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Soil Bin Studies on Plug and Finger-type Onion Seedling Transplanting Mechanisms

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ABSTRACT

A study was conducted to develop a plug- and finger-type onion seedling transplanting mechanisms in a soil bin and examine the effects of age of seedling and machine parameters (speed of operation, height of seedling drop, finger material) on plant spacing, planting depth, successful transplanting, furrow closure, filling efficiency and plant damage. Plant spacing ranged from 121.4 mm to 133.5 mm using plug metering mechanism, while it was 167.9 mm to 195.0 mm with finger-type metering mechanism. The percent seedling transplanted and percent furrow closure with plug mechanism varied from 76.67 % to 100 % and 73.33 % to 100 %, respectively; and in finger-type metering mechanism they ranged from 18.33 % to 78.33 % and 15 % to 73.33 %, respectively. Plug filling efficiency ranged from 96.67 % to 32.22 % with plug mechanism, and 95.28 % to 22.5 % with finger metering mechanism. Percent seedling damage with plug mechanism ranged from 0 % to 17.54 %, and was lower than 0 % to 31.05 % caused by finger-type metering mechanism. The performance of plug-type metering mechanism for onion seedling was closer to the recommended practices as compared to finger-type metering mechanism.

Onion (*Allium Cepa*) is an important vegetable crop grown all over the world. The world production was about 93.17 MT of bulbs from 4.95 Mha in the year 2016 (Anon., 2017a). In India, it is cultivated extensively in Maharashtra, Karnataka, Madhya Pradesh, Rajasthan, Gujarat and Bihar covering 77.57 % of total cultivated area and 76.96 % of total production of the country (Anon., 2015).

Onion is raised by direct seed sowing, planting bulbs, or by nursery raising and subsequent transplanting in field. Onion transplanting is most common method used in India due to its high yield and better quality (Sadhu, 1982). However, transplanting of onion seedlings is done manually in all onion growing regions of the country, as no suitable machine is yet available. Also, there is a sizeable increase in acreage from 0.87 Mha to 1.31 Mha and corresponding production from 9.38 MT to 22.43 MT from 2000-01 to 2016-17, respectively,in India (Anon., 2017b).

Manual transplanting of onion seedling is labour-intensive, and requires adoption of odd posture. The labour requirement in manual transplanting of vegetable seedlings is also high at 253 man.h.ha^{-1} (Satpathy, 2003). Vegetable crops are sensitive to climatic conditions, and require timely field operations. Also, onion plants are delicate and perishable which leads to higher seedling mortality (Pandirwar *et al*., 2015). However, labour shortage during peak season causes delay in transplanting, leading to drastic reduction in yields (Chaudhuri *et al*., 2002).

A number of attempts have been made in India and in other countries to mechanize the operation of vegetable transplanting. Plug type and finger type metering mechanisms are the two commonly used semi-automatic metering mechanisms used in most of the transplanters developed till now. An important performance criterion for transplanters is that seedling must be oriented properly and remain in good contact with the soil (Srivastava *et al.,* 2006). Plug metering mechanism is a gravity-feed system that carries the seedlings in the furrow with minimum physical contact. Finger-type transplanting mechanism holds a seedling erect until the roots placed in the furrow are covered and compacted by a press wheel. Gravity fed plug-type transplanting mechanism has the advantage of high feed rates as compared to finger-type mechanism. Such mechanisms are more suitable for long bare-root seedlings like that of onion. Gutiérrez *et al.* (2009) had studied a transplanting mechanism for bare-root plants on mulched soils, comprising of mechanisms namely cutter, a hook and a clamp to make automatic operations of cutting the plastic, hide the cut-plastic and insert the plant in the ground. Placement of the plants by clamp was 95 %, with 85 % correctly oriented. In India, Nandede *et al*. (2015) developed a multi-stage rotating cup type metering mechanism for transplanting of tomato, brinjal and chili seedlings raised in paper pots. The soil bin setup had a seedling feeding wheel, metering wheel, fixed slotted plate, seedling delivery tube, and furrow opener, furrow closer and a power transmission system. The mean values of feeding efficiency, conveying efficiency, planting efficiency and overall efficiency of the multistage metering unit were observed to be higher than 90 % for forward speeds of 0.6 $km.h^{-1}$ to 2.2 $km.h^{-1}$. Chilur *et al*. (2018) developed and tested auger type metering mechanism for transplanting of vegetable seedlings raised in paper pots. A single-row laboratory setup comprised of an auger, seedling delivery tube, shovel furrow opener, double disc furrow closer, power transmission system and frame. The mechanism was found suitable for metering of vegetable pot seedlings at the rate of 53 $seedling.min^{-1}$ to 65 $seedling.min^{-1}$ for forward speeds from 1.6 $km.h^{-1}$ to 2.0 $km.h^{-1}$ with more than 90 % conveying efficiency, feeding efficiency, transplanting efficiency and overall efficiency. In other studies, seedling raising trays have been modified for automating the operation of transplanting. Nandede *et al*. (2018) developed a split-cell type metering mechanism for automatic transplanting of plug-type vegetable seedlings. The experimental setup consisted of split cell metering mechanism made up of nitrite rubber, seedling delivery tube, furrow opener, furrow closer, power transmission system and frame. The soil bin studies showed that, a forward speed up to 2.0 $km.h^{-1}$ was suitable for automatic feeding and metering of vegetable seedlings effectively at transplanting rate of 50 to 67 $seedling.min^{-1}$. Most of the transplanters and metering mechanisms developed are for the vegetables seedlings like tomato, brinjal, chilli, etc. None of these machines are suitable for onion seedling transplanting.

As the demand for mechanization of onion production has increased, it is imperative to develop a suitable mechanism for onion seedling transplanting. Therefore, a study was undertaken with the objectives to develop a plug- and finger-type transplanting mechanisms for onion seedling suitable to Indian conditions, and evaluate their performance in a soil bin.

