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Design and Development of a Seed Metering Mechanism for Ginger Planter

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Manual ginger planting is a tedious, drudgery-prone, and time-consuming operation, due to the constant bending posture during planting. To address this issue, a seed metering mechanism was developed and evaluated at the ICAR-Central Institute of Agricultural Engineering, Bhopal. The metering mechanism consisted of a vertical rotating disc, fingers, lever and cam, seed hopper, agitator, and rhizome delivery system. The laboratory study was conducted using a sticky belt set up to determine the seed distribution pattern at different forward speeds (0.42 m/s, 0.56 m/s, 0.69 m/s, and 0.83 m/s), rhizome sizes viz. small (< 35 mm), medium (35–50 mm), and large (> 50 mm), and types of pickup fingers (P_1 and P_2). The factorial CRD design with three replications for each variable was used in the laboratory experiment. The performance parameters were measured, including average spacing, missing index, multiple index, quality of feed index and visible damage. The result revealed that speed of operation, seed size and finger type had statistically significant effects on the average seed spacing. As the speed of operation and seed size increased, the multiple index and Quality of Feed Index (QFI) decreased, while the missing index and damage percentage increased for both types of fingers. The main factor significantly influencing the performance indices was the speed of operation. The highest QFI of 77.14% was observed at the forward speed of 0.56 m/s for P_2 fingers. The lower values of miss index, multiple index, and visible damage were observed with P_2 as compared to P_1. The visible damage was observed to increase at increasing speeds and seed sizes for both types of fingers. The performance of the metering system was found satisfactory with finger (P_2) at the optimum speed of 0.56 m/s for medium seed sizes. The automatic seed metering mechanism holds great potential for ginger planting to improve accuracy, efficiency, yields, and cost-effectiveness.

Keywords: Damage, Ginger, Mechanization, Quality of feed, Rhizome

Introduction

Ginger is an essential commercial crop in India. It is cultivated for its aromatic rhizomes and used as spices and medicine.[1] India, China, Japan, Nepal, Thailand, Indonesia, Nigeria, Bangladesh, and Cameroon collectively contribute to nearly half (approximately 50%) of global production. In addition to being the world's largest producer of ginger, India is also its largest consumer and exporter.[2] During the year 2018–19, ginger production in India was reported to be 1788 thousand metric tons, cultivated across 164 thousand hectares of land followed by China, Nigeria, Nepal, and Indonesia.[2] Indian production has been showing a steadily increasing trend due to the improvement in both area and productivity. The trends in ginger cultivation area, production, and productivity for ten years are presented in Fig. 1.[(3)] Madhya Pradesh, Karnataka, Assam, Maharashtra, and Gujarat states together accounted for more than 50% of the total production of ginger. During 2021–22 the highest production of ginger was recorded in Madhya Pradesh with 692.11 thousand tones (31.18%) of the total production followed by Karnataka and Assam (Table 1).[(4,5)] Ginger is propagated by rhizomes planted on ridge and furrow systems at a depth of 5 to 10 cm. The spacing between rows is typically 30 to 60 cm, while the spacing between individual plants is 20 to 30 cm.[6,7] The planting of ginger rhizomes is a tedious and time-consuming operation, particularly for small-scale farmers who may have limited access to labour and equipment during the peak season. This can make it difficult for farmers to plant ginger on time, which can affect the yield and quality. The scarcity of labour leads to higher cultivation costs, which will result in lower profits. Ginger-growing states experience labour shortages, during planting season as it coincides with field operations of *Kharif* crops. In general, the ginger rhizomes planted manually require 200–250 man-h/ha.[8,9] The conventional way of planting ginger seed rhizomes by the farmers involves soil digging, shallow furrow opening using a spade, placing the rhizome in the furrow opened, and afterward covering them with the soil.[8] In India, the lack of appropriate machines prevents the mechanization of

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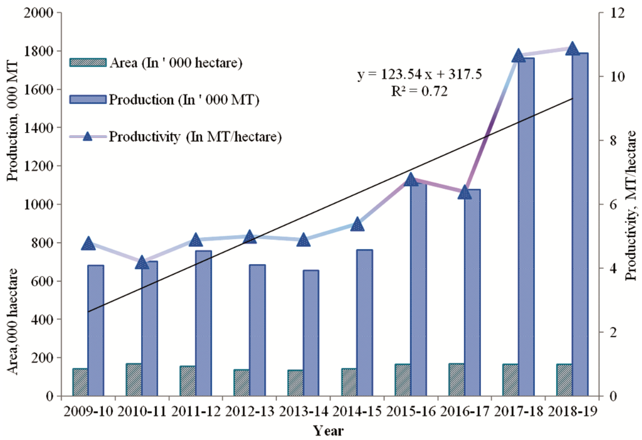


