino, R. B., V. E. B. Camaso, and C. C. Tiw-an. 2020. Assessment of mechanization level of onion production in Nueva Ecija. *CLSU International Journal of Science & Technology*, 4(1): 82-99.

Hanci, F. 2018. A comprehensive overview of onion production: Worldwide and Turkey. *Journal of Agriculture and Veterinary Science*, 11(9): 17-27.

Ibrahim, M. M., E. Amin, and A. Farag. 2008. Developing a multi-purpose digger for harvesting root crops. *Misr Journal of Agricultural Engineering*, 25(4):1225-1239.

Khura, T. K., I. Mani, and A. P. Srivastava. 2011. Design and development of tractor drawn (Allium cepa) onion harvester. *Indian Journal of Agricultural Sciences*, 81(6): 528–532.

Liu, S., S. Weng, Y. Liao, and D. Zhu. 2014. Structural bionic design for digging shovel of cassava harvester considering soil mechanics. *Applied Bionics and Biomechanics*, 11(1-2): 1-11.

Mehta, I. 2017. Origin and history of onions. *IOSR Journal of Humanities and Social Science*, 22(9): 07-10.

Nasr, G. E. M., M. N. Rostom, M. M. M. Hussein, A. E. Farrag, and M. F. A. Morsy. 2019. Development of suitable potato crop harvester for small holdings. *CIGR Journal*, 21(2): 34–39.

Paras, F. O., and R. M. C. Amongo. 2011. Technology transfer strategies for small farm mechanization technologies in the Philippines. Available at: https://www.fftc.org.tw/htmlarea_file/library/20110726161100/eb570.pdf. Accessed 13 June 2022.

Philippine National Standard. 2020. PNS/PAES107. Agricultural machinery – hitch for walking-type agricultural tractor specifications. College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, College, Laguna, PH 4031: AMTEC.

Philippine National Standard. 2011. PNS/PAES160. Agricultural machinery – sugarcane planter-methods of test. College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, College, Laguna, PH 4031: AMTEC.

Philippine National Standard. 2000. PNS/PAES301. Engineering materials- v-belts and pulleys for agricultural machines-specifications and applications. College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, College, Laguna, PH 4031: AMTEC.

Philippine National Standard. 2000. PNS/PAES303. Engineering materials- roller chains and sprockets for agricultural machines-specifications and applications. College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, College, Laguna, PH 4031: AMTEC.

Philippine Statistics Authority (PSA). 2014. 2013 Cost and returns of onion production. Available at: https://psa.gov.ph/content/costs-and-returns-onion-production. Accessed 18 March 2022.

Resurreccion, A. N. 2010. Agricultural machinery and mechanization. PSAE Region IV - Agricultural Engineering Board Review Materials. Available at: https://pdfcoffee.com/qdownload/i-1c-farmmech-20-60-pdf-free.html. Accessed 18 March 2022.

Romano, L. N., N. Back, A. Ogliari, and V. K. Marini. 2005. An introduction to the reference model for the agricultural machinery development process. *Product: Management and Development*, 3(2): 109-132.

Singh, M. C. 2014. Development and performance evaluation of a digger for harvesting onion *(Allium cepa* L.). *International Journal Agricultural Engineering,* 7(2): 391-394.