MATERIALS AND METHODS

Measurement of Biometric Properties of Onion Seedlings

Onion seedlings of commonly grown varieties namely, Pusa Ridhi and Sel.-126 (*Kharif* variety) and Pusa Red (*Rabi* grown) were raised on the experimental farm of the Division of Agricultural Engineering, IARI, New Delhi. The biometric properties of 50-, 60- and 70-day old onion seedlings relevant to onion seedling transplanter, namely weight of seedling, moisture content, bulb and stem diameter, height, compressive strength (using texture analyser) and coefficient of static friction were measured.

Development of Experimental Onion Seedling Transplanting Mechanisms

A semi-automatic plug-type metering mechanism and a finger-type picking mechanism of vegetable transplanter were developed based on biometric properties of onion seedlings. In order to evaluate the feasibility of the two mechanisms at selected operating parameters, an experimental set up was developed and tested in a soil bin.

Plug-type metering mechanism

The plug-type metering mechanism (Fig. 1 and Fig. 2) consisted of a plug metering assembly mounted on a vertical shaft of 25 mm diameter and powered with a pair of bevel gears with ratio of 1:1. The whole assembly (Fig. 1) with twenty plugs was mounted on a frame such that it could rotate around it. An operator sitting on a chair fixed on soil bin carriage filled onion seedlings in each plug one by one. Each plug (Fig. 2a) made of aluminium pipe was 200 mm long and 30 mm in diameter with opening at the bottom equipped with spring operated lid. A stationary cam was fitted at the delivery end of the frame above the dropping funnel to open the lid of plugs. The dropping funnel made of 2 mm thick MS sheet (Fig. 2b) was provided

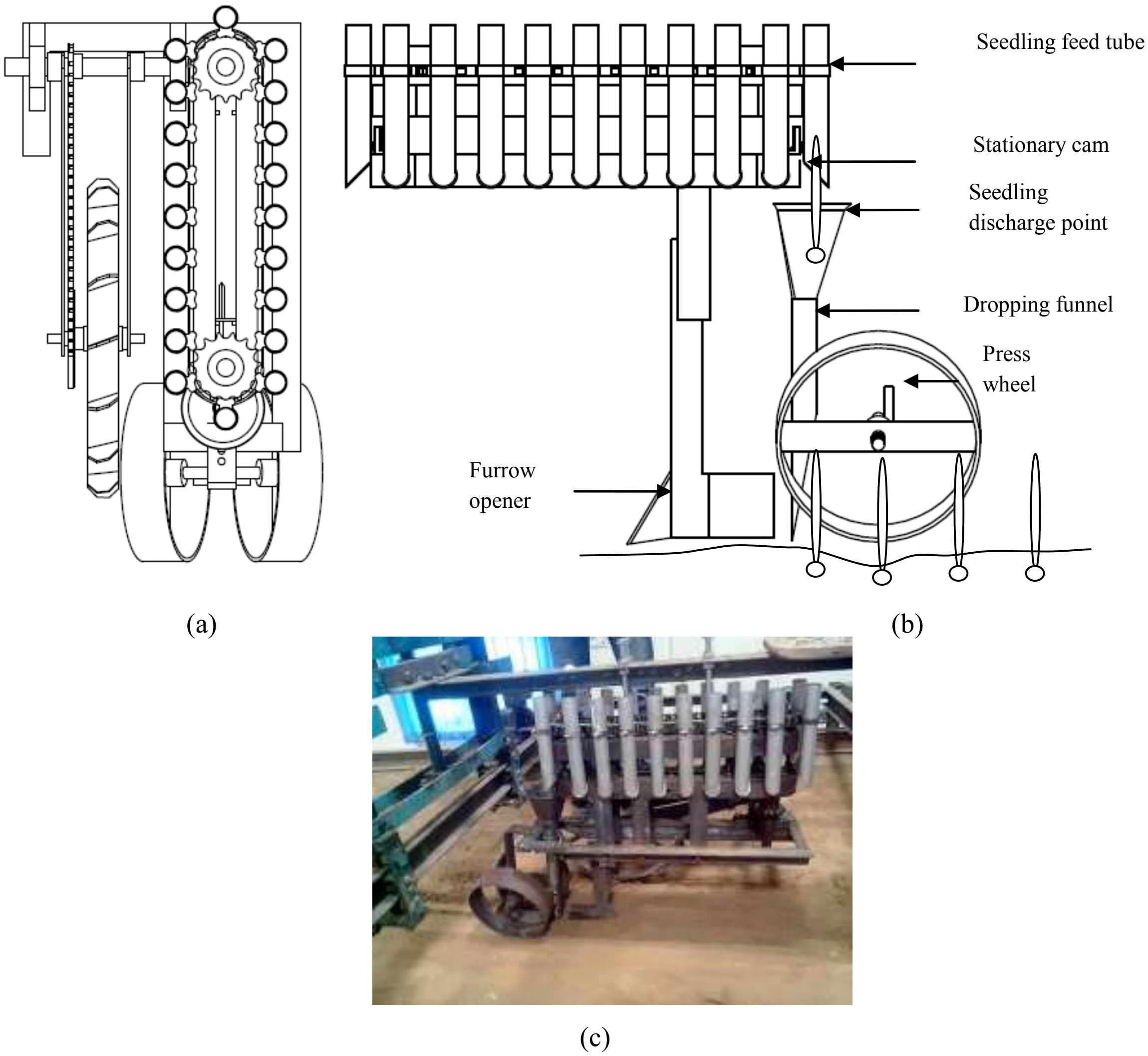
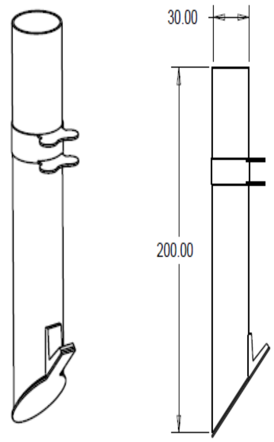