Fig. 1 — Graph showing the trend of ginger cultivation area, production and productivity in India

Table 1 — Indian production of ginger

Sl. No.	State	Production (000 Tonnes)	Share (%)
1.	Madhya Pradesh	692.11	31.18
2.	Karnataka	306.34	13.8
3.	Assam	170.73	7.69
4.	Maharashtra	164.23	7.40
5.	West Bengal	135.07	6.09
6.	Orissa	128.01	5.77
7.	Gujarat	109.12	4.92
8.	Sikkim	72.71	3.28
9.	Kerala	72.70	3.28
10.	Meghalaya	67.67	3.05
11.	Mizoram	60.83	2.74
12.	Manipur	51.91	2.34
13.	Nagaland	40.81	1.84
14.	Uttarakhand	39.02	1.76
15.	Arunachal Pradesh	30.9	1.39
16.	Tripura	16.16	0.73
17.	Telangana	15.46	0.70
18.	Himachal Pradesh	13.35	0.60
19.	Chattisgarh	9.79	0.44
20.	Tamil Nadu	7.38	0.33
21.	Uttar Pradesh	4.23	0.19
22.	Andhra Pradesh	3.82	0.17
23.	Bihar	3.13	0.14
24.	Haryana	2.51	0.11
25.	Others	1.10	0.05

Source: National Horticulture Board (NHB) 2021–22

ginger planting operations. Ginger sowing and planting using traditional methods is time-consuming, labor-intensive, low-productive, and inefficient from a health and economic perspective. Mechanical planting of ginger would significantly reduce the need for surplus labour and drudgery-related issues arising from the traditional method.[9] The seed metering mechanisms have been a crucial component in the in the advancement of modern agriculture. Advances in seed metering mechanisms have made it possible to plant crops more efficiently, accurately, and cost-effectively, which has helped to improve the productivity and sustainability of agriculture. Various types of seed metering mechanisms have been developed for small to medium size seeds but rare of them are for seed rhizomes. Several seed metering mechanisms designed for crops related to ginger have been evaluated, and reported that the quality of feed is higher when operating at a lower forward speed.[8,9] In some research studies, it was observed that the missing and damage increased as the speed of the metering system was increased.[8–10] Overall literature reveals that the development of a seed metering system for the precise planting of ginger is an significant advancement in agricultural technology. A very limited amount of research has been done on ginger rhizome metering mechanisms. The development of a semi-automatic metering mechanism is a step in the right direction, but an automatic seed metering mechanism would offer a higher level of efficiency and reliability in the mechanization of ginger planting. The development of an automatic metering mechanism for ginger rhizomes is particularly important because of the unique properties of this crop. Ginger rhizomes are irregularly shaped and vary in size, making it difficult to achieve uniform plant spacing and planting depth using existing metering mechanisms. Therefore, an automatic seed metering mechanism was designed and developed at the ICAR-CIAE, Bhopal for the planting of ginger rhizomes. This metering mechanism holds significant importance and offers substantial benefits to farmers because it reduces the time and manpower required for planting operations, leading to better yields and reduced input costs.

Materials and Methods

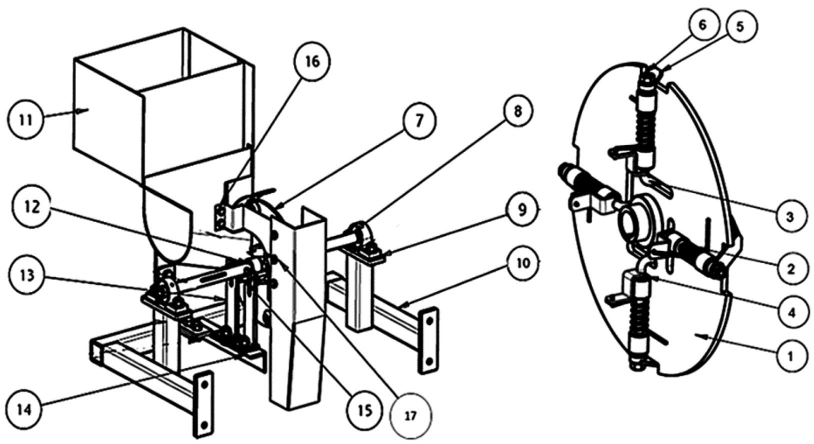
To address the ongoing challenges encountered by farmers during ginger planting, an automatic seed metering mechanism has been developed and evaluated. The prototype of this automatic metering mechanism was fabricated during 2017–18 at the research workshop of ICAR-Central Institute of Agricultural Engineering, Bhopal.