Fig. 1: Plug-type metering mechanism

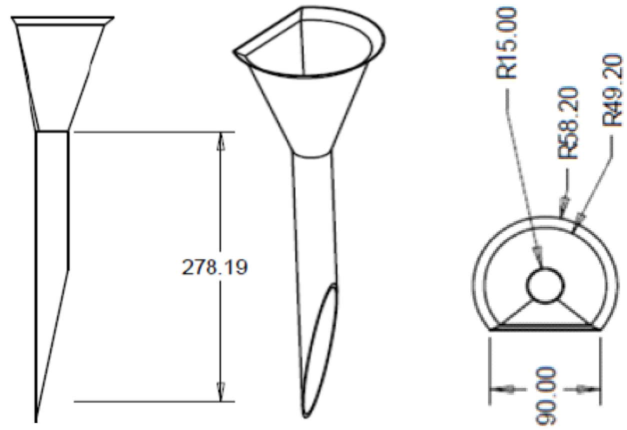
to receive and guide the seedlings falling from the plug in the direction of travel of the machine. A chisel-type furrow opener (Fig. 2c) having triangular shape soil working tool made of M.S. flat of 10 mm thickness was positioned immediately at the back of the dropping funnel to open a thin continuous furrow. A pair of rotating type tilted press wheels of diameter 254 mm was provided besides the dropping funnel to cover the roots and bulb of the seedlings with soil. The plug assembly was driven by a ground wheel of 400 mm diameter (Fig. 2d) provided on one side of the machine, main shaft and plug metering assembly shaft. The ground wheel rotated a hub with 35 teeth sprocket attached on the ground wheel axle, and power was transmitted through a chain to another 15 teeth sprocket on the main shaft. The power to a vertical plug metering assembly shaft was transmitted from the horizontal main shaft through a 1:1 bevel gear assembly.

Finger-type metering mechanism

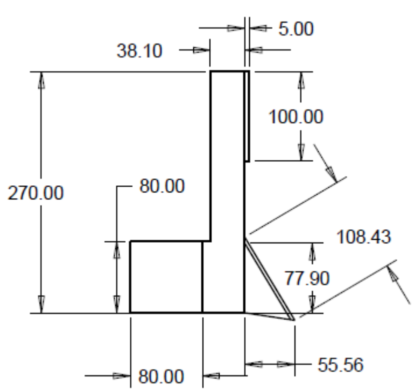
The finger-type metering mechanism (Fig. 3) consisted of a finger assembly (Fig. 4b) with sixteen fingers mounted at equal spacing on a 5 mm thick circular disc of diameter 300 mm. Each finger made of aluminium and galvanized iron (Fig. 4a) remained open before passing over a finger guide, and closed during its passage through the finger guide. The finger again opened at bottom end of the guide to release the seedling in a furrow. A person sitting on the machine placed the seedling in each finger one by one when it opened at the top position. The finger guide closed each finger at the feeding end, and carried the seedlings up to the delivery end till the finger delivered the seedling in the furrow. A chisel-type furrow opener developed for the plug metering mechanism (Fig. 2c) was provided at the front end of main frame in alignment with the finger assembly. A ground wheel of diameter 400 mm



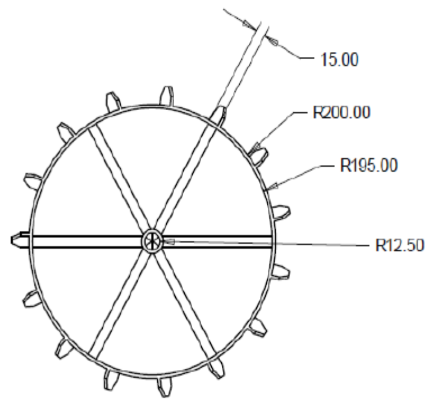
(a) Aluminium plug



(b) Dropping funnel

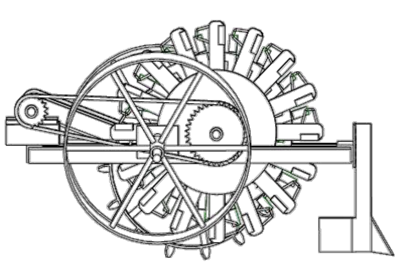


(c) Chisel furrow opener

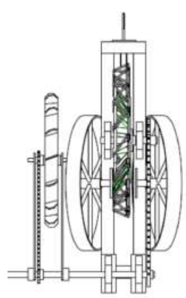


(d) Ground wheel

Fig. 2: Components of plug-type metering mechanism



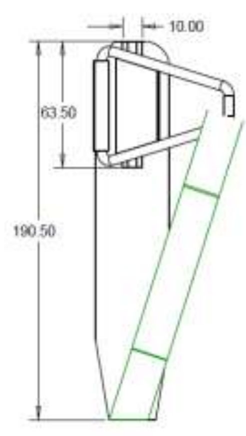
(a)



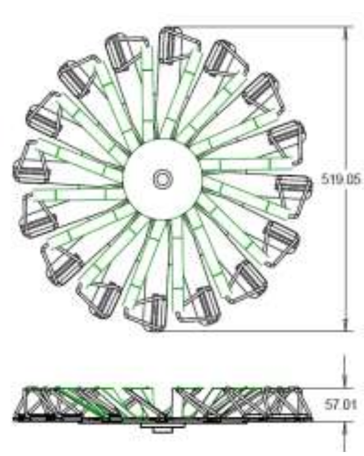
(b)

(c)

Fig. 3: Finger-type metering mechanism



(a) Finger



(b) Finger assembly

Fig. 4: Components of finger-type metering mechanism

was provided on one side of machine to power the main shaft and the finger assembly shaft which drives the finger mechanism. The ground wheel rotated a hub with 15 teeth sprocket attached on the ground wheel axle, and power was transmitted through a chain to another 15 teeth sprocket on the main shaft. The power to the finger assembly shaft was transmitted from a horizontal 15 teeth sprocket on the main shaft to a 36 teeth sprocket on the finger assembly shaft. A pair of press wheels, each with outer diameter of 454 mm, was also provided to compact the soil around the transplanted bulbs.

Testing of Onion Seedling Transplanting Mechanisms in Soil Bin

The developed mechanisms were tested in the soil bin at the Division of Agricultural Engineering, IARI, New Delhi. Onion seedlings were grown under standing practice of nursery raising at the experimental farm of the Division of Agricultural Engineering, IARI, New Delhi. Sandy loam soil in the soil bin was prepared to proper tilth in top 100 mm layer using a rotary tiller. The desired moisture content and bulk density were obtained by sprinkling water on soil, pulverizing it using a rotary tiller, levelling and then compacting the soil using a levelling blade and roller, respectively (Fig. 5).