Design of Seed Metering Mechanism

The major engineering properties of ginger seed rhizomes (Variety–*Suprabha*) were determined which play a significant role in the design of a seed metering mechanism. The metering mechanism was designed

Table 2 — Engineering properties of ginger seed rhizomes (Variety – *Suprabha*)

Sl No.	Properties	Max	Min	Mean	SD	CV, %
1	Length, mm	74.24	25.00	46.67	13.16	31.48
2	Width, mm	56.00	20.50	31.30	9.61	30.72
3	Thickness, mm	36.00	10.40	18.20	3.72	20.46
4	Geometric Mean, mm	50.32	14.02	29.54	7.14	24.18
5	Surface area, mm^2	7950	617	2899	1431	49.36
6	Shape index	3560	154.9	414.2	275.9	66.61
7	Weight,g	38.60	10.00	15.77	8.85	64.28
8	Bulk Density, g/cm^3	0.64	0.59	0.61	0.03	6.55
9	Coefficient of friction, μ	0.70	0.55	0.62	0.07	11.29
10	Angle of repose, degree	42.00	24.00	34.00	4.00	11.76



1. Metering disc plate 2. Torsion spring 3. Pickup-finger lever 4. Pivoted washer 5. Pickup-finger 6. Hexagonal nut 7. Metering disc assembly 8. Bearing block 9. Nut and bolt 10. Main frame 11. Seed hopper 12. Main shaft 13. Cam assembly 14. Cam support 15. Cam 16. Plastic brush 17. Seed delivery tube

Fig. 2 — Schematic diagram of automatic ginger rhizome seed metering mechanism

by taking into consideration the major physical and mechanical properties of ginger rhizomes such as dimensions, coefficient of friction, angle of repose, bulk density, and weight (Table 2). Based on that design considerations were made for the development of the ginger rhizome metering mechanism as shown in Table 2.[11–13] The metering mechanism was designed using CAD software (Pro/ENGINEER), and the schematic diagram is depicted in Fig. 2.

Diameter of the Seed Metering Disc

The proper design of the seed metering disc holds utmost importance in determining the number of seed pickup fingers required to achieve the required seed spacing. Hence, seed metering disc's diameter was determined using the following equation.[14]

$$D_m = \frac{Vr}{\pi \times 1000 \times Nr}$$

where, D_m = metering disc diameter, mm V_r = Peripheral speed of the ground wheel, m/min
N_r = rpm of metering disc.

Hence, the metering disc was designed with dimensions of 300 mm in diameter.

Numbers of Pickup- Fingers on Seed Metering Disc

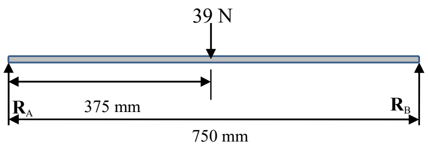
The number of pickup fingers for the seed metering disc is the function of the operational speed and the seed spacing. The numbers of pickup fingers on the seed metering disc were determined by following equation.[15]

$$\text{Number of seed pickup fingers} = \pi \times \frac{\text{Drive wheel diameter, mm}}{(\text{Plant spacing, mm} \times \text{Drive ratio})}$$

Diameter of Metering Shaft

The shaft of metering mechanism is subjected to combined bending and torsion moment

Torque transmitted by shaft, T = 9.81× 4 × 150 N-mm



$R_A + R_B = 39$ N
$R_A = 39/2 = 19.5$ N

Bending moment at centre point, $M_A = R_A \times 375$

For rotating shafts subjected to suddenly applied load with minor shocks. Assuming $K_m = 2$ and $K_t = 1.5$ and $\tau = 56$ MPa.[16]

Equivalent torque, $T_e = \sqrt{(Kt \times T)^2 + (Km \times M)^2}$

$Te = \frac{\pi}{16} \times \tau \times d^3$

Therefore, $d = 3\sqrt{\frac{Te \times 16}{\pi e56}}$ = 11.58 mm ≈ 20 mm (assumed factor of safety of 1.5)

Description of the Seed Metering Mechanism

The metering mechanism consisted of a frame, seed hopper, vertical rotating disc, pickup finger, finger lever with torsion spring, agitator, and seed delivery system (Fig. 2). The metering system was fitted on a frame using a combination of the shaft and ball bearings. The frame for the metering mechanism was fabricated from MS square pipe with dimensions of 50 × 50 × 5 mm. A seed metering disc with a diameter of 300 mm was fabricated using a 5 mm thick MS sheet. To drive the vertical rotating disc, the metering shaft was fabricated of 20 mm diameter. The four numbers of seed pickup finger and finger lever are fixed to the circular disc using nuts and bolts. Pickup fingers were fabricated using MS material and designed with two distinct cup shapes. The dimensions of these finger cups are presented in Fig. 3 The lever of pickup finger is made of MS rod and measures 141.5 mm in total length, with a 90° bend at 102.5 mm, and it is held in place by a holder. A torsion spring is mounted on the flat to maintain tension on the finger lever. The MS flat, which was 55 mm in length, 15 mm in width, and 3 mm in thickness, was affixed to the bottom side of the finger lever. The primary hopper was designed in a trapezoidal shape with an inclination angle of 42° to facilitate ease in the flow of the rhizome to the bottom of the secondary hopper. The seed hopper with a 10 kg capacity was fabricated using 1.6 mm thick MS sheet. A seed delivery system is made of an MS sheet having 455 mm height and 100 mm width and was used to deliver the rhizomes directly into the seed boot. To ensure the seed would fall straight into the boots without striking their inner surfaces, the width of the delivery tube was selected accordingly.

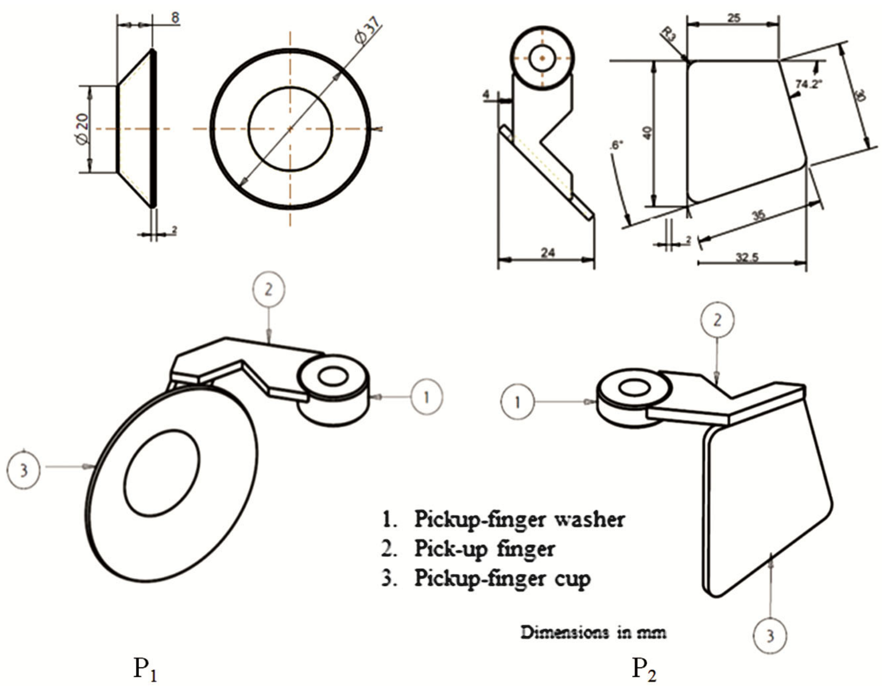


Fig. 3 — Schematic diagram of pickup-finger types used in the experiment

Working Principle of the Seed Metering Mechanism

The metering mechanisms are positioned beneath the seed hopper and operated by a ground wheel on the sticky belt test configuration, using a chain and sprocket system. Pickup fingers are positioned against the vertical rotating disc's periphery through a 50 × 19.5 mm cut, while the torsion spring-loaded finger lever is pressed against the other side of the disc. As the vertical disc rotates, the pickup fingers attached to the outer periphery of the vertical disc hold the ginger rhizome seed entering into the cup at the base of the seed hopper. This action is achieved through the action of the lever and the cam, facilitating the transfer of seeds out of the seed hopper. The rhizomes are hold by the fingers till the vertical rotation by 190° and the rhizomes get released into the seed boot from the finger again due to the action of the lever and cam. The finger lever is fixed to the torsion spring, which is under tension when touches the pin-position cam. As a result, ginger seeds drop into the furrow via the delivery system (Fig. 2). To make picking ginger rhizomes easier, the hopper has an agitator at the bottom for increasing flowability. Furthermore, a nylon plastic brush is used to remove the extra seeds picked up by the fingers.