The plug and the finger transplanting mechanisms were mounted on a carriage running on the soil bin rails, and driven by endless winch-rope mechanism. Observations on the independent and dependent parameters affecting mechanical transplanting of onion seedlings as plant spacing, planting depth, furrow closure, filling efficiency, damaged seedlings and success of transplanting were recorded for different combinations of speed of transplanting (0.48, 0.67, 1.25 km.h^{-1}), age of seedlings (50, 60 and 70 days as recommended by onion breeder) and height of dropping (300 and 400 mm) for metering mechanisms (Table 1). The forward speeds of 0.48 and 0.67 km.h^{-1} were selected to enable manual feeding of seedlings for obtaining recommended plant spacing of 100 mm (Anon., 2018). The performance of machine at higher speed of 1.25 km.h^{-1} was also observed, but manual feeding was difficult. Operation of the mechanisms at

Fig. 5: Soil bin preparation for experimentation

Table 1. Design of soil bin experiment on onion seedling transplanting mechanisms

Sl. No	Variable		Level
Independent variable			
A) Seedling parameter			
1.	Age of seedling	(50, 60 and 70 days)	3
B) Machine parameter			
1.	Forward speed (Fs) (0.48, 0.67, 1.25 km.h^{-1})		3
2.	Transplanting mechanisms (plug, finger type)		2
3.	Drop height (300 mm, 400 mm)		2
4.	Finger material (Aluminium, G. I.)		2
C) Number of replications			3
No. of experimental runs			3 x 3 x 2 x 2 x 3 = 108
Dependent variable			
Observations for each seedling			Unit
1	Plant to plant spacing		mm
2.	Planting depth		mm
Performance parameter			Units
1.	Filling efficiency		Percentage
2.	Damaged seedlings		Percentage
3.	Transplanted		(1-Transplanted, 0- Not transplanted)
4.	Furrow closure		(1-Appropriate, 0-Improper)

(a) (b)

Fig. 6: Measurement of a) plant spacing, and b) planting depth of transplanted seedling

higher speed of 1.25 km.h^{-1} was conducted to assess the possibility of the mechanism for automatic picking and feeding. All twenty plugs of the plug mechanism were fed with seedlings before start of operation at forward speed of 1.25 km.h^{-1}.

Parameters observed

Following observations were taken on each set of treatment combination.

Plant spacing

The distance between the collars of transplanted onion seedlings was measured with accuracy of 5 mm using a steel tape. The distance was measured at closed furrow surface level (Fig. 6a).

Seedling transplanted

A seedling was considered as transplanted if it got properly placed at a location with complete or incomplete furrow closure. Visual observations for whether a seedling was transplanted or not were recorded as “1” for transplanted and “0” for not transplanted.

Furrow closure

A furrow was said to be properly closed if the bulb and root of the seedling was not visible and covered completely with soil. Visual observations for furrow closure were recorded as “1” for proper furrow closure and“0” for the rest.

Planting depth

Planting depth is the length of seedlings under the soil from furrow surface. It was measured by uprooting each seedling in a row (Fig. 6b). It was measured for all successfully transplanted plants with proper furrow closure.

Damaged seedling

The number of seedlings damaged either due to crushing in metering device or getting pressed below the wheels was counted. The percent seedlings damaged out of total seedlings transplanted were calculated.

Filling efficiency

Plug or finger filling efficiency was observed for selected forward speeds and age of seedlings during soil bin studies. The numbers of seedlings that could be fed by the operator out of 20 seedlings were recorded. The percent seedling fed was calculated using measured data.

Moisture content

Moisture content (per cent) on dry weight basis of soil was measured by standard oven drying method. The samples collected randomly from five different locations in soil bin up to a depth of 100 mm were weighed and kept in an oven at 105±5 ºC for 24 hours. The samples were again weighed, and the soil moisture content was determined (dry weight basis) by the following formula:

$$\text{Soil moisture (\%, db)} = \frac{\text{Weight of wet soil (g)} - \text{weight of oven dried soil(g)}}{\text{Weight of oven dried soil (g)}} \times 100 \ldots \quad (1)$$

Bulk density

Bulk density of the soil was determined using a bulk density kit. A core sampler having 50 mm diameter and

100 mm length, marked at each 10 mm interval along its length, was used for taking a soil sample. It was initially inserted into the soil up to 50 mm, and the soil collected was removed immediately as the first sample. The sampler was again inserted in the soil at the same location up to 100 mm depth so as to collect the soil from next 50 mm depth.

Soil samples were collected from three different locations of the soil bin. The samples were weighed, and then kept in an oven at 105±5 °C for 24 hours. The weight of dry soil was recorded, and bulk density (dry weight basis) was calculated by the following relationship:

$$B.D. = \frac{W_s}{V_c} \quad \ldots(2)$$

Where,

B.D. = Bulk density, kg.m^{-3}

W_s = Dry weight of soil sample, kg, and

Ve = Volume of core sampler, m^3.

Statistical Analysis and Selection of Optimum Operating Conditions

Experimental data was analysed using statistical package SAS 9.3 at 5 % level of significance by factorial RBD and Tukey's honest significant difference (HSD) test, a single-step multiple comparison procedure and statistical test. The test compared the difference between each pair of means with appropriate adjustment for the multiple testing. Simple two-way analysis of variance (ANOVA) was done for dependent variables, and p-value was used to analyse the effect of independent variables.

RESULTS AND DISCUSSION

Biometric Properties of Onion Seedling

Biometric properties of *Pusa Red*, *Sel-126* and *Pusa Ridhi* onion 50-, 60- and 70-day old seedlings, relevant to the development of onion seedling transplanting mechanisms, are given in Table 2. The weight of seedlings without de-topping ranged from 0.53 g to 3.05 g, while de-topped seedling weight ranged from 0.47 g to 1.68 g for the three cultivars. The bulb and collar diameter for all varieties ranged from 3.13 mm to 5.76 mm and 2.44 mm to 4.33 mm, respectively. The length of seedling varied from 144.8 mm to 346.5 mm, *Pusa Red* variety being taller than *Sel-126* and *Pusa Ridhi* varieties.