Laboratory Evaluation of the Seed Metering Mechanism

A laboratory study was carried out to optimize the operational parameters of the ginger rhizome metering mechanism. A 10 m long rubber conveyor belt was operated at a forward speed ranging from 0.42 to 0.83 m/s by two rollers, each with a diameter of 300 mm, mounted on a stand. An advanced variable speed motor with a power of 5 kW was utilized to drive the two rollers. The grease was applied to the belt surface to hold the rhizomes in place and prevent bouncing or rolling. The ginger metering mechanism was affixed to the sticky belt setup using suitable accessories and fasteners. To position the metering mechanism on the belt, the drive wheel was placed on its surface and the metering disc was rotated (Fig. 4). A digital electronic tachometer was employed to measure the rotational speed accurately. The released rhizomes were deposited onto the greased belt, and the seed spacing distribution was measured using a measuring scale. The lab experiments were conducted, with two types of pickup-finger (round, P_1, and trapezoidal, P_2) as shown in Fig. 3, three levels of rhizome sizes (small < 35 mm, medium 35–50 mm, and large > 50 mm), and four levels of forward speeds (0.42, 0.56, 0.69, and 0.83 m/s). The experimental plan of the metering mechanism for laboratory study is presented in Table 3.

Miss Index: It is an indicator of how frequently seeds deviate from the intended spacing. It quantifies the percentage of instances where the spacing exceeds 1.5 times the desired spacing.[11, 17, 18]

$$M = n_3/ N$$

where,

N = Total number of observations

n_3 = Number of spacing in the area > 1.5 times of the desired spacing

Multiple Index: It signifies the occurrence of multiple seeds being placed within the intended spacing. It refers to spacing that is equal to or less than half of the desired seed spacing.[17,18]

$$D = n_1/N$$

Where,

N = Total number of observations

n_1 = Number of spacing in the area ≤ 0.5 times the desired seed spacing

Quality of Feed Index: It refers to the percentage of seed spacing that falls between half and 1.5 times the desired seed spacing.[11,17,18]

QFI = 1 − (Miss Index + Multiple Index)

Fig. 4 — Sticky- belt test setup for laboratory evaluations of metering mechanism

Table 3 — Experimental plan of metering mechanism for laboratory study

Independent Variable	Types of fingers	Size of seed, mm	Speed of operation, m/s
Level of variables	Pickup-finger (Round cup) = (P_1)	Small = (< 35 mm)	S_1 = (0.42 m/s)
	Pickup finger (Trapezoidal cup) = (P_2)	Medium = (35–50 mm)	S_2 = (0.56 m/s)
		Large = (>50 mm)	S_3 = (0.69 m/s)
			S_4 = (0.83 m/s)

Physical Damage: The metering mechanism is estimated to have caused a certain percentage of physical damage based on the visible damage observed after passing the rhizome seed through it. The rhizome dropped on the moving sticky belt was collected and examined for any visible seed damage. The physical damage to the ginger rhizome was determined by the following formula.[8,17]

$$\text{Physical damage, \%} = \frac{\text{Total number of ginger rhizome damaged}}{\text{Total number of ginger rhizome picked}} \times 100$$

Statistical Analysis

The statistical analysis was performed using SAS (9.3) software to assess the effect of independent variables on various performance indices, including average seed spacing, multiples index, miss index, quality of feed index (QFI), and physical damage. A total of 24 experiments were conducted in triplicate, employing a factorial Completely Randomized Design (CRD) to examine how independent variables influenced the performance of the metering system.

Results and Discussion

Effect of Independent Variables on Spacing

The seed spacing was measured at different forward speeds and rhizome seed sizes for both pickup fingers (P_1 and P_2) to determine the average spacing. Table 4 shows that the average spacing between the placements of rhizomes increased as the speed of the metering mechanism increased, but it remained close to the desired nominal seed spacing of 300 cm. The highest deviation from the average and coefficient of variation were observed for the P_1 finger, which was 7.06 and 17.88%, respectively. The corresponding values for P_2 fingers were found to be 6.18 cm and 17.51%, respectively. The results of the ANOVA analysis revealed significant variations in plant spacing concerning seed size and the speeds of both types of fingers (Table 5). Furthermore, it was observed that the deviation in average spacing increased as the speed of the metering mechanism

Table 4 — Average spacing of ginger seed rhizome during evaluation

Pickup-finger type	Size of seed	Forward speed, m/s	Av. spacing, cm	SD, cm	CV, %	Ratio of mean /nominal spacing
P_1	Small	S_1	31.65	3.14	9.93	1.06
		S_2	32.11	3.45	10.74	1.07
		S_3	33.29	3.83	11.52	1.11
		S_4	34.50	4.27	12.94	1.15
	Medium	S_1	32.63	3.04	9.31	1.09
		S_2	32.19	3.42	9.45	1.10
		S_3	33.55	3.96	11.79	1.12
		S_4	33.81	4.61	13.64	1.13
	Large	S_1	33.63	3.44	10.22	1.12
		S_2	34.33	3.95	11.50	1.14
		S_3	36.55	4.78	12.61	1.22
		S_4	39.47	7.06	17.88	1.25
P_2	Small	S_1	29.66	2.16	7.29	0.99
		S_2	31.97	3.04	9.51	1.07
		S_3	32.55	3.25	9.97	1.09
		S_4	33.14	3.75	10.81	1.10
	Medium	S_1	30.83	2.25	7.31	1.03
		S_2	31.11	2.92	9.37	1.04
		S_3	32.65	3.22	9.87	1.09
		S_4	33.96	3.98	11.73	1.13
	Large	S_1	31.11	2.94	9.25	1.04
		S_2	31.17	3.75	11.84	1.04
		S_3	33.17	4.79	14.64	1.11
		S_4	35.29	6.18	17.51	1.18

Table 5 — ANOVA for effect of independent variables on dependent variables

Source	DF	P-Value				
		Spacing	Miss	Multiple	QFI	Damage
Model	17	$<0.001^{**}$	$<.0001^{**}$	$<.0001^{**}$	$<.0001^{**}$	$<.0001^{**}$
Error	54	—	—	—	—	—
Corrected total	71	—	—	—	—	—
Type (A)	1	$<.0357^{*}$	$<.0001^{**}$	$<.0001^{**}$	$<.0001^{**}$	0.0447^{*}
Size (B)	2	$<.001^{**}$	$<.0001^{**}$	$<.0001^{**}$	0.0420^{*}	$<.0001^{**}$
Speed (C)	3	$<.0001^{**}$	$<.0001^{**}$	$<.0001^{**}$	0.0218^{*}	$<.0001^{**}$
A*B	2	0.529^{*}	0.903^{NS}	0.098^{NS}	0.189^{NS}	0.770^{NS}
A*C	3	0.491^{NS}	0.786^{NS}	0.617^{NS}	0.850^{NS}	0.290^{NS}
B*C	6	0.213^{NS}	0.605^{NS}	0.976^{NS}	0.994^{NS}	0.999^{NS}
CV	—	10.99	19.43	20.78	10.08	23.65
R^2	—	0.89	0.86	0.81	0.70	0.78
RMSE	—	3.62	0.029	0.050	0.041	2.15

CV = Coefficient of Variance, R^2 = Coefficient of Determination, , RMSE = Root Mean Square error ** = Significance ($p \leq 0.01$), * = Significance ($p \leq 0.05$) and ^{NS} = Non- Significance

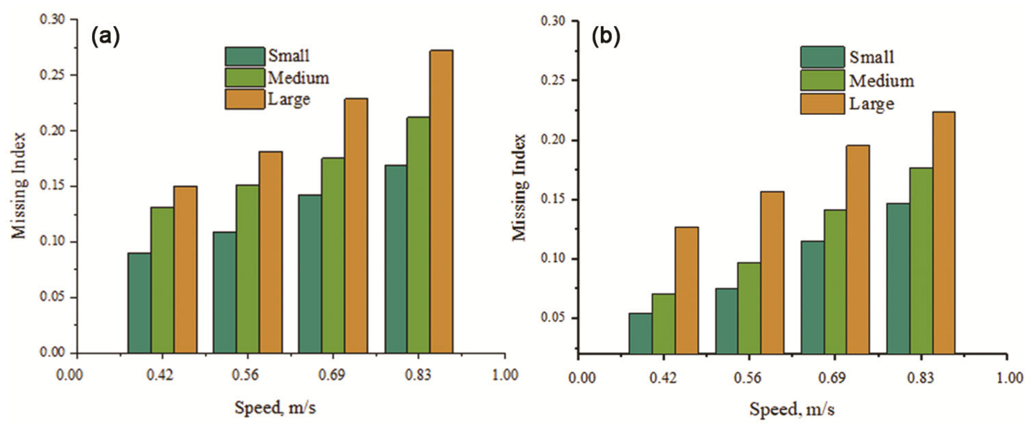


Fig. 5 — Effect of speed and seed size on missing index for P_1 and P_2 fingers

increased. This may be due to irregular seed sizes, wheel slippage, and finger vibrations during rhizome release. Additionally, the coefficient of variance (CV) was observed to increase with the size of seed and forward speed of the metering mechanism. The results are similar to the metering mechanisms that have been reported previously.[17,18]