The holding mechanism and plug dimension were designed on the basis of seedling dimensions. The length of onion seedlings were too long to be handled with metering mechanism of a transplanter. Prior to transplanting operation, the top shoots of a seedling were required to be cut to enhance the fast development

Table 2. Biometric properties of onion seedlings at different age

Age of seedling, Days	Weight without de-topping, g	Weight with de-topping, g	Bulb diameter, mm	Collar diameter, mm	Length, mm	Compressive strength of bulb, N	Compressive strength of collar, N
Pusa Red							
50	0.57 ± 0.16	0.47 ± 0.13	3.13 ± 0.4	2.44 ± 0.38	176.5 ± 1.35	10.65 ± 1.61	4.38 ± 0.87
60	2.49 ± 0.46	1.35 ± 0.19	4.88 ± 0.4	3.78 ± 0.37	320.4 ± 3.17	15.93 ± 2.17	6.75 ± 1.54
70	3.05 ± 0.55	1.68 ± 0.29	5.76 ± 0.56	4.33 ± 0.41	346.5 ± 3.88	18.53 ± 3.47	7.80 ± 1.45
Sel. 126							
50	0.61 ± 0.20	0.54 ± 0.15	4.07 ± 0.62	2.96 ± 0.57	152.7 ± 2.09	10.88 ± 1.46	4.93 ± 0.63
60	1.21 ± 0.27	0.98 ± 0.11	4.86 ± 0.49	3.30 ± 0.34	196.4 ± 4.51	15.24 ± 2.18	7.10 ± 1.13
70	1.37 ± 0.21	1.12 ± 0.11	5.35 ± 0.69	3.54 ± 0.31	215.8 ± 3.07	19.54 ± 2.09	8.17 ± 1.54
Pusa Riddhi							
50	0.53 ± 0.19	0.49 ± 0.16	4.31± 0.21	2.73 ± 0.61	144.8 ± 2.16	9.76 ± 1.57	4.08 ± 0.75
60	1.07 ± 0.20	0.86 ± 0.21	4.74 ± 1.15	3.45 ± 0.38	182.7 ± 2.06	14.77 ± 1.26	6.28 ± 0.61
70	1.35 ± 0.44	1.05 ± 0.30	5.48 ± 0.97	3.59 ± 0.42	194.5 ± 3.71	18.69 ± 1.43	7.98 ± 1.21

of shoots as also for easy handling and transplanting by the metering mechanism. The uniform length obtained after de-topping would enhance the machine performance.

The average coefficient of static friction for mild steel (MS), aluminium and galvanized iron (GI) varied from 0.63 to 0.79. The compressive strength of bulb and stem of seedling were 9.76 N to 19.54 N for bulb, and 4.08 N to 8.17 N for stem for 50- to 70-day old seedling. Compressive strength of onion seedling thus increased with increase in age of seedling. Seedling of 60- and 70-day age had higher compressive strength, and hence was more suitable for handling and transportation, uprooting from nursery, holding and dropping in the machine and also for soil covering and compaction with press wheels.

Soil Bin Testing

The mean values of different performance parameters as plant spacing, planting depth, percent seedling transplanted, furrow closure, filling efficiency and percent seedling damage for different factorial combinations of age of seedlings, speed of operation, height of dropping and finger-type for both metering mechanisms are given in Table 3 and 5.

Effect of forward speed and seedlings age on transplanting mechanism

Plant spacing

The forward speed of travel of both mechanisms significantly affected plant spacing as evident from the p-values (Table 4, 6). With increased speeds from 0.48 $km.h^{-1}$ to 1.25 $km.h^{-1}$, plant spacing increased from 126.4 mm to 130.6 mm and 170.8 mm to 190.3 mm for plug- and finger-type mechanism, respectively, for seedlings of all ages (Table 3 and 5).

The increase in plant spacing with forward speed might be due to forward movement of the rolling press wheels, which displaced a seedling from its actual transplanted position. Turbatmath (2010) also observed enhanced plant spacing from 102.8 mm to 153.3 mm in plug-type mechanism and 163.3 mm to 193.8 mm in finger-type mechanism with increase in forward speed from 0.75 $km.h^{-1}$ to 1.25 $km.h^{-1}$.

The change of drop height in plug mechanism also had marked effect on plant spacing. Plant spacing increased from 127.5 mm to 128.9 mm with rise in seedling drop

Table 3. Mean values of different performance parameters and pair-wise comparisons of factor levels for plug-type metering mechanism

Response	Mean				
	Plant spacing, mm	Planting depth, mm	Seedling transplanted, %	Furrow closure, %	Plant damage, %
A_1 (50)	129.5^A	23.3^A	91.9^A	87.8^B	11.4^A
A_2 (60)	129.2^{AB}	23.7^A	92.8^A	90.6^{AB}	6.2^B
A_3 (70)	125.8^A	24.8^A	93.3^A	91.7^A	4.7^B
SE	0.099	0.043	0.008	0.010	0.011
LSD	0.284	0.125	0.024	0.028	0.033
S_1 (0.48)	126.4^A	23.9^A	95.6^A	93.3^A	4.9^B
S_2 (0.67)	127.6^{AB}	23.5^A	96.9^A	94.7^A	7.3^{AB}
S_3 (1.25)	130.6^A	24.3^A	85.6^B	81.9^B	10.1^A
SE	0.099	0.043	0.008	0.010	0.011
LSD	0.284	0.125	0.024	0.028	0.027
H_1 (30)	127.5^A	21.5^B	90.6^B	87.2^B	8.2^A
H_2 (40)	128.9^A	26.3^A	94.8^A	92.8^A	6.7^A
SE	0.081	0.035	0.007	0.008	0.009
LSD	0.232	0.102	0.016	0.023	0.027