Effect of Independent Variables on Miss Index

The missing is the term used to describe a rhizome that is not picked up by the metering system and delivered into the furrow through the delivery system. The lower missing index values indicate a more efficient metering system.The results presented in Fig. 5 indicate that the average missing index values increased as the forward speed and seed size increased for both types of fingers. The irregular shape of rhizome picking fingers during the operation of the metering mechanism may cause these missing. Improper gripping of the rhizome between fingers while picking up from the hopper may also contribute to this issue. The higher missing index values observed at higher speeds for large-size rhizomes might be due to the shorter exposure period of opening fingers while picking up the rhizome. Forward speed and seed size have a significant effect on the missing index at a 1% level of significance, but their interaction has no significant effect on either type of finger (Table 5). The overall average value of the missing index for small and medium-sized rhizomes was less than that of large-sized rhizomes. This indicates that more variation occurred for large rhizomes due to their non-uniform shape and potential disturbance in the picking and dropping process compared to small-sized rhizomes. The average missing index increased at higher operational speeds, ranging from 0.05 to 0.28 for large-sized rhizomes at an operational speed of 0.43 to 0.83 m/s. The

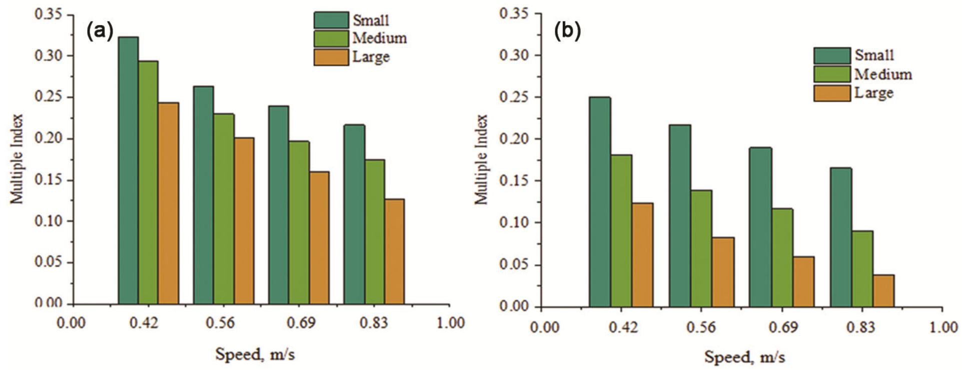


Fig. 6 — Effect of speed and seed size on multiple index for P_1 and P_2 finger

variation of the missing index with increasing forward speed is depicted in Fig. 5. An increase in ginger rhizome size and forward speed correlates with an increase in the missing index for both types of fingers. The highest missing index of 0.28 and 0.23 was recorded for large-sized ginger rhizomes at the forward speed of 0.83 m/s, while the lowest ginger rhizome missing index of 0.05 and 0.09 was obtained for small rhizome size at the speed of 0.56 m/s for P_1 and P_2 fingers, respectively. This is due to the smaller rhizomes have a tendency to fall out more readily compared to larger ones. These results align with findings from other studies.[19,20]

Effect of Independent Variables on Multiple Index

The occurrence of multiples refers to the situation where the metering mechanism delivers more than one rhizome seed due to its small size and irregular shape. The multiples index of ginger rhizome for all seed sizes and forward speeds of the metering mechanism were measured, and the results are shown in Fig. 6 for both types of fingers. It can be observed from Fig. 6 that the multiple index decreased as the forward speed of the metering unit increased for both types of fingers. This suggests that the percentage of multiples decreased with an increase in the forward speed. The possible reason for this could be the irregular shape and size of the seed and less time to grip multiple seed of fingers from the hopper of the metering unit. These findings align with results reported in previous studies.[17,21,22] In addition, the study revealed that larger rhizome sizes had lower values of multiple index compared to smaller sizes. The finger type, forward speed, and rhizome size had a significant effect on the multiple index at a 1% level of significance, whereas their interaction effect was not found to be significant (Table 5). The average multiple index was higher at lower operational speeds, ranging from 0.04 to 32%, with the lowest value obtained at an operational speed of 0.83 m/s for large-sized seeds. Overall, the multiple index was within acceptable limit with P_2 fingers compared to P_1 fingers at a speed of 0.56 m/s.

Effect of Independent Variables on QFI

In general, a higher QFI value indicates better functioning of the metering mechanism by measuring how closely the spacing matches the theoretical spacing. The findings indicated that the average value of QFI was significantly affected by the type of finger, seed size and speed of the metering mechanism (Table 5). The speed of operation and rhizome size had a significant effect on the QFI at a 5% significance level while finger type at a 1% significance level. Furthermore, the combined effect of independent parameters had a non-significant effect on QFI. Moreover, the highest QFI values were recorded for the forward speed of 0.56 m/s with medium-size seeds (Fig. 7), which aligns with findings from previous research studies.[22–24] The mean QFI was higher at 0.56 m/s operational speed for both types of fingers. It ranges between 53.5 to 77.4% for both types of fingers. The maximum value was obtained at an operating speed of 0.56 m/s for medium-sized rhizomes with P_2 pickup finger. This could be attributed to the fact that the fingers of the metering mechanism are provided with an optimal amount of time for picking up the seed rhizomes, and vice versa.