Note: A_1- 50 days, A_2- 60 days, A_3- 70 days; S_1- 0.48 $km.h^{-1}$, S_2- 0.67 $km.h^{-1}$, S_3- 1.25 $km.h^{-1}$; H_1=300 mm,H_2=400 mm
#Mean with same letter are not significantly different

Table 4. Effect of seedling and machine parameters on performance parameters of plug-type mechanism

Variable	Main effect (p-value)			Interaction effect (p-value)			
	A	H	S	AxH	AxS	H x S	AxHxS
Plant spacing	0.022*	0.244	0.014*	0.25	0.932	0.344	0.531
Planting depth	0.059	<.0001**	0.45	0	0.03*	0.451	0.108
Transplanted	0.499	<.0001**	<.0001**	0.097	0.117	0.499	0.157
Furrow closure	0.023*	<.0001**	<.0001**	0.285	0.223	0.785	0.337
Plant damage	0.001**	0.259	0.013*	0.028*	0.515	0.726	0.77

Note: A- Age, H- Drop height, S- Speed.
** Significant at 5% level of significance*

Table 5. Average values of different performance parameters and pair-wise comparisons of factor levels for finger-type mechanism

Response	Mean				
	Plant spacing, mm	Planting depth, mm	Seedling transplanted, %	Furrow closure, %	Plant damage, %
A_1 (50)	178.3 ^{A}	30.3 ^{A}	54.2 ^{A}	50.6 ^{A}	20.5 ^{A}
A_2 (60)	179.2 ^{A}	30.6 ^{A}	55.3 ^{A}	52.8 ^{A}	11.0 ^{B}
A_3 (70)	180.5 ^{A}	31.4 ^{A}	54.2 ^{A}	50.8 ^{A}	03.4 ^{C}
SE	0.180	0.044	0.013	0.012	0.021
LSD	0.517	0.127	0.037	0.035	0.060
S_1 (0.48)	170.8 ^{B}	31.3 ^{A}	73.6 ^{A}	70.6 ^{A}	10.0 ^{A}
S_2 (0.67)	177.0 ^{B}	31.6 ^{A}	67.8 ^{B}	65.3 ^{B}	12.7 ^{A}
S_3 (1.25)	190.3 ^{A}	29.4 ^{B}	22.2 ^{C}	18.3 ^{C}	12.2 ^{A}
SE	0.180	0.044	0.013	0.012	0.021
LSD	0.517	0.127	0.037	0.035	0.060
F_1 (Al)	177.5 ^{A}	31.2 ^{A}	54.8 ^{A}	50.9 ^{A}	11.0 ^{A}
F_2 (GI)	181.1 ^{A}	30.4 ^{A}	54.3 ^{A}	51.9 ^{A}	12.2 ^{A}
SE	0.147	0.036	0.011	0.010	0.017
LSD	0.422	0.104	0.030	0.029	0.049

Note: A_1- 50 days, A_2- 60 days, A_3- 70 days; S_1- 0.48 km.h^{-1}, S_2- 0.67 km.h^{-1}, S_3- 1.25 km.h^{-1}; F_1- Aluminium, F_2– Galvanised iron
#Mean with same letter are not significantly different

Table 6. Effect of seedling and machine parameters on performance parameters of finger-type mechanism

Variable	Main effect (p-value)			Interaction effect (p-value)			
	A	F	S	A x F	A x S	F x S	A x F x S
Plant spacing	0.686	0.095	<.0001**	0.802	0.344	0.434	0.871
Planting depth	0.208	0.144	0.003**	0.014*	0.6	0.802	0.697
Transplanted	0.784	0.713	<.0001**	1	0.96	0.075	0.296
Furrow closure	0.392	0.52	<.0001**	0.727	0.856	0.334	0.305
Percent damage	<.0001**	0.627	0.631	0.692	0.208	0.702	0.358

Note: A :Age, F: Finger material, S: Speed
** Significant at 5% level of significance*

height from 300 mm to 400 mm (Table 3). The increase in spacing was due to increase in travel time of seedling from the delivery point to the bottom surface of furrow. Fingers carried the seedlings in furrow, and thus age of seedling did not have any effect on plant spacing unlike in gravity fed plug mechanism. However, the position of seedling in a finger with respect to the finger groove might increase or decrease plant spacing accordingly, as seedling might have been released in the furrow before or after the delivery point.

Planting depth

The planting depth was adjusted by maintaining the soil working element of furrow opener at a constant depth below the soil surface with the help of height adjusting screw on the carriage of soil bin. It was observed that the depth of planting in both plug and finger mechanism did not depend on the forward speed and the age of seedling. Although the depth of planting was independent of seedling and machine parameters, the height of seedling drop in plug mechanism significantly affected the depth of planting as evident from p-value (Table 4). There was significant increase in depth of planting from 21.5 mm to 26.3 mm as the height of seedling drop increased from 300 mm to 400 mm in plug mechanism. Turbatmath (2010) also reported planting depth of 15.8 mm to 23.9 mm between forward speed of 0.75 $km.h^{-1}$ and 1.25 $km.h^{-1}$ for VI, VII and VIII week onion seedlings in case of plug-type semi-automatic transplanting mechanism, which was closer to the recommended planting depth of 20-25 mm.

Percent seedling transplanted

To achieve higher field capacity, it is desirable to transplant at higher forward speeds, provided manual feeding of seedlings is not a limitation. The forward speed of operation in both plug and finger mechanisms had significant effect (Table 4,6) on percent seedling transplanted. The percent transplanted was 95.6 % and 96.9 % for plug, while it was 73.6 % and 67.8 % for finger mechanism at 0.48 $km.h^{-1}$ and 0.67 $km.h^{-1}$, respectively (Table 3, 5). As the forward speed increased to 1.25 $km.h^{-1}$, the average percent of seedlings transplanted decreased to 85.6 % and 22.2 %, for plug and finger mechanisms, respectively. At forward speed of 1.25 $km.h^{-1}$, some seedlings in plug-type mechanism got obstructed by the previous seedling due to insufficient opportunity time to get into the furrow. On the other hand, there was more chance of seedlings getting trapped in the finger itself in finger mechanism due to quick opening and closing of a finger at higher speed. Gaikwad (2010) also reported an increased number of unsuccessful transplanted seedlings at higher forward speed (2.5 $km.h^{-1}$) due to increased inclination of seedlings from the vertical in case of close spaced seedlings.

Percent of seedling transplanted was independent of the age of seedlings for both plug and finger mechanism (Table 4, 6). However, drop height had prominent effect on percent seedling transplanted. It was higher (94.8 %) at 400 mm drop height than 90.6 % at 300 mm (Table 3). With increase in drop height, successive seedlings got enough time to travel through the funnel, resulting in appropriate placement of seedling in the furrow slit.

Percent furrow closure

The forward speed of transplanting had prominent effect on proper furrow closure. At 0.48 $km.h^{-1}$ and 0.67 $km.h^{-1}$ forward speeds, the percent furrow closure was 93.3 % and 94.7 % for plug while it was 70.6 % and 65.3 % for finger mechanism, respectively. As the forward speed increased to 1.25 $km.h^{-1}$, proper furrow closure decreased to 81.9 % and 18.3 % for plug and finger mechanisms, respectively (Table 3, 5). With increased speed, the inclination of transplanted seedlings in the direction of travel increased causing retention of some part of the bulb and root outside the soil surface, thereby leading to lower values of furrow closure (Fig. 7). This also attributed to the higher forward force imparted to the seedling and soil by rolling press wheels at higher speeds. Gaikwad (2010) reported increased number of unsuccessful transplanted seedlings due to improper furrow closure at higher speed of travel of 2.5 $km.h^{-1}$.

In plug mechanism, the age of seedling also significantly affected the extent of furrow closure because 50-day old younger seedlings being lighter could not stand upright when dropped into the furrow. The speed of

Fig. 7: Improper furrow closure

transplanting, age of seedling and height of seedling drop significantly affected the furrow closure (Table 4). Furrow closure was unaffected by the age of seedling with finger mechanism, because seedlings were released in furrow slit by the finger itself in definite position irrespective of size and weight of seedlings.

Filling efficiency

During soil bin testing of the mechanisms, the operator sitting on the carriage held about 20 seedlings in his hand and filled each plug/finger one by one. The percent plug/finger filling efficiency was considerably affected by the forward speed of travel due to feeding limitations of the operator. With increase in forward speed from 0.48 $km.h^{-1}$ to 1.25 $km.h^{-1}$, plant filling efficiency decreased from 96.67 % to 32.22 % (Fig. 8) in plug mechanism, and 95.28 % to 22.5 % (Fig. 9) in finger mechanism. At 0.67 $km.h^{-1}$ forward speed, the efficiency was 92.22 % in plug mechanism and 87.33 % in finger mechanism (Fig. 8, 9). At higher forward speed, the operator was unable to synchronize between isolation of individual seedling from the bunch of seedlings in hand and the speed of metering mechanism. With increase in forward speed, some seedlings got stuck in the plugs and the fingers due to smaller operating time intervals of successive plugs and fingers. Hand feeding rates are limited to about 60-90 seedlings per row per minute (Brewer, 1997). Splinter and Suggs (1959) found that two operators feeding a single row transplanter achieved 90 tobacco seedlings per minute. Suggs (1979) found that one operator could plant 79.2 tobacco plants per minute with missing of 2.3 % in a conventional transplanter with single loading finger. Kavitha *et al*. (2007) also reported that an increase in percent plant missing from 0 % to 12.33 % with increase in speed of operation from 0.6 $km.h^{-1}$ to 1.8 $km.h^{-1}$ in plug-type metering mechanism developed for wide-spaced crops like brinjal, chilli and tomato.

Filling efficiency was also influenced by the age of seedlings. Seedlings of age 50 days showed lower filling efficiency (71.39 % in plug and 65.55 % in finger mechanism) as compared to 60-day and 70-day old seedlings (Fig. 10, 11). Being strong, resilient and erect, older seedlings could easily be separated from cluster of seedlings by hand as compared to 50-day old young fragile and damage prone seedlings.

Percent damage

Percent plant damage was dependent upon the age

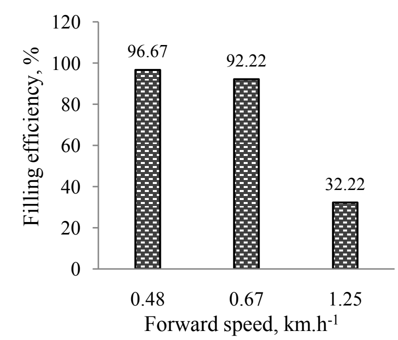


Fig. 8: Effect of forward speed on filling efficiency in plug type mechanism

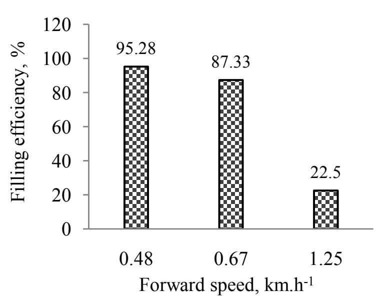


Fig. 9: Effect of forward speed on filling efficiency in finger type mechanism

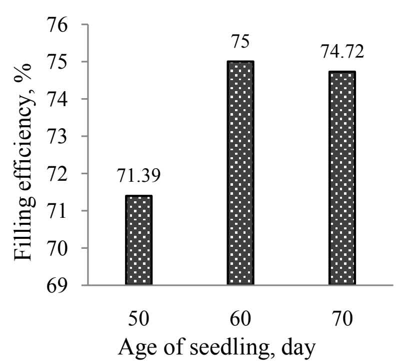


Fig. 10: Effect of age of seedling on filling efficiency in plug type mechanism

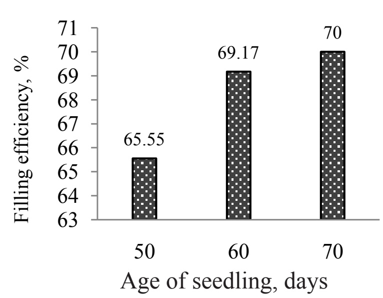


Fig. 11: Effect of age of seedling on filling efficiency in finger type mechanism

of seedlings in both finger and plug mechanisms. The damage decreased from 11.4 % to 4.7 % in plug mechanism (Table 3), and from 20.5 % to 3.4 % in finger mechanism with increase in seedling age from 50-day to 70-day (Table 5). The 50-day seedlings were delicate and tender, and thus more prone to damage as compared to robust 60- and 70-day old seedlings. It was difficult to separate 50-day old seedlings from a bunch/cluster, and they often got damaged before feeding. Plug opening point and press wheels were other locations where some seedlings got damaged.