Effect of Independent Variables on Physical Damage

The physical damage of ginger rhizomes commonly occurred during seed metering due to the presence of mechanical devices. Visible damage to the ginger rhizome might be occurring due to frictional force caused by the relatively moving part

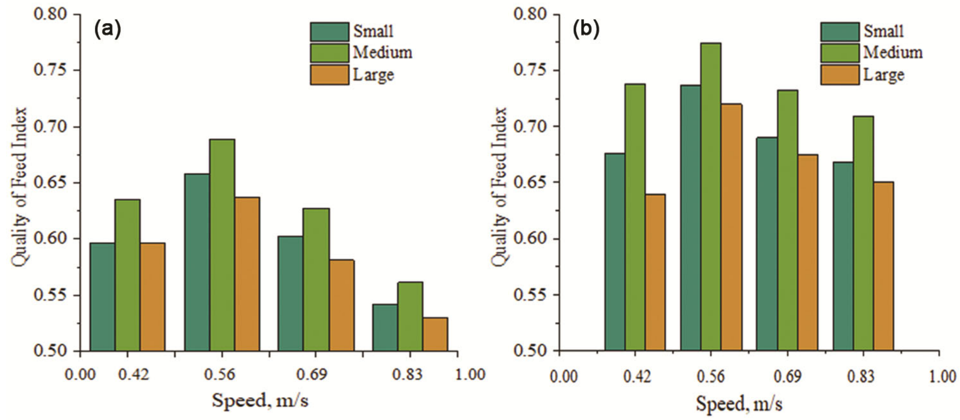


Fig. 7 — Effect of speed and seed size on QFI for P_1 and P_2 fingers

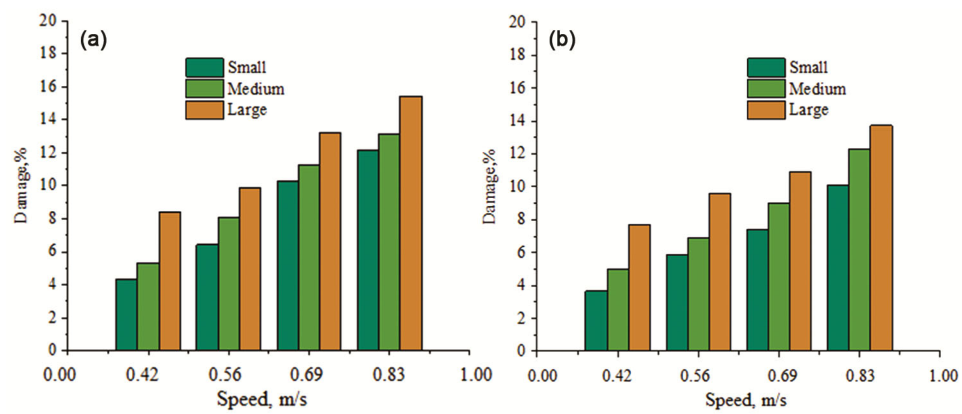


Fig. 8 — Effect of speed and seed size on damage for P_1 and P_2 fingers

of the metering mechanism. However, the damage to the rhizome was within limits. The speed of operation and rhizome size had a significant effect on the QFI at a 1% level of significance while finger type at 5% level of significance (Table 5). As shown in Fig. 8 the percentage of physical damage was increased with an increase in seed size and speed. The damage with the P_1 finger varied from 4.3 to 15.4 %, whereas for the P_2 finger, it was between 3.6 to 13.7 %. The percent of physical damage was generally higher for the P_1 finger than for the P_2 finger, possibly due to the irregular shape of the rhizomes, and the way the finger cups picked them up, resulting in higher mechanical injury as they passed through the metering mechanism. These findings are consistent with those reported by other studies.[18]

Conclusions

Based on the experimental findings it can be concluded that the speed of operation and the size of rhizome seeds significantly influence the missing index, multiple index, QFI, and physical damage. The average spacing of rhizome placement was observed to increase with the increased speed of operation, while the QFI decreased as misses and accumulations increased for both pickup fingers. Considering the irregular shape and the higher degree of variability in the size of seeds, the performance of the P_2 finger was found to be satisfactory for medium-sized ginger rhizomes at the forward speed of 0.56 m/s under laboratory conditions. However, to ensure its effectiveness under field conditions, further minor design refinements in the hopper and finger may be required to improve its performance. The developed mechanism holds significant potential for advancing the mechanization of ginger planting operations in regions where ginger cultivation is prevalent.

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Declaration of Competing Interest

The authors affirm that they do not have any known conflicts of interest or financial interests that might have influenced the research presented in this paper.

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