There was chance of seedling damage by the fingers of operator in finger mechanism when the operator could not place the seedlings in the specially designed long groove to house seedlings. Older seedlings of 60- and 70-day could bear the load of press wheels, compressive force of plug lids and compressive gripping force of finger that was not in the case of younger seedlings. With increase in speed of operation, percentage plant damage increased significantly from 4.9 % to 10.1 % in plug mechanism (Table 3) and 10.0 % to 12.7 % (Table 5) in finger mechanism (Table 4, 6).

Comparison of Performance of Plug and Finger-Type Mechanism

The plant spacing in plug metering mechanism ranged between 121.4-133.5 mm, closer to the recommended plant spacing of 100 mm (Anon.,2018)as compared to 167.9 – 195.0 mm in finger metering mechanism. This was because of the reason that at the same forward speed, the operator took more time to feed seedling at the appropriate position in finger-type metering mechanism. It was difficult to synchronize the feeding operation with the speed of the mechanism. In plug-type mechanism, it took relatively less time to isolate and feed seedlings in an individual plug as the operator had to drop the seedling in the plug opening, and thus more feeding tubes per unit time could be fed. In order to increase the filling efficiency and minimizing the missing percentage at same forward speed, finger-type metering mechanism had to operate at lower speed ratios and with more finger spacing than plug mechanism and resulting in higher spacing. In plug-type mechanism, thin and younger seedlings could also be transplanted successfully without much damage. Finger mechanism performed better only with thick and strong older seedlings, as damaged thin seedlings resulted in lower transplanting rates.

The percent seedling transplanted and furrow closure was higher in plug-type metering mechanism than the finger mechanism. The percent plant missing was also within the permissible limit of 5 % (Mori, 1975), and with higher filling efficiency of 76.67 – 100 % in plug mechanism as seedling feeding was easier as compared to finger-type mechanism. The operator on a plug-type mechanism had an additional advantage of feeding plug assembly before start of operation, which was not possible in finger-type mechanism. Percent seedling damage with use of plug mechanism ranged from 0 – 17.54 %, lower than 0 - 31.05 % with finger metering mechanism. Seedling came into contact with only the moving press wheel of plug-type metering mechanism where chance of seedling damage was higher. Thin younger seedling might get damaged in finger mechanism due to excessive gripping pressure exerted by the fingers during its passage through finger guide, and also during furrow closure by the press wheel. It is evident from the above that the performance of plug-type metering mechanism was superior to finger-type metering mechanism with respect to plant spacing, planting depth, percent seedling transplanted, and percent proper furrow closure, filling efficiency and percent seedling damage. Therefore, plug-type metering mechanism can be used for onion seedling transplanter.

Selection of Operating Parameters

Preceding sections indicated that the plug-type metering mechanism showed better performance than the finger-type mechanism. Fine and levelled seedbed with optimum moisture content is needed for desirable performance of plug metering mechanism. Secondary tillage operations and levelling of seedbed should be done before transplanting. It was evident from the results that the performance of plug-type metering mechanism was superior for 60- and 70-day old seedling with respect to all parameters under investigation. However, 70-day old seedling is old for transplanting, and may reduce the bulb size and the yield. Thus, 60-day seedling, which is in the range of the recommended seedling age of 56-63 days for late *kharif* and *rabi* crop (Anon., 2018), could be recommended for transplanting with plug mechanism to minimize the seedling mortality and improved transplanting efficiency. It is recommended to provide a seedling drop height of 400 mm from the delivery end of the machine to the bottom of the furrow for highest percentage of seedling transplanted (94.8%) with minimum plant damage (6.7%) than at 300 mm dropping height.

Average seedling feed rate for manually fed transplanters are 50 seedling.min^{-1}, which translates to maximum forward speed of 0.1 m.s^{-1} (0.36 km.h^{-1}) for closed spaced (100 mm to 120 mm plant spacing) onion crop. If an operator is properly trained in feeding of seedlings, higher feed rate of more than 60 seedling. min^{-1} could be achieved. A machine could then be operated at a forward speed of 0.6 km.h^{-1}. In the soil bin study, the performance of plug metering mechanism was better at both 0.48 km.h^{-1} and 0.67 km.h^{-1} forward speed in terms of percent seedling transplanted, furrow closure, filling efficiency and percent damage. Machine operation at high forward speed is desirable to gain economic advantage of mechanical transplanting over manual transplanting, provided percent plant missing is minimized. Therefore, optimum combination for achieving maximum successful onion seedling transplanting would be with a plug-type machine configuration operated at forward speed of 0.67 km.h^{-1} using 60-day old onion seedlings with 400 mm drop height in soil with moisture content of 9-16 % (d.b.) and soil bulk density of 1100 - 1450 kg.m^{-3} (d.b.).

CONCLUSIONS

Onion seedling of 50- and 60-day age was found suitable for transplanting with plug-type mechanism. Seedling of 60- and 70-day old was suitable for finger-type mechanism due to higher seedling compressive strength and dimensions of bulb and collar, resulting in less damage. Plug-type metering mechanism was found to be more suitable over finger mechanism due to its ease of seedling feeding, desirable plant spacing, and higher transplanting efficiency, proper furrow closure and less seedling damage. Both plug-type and finger-type mechanisms gave better performance at travel speed of 0.48 km.h^{-1} and 0.67 km.h^{-1} than at 1.25 km.h^{-1}. Plug-type transplanting mechanism with chisel-type furrow opener and press wheel furrow closing-cum-compaction device gave higher percent of seedling transplanted with proper furrow closure and less seedling damage in sandy loam soil.

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