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An Evaluation of a Vacuum Distribution Device for Seed Pick-Up Regularity of A Multiple -Rows Pneumatic Plate

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Abstract: The aim of the study was to investigate the effect of an adjustable vacuum distribution device on seed pick-up similarity of a multiple-rows pneumatic plate metering device due to unequal rows performance. A completely vacuum opened angle of the device (30°), Six vacuum opening angles (5°, 10°, 15°, 20°, 25° and 30°) and different angles set up on rows (4°, 7°, 10° and 30° through row 1,2,3, and 4, respectively) were separately examined at six rotating speeds. Results revealed that under same speed and same vacuum opening angle, an increase in vacuum provided more consistent rows pick-up, while increase in angle increased rows pick-up coupled with the increase in their variation. Row1 and row4 generally tend to have the highest and lowest seed pick-up, respectively, under most of investigated angles and speeds. Rows consistency CV declined under the increase of both opening angle and velocity. Results of different rows angles set up were found to be better than those of the same angle. Different rows angles resulted in better rows CV value of 2.01%, 1.78%, 1.89%, 1.34%, 1.77% and 2.45% at speed of 5, 10,15,20,25 and 30 r.min-1, respectively. Results concluded that vacuum distribution device could be acceptably used for improving rows performance, but further studies are necessary to develop an outside-control method for easy application.

Keywords: Pneumatic Metering Device, Multi-Rows Plate, Vacuum Distribution Device.

1. Introduction

Crop productivity and production are considerably relying on the appropriate position that seed has been located. It is most important to place seeds at similar gap within the rows; whereas this will make plant roots grow to its normal and optimum size and increase yield by decreasing competition for water, light and essential nutrients [1,2]. A uniform distribution of seeds can not only provide an appropriate plant space but also offer regular root size, which definitely increases yield and reduce harvest losses [3]. Therefore, the function of any seeder is aimed to position the seed in it's a proper environment that could be easily germinated. There are a set of factors influencing plants distribution in the field. Among them, is the failure of the metering mechanism to pick or drop seeds which produce enormous missing and great spacing between grains, or may result in multiple seed pick-up and then narrow distance between cereals and crowded plants.

Among precision planters, vacuum types are the most preferable due to their observable advantages over mechanical types. They quietly meter seeds of different shape and size, accurate in seed rate with lower damage [4]. Additionally, precision planting decreases excessive use of seeds by reason of uniform distribution and avoid seed rolling in the furrow which results in a consistent distribution per unit length. They also provide homogeneous plants germination that makes easier to perform subsequent operations with lower cost [5]. Moreover, they work at high operating speeds [6].

A wide variety of measures have been formerly evolved to study seed drill performance with regard to seed spacing [7]. An adjustment of spacing between plants in a soil bin or in the field had been employed as a planter performance parameter [8]. The gap between plants within a row influences by some factors, such as failure of seed to be dropped, multiple seed drop at the same time, an inability of seeds to grow, and the position variability around dropping points [9]. Quality of feed index, multiple index, missing index, mean spacing and the coefficient of variation (CV) are considered to be the main five indices for seeding accuracy. Mean spacing influences by both seed density and intra-row distribution, while 20% CV was mentioned to be an acceptable seed precision achieved by mechanical and pneumatic type seeders when they appropriately operated [10]. Karayel mentioned that the optimal seeding quality was guaranteed when a precision planter was operated after preparing the soil with a suitable tillage implement. The operation resulted in a most consistent depth of seeding, better regular seed spacing, and higher seedling emergence. To find out the optimal vacuum value of a precision planter a mathematical model depending on seed physical properties was instituted [11]. The model was acceptably depicted vacuum pressure required by the planter with chi-square; root means square error and modeling efficiency of 2.51×10^{-3}, 2.74×10^{-2} and 0.99, respectively. [12] designed a multi-rows pneumatic plate for metering rapeseed. Through this endeavor they investigated the effect of metering plate speed, vacuum pressure and rows levels on device performance and developed a mathematical model for predicting of vacuum amount which matches the corresponding plate rotating speed. [13] simulated pressure contour and velocity of positive and negative pressure around metering nozzle of a pneumatic plate for precision rapeseed and matched the results with that attained at laboratory experiments. They built up mathematical models for independent pressure types at the nozzle air inlet and outlet. [14] inspected rapeseed metering process of a pneumatic cylinder-type centralized precision metering device. They analyzed the influence of operational and structural parameters on seed sucking, retaining and releasing operation. Extended Discrete Element Method (EDEM) software was used for simulating sucking process and estimated the positive and negative pressure values combined with the device structural parameters. A simulation of gas-solid flow in seed feeding operation of an air-assisted centralized metering unit was conducted by using Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD) methods. The trial investigated the impact of throat area and length, inlet velocity of airflow and seed feeding rate. Results illustrated that throat area and air velocity influenced the outlet of air and seed velocities, while throat length and feeding rate affected grain motion [6]. studied the impact of rotating speed, negative pressure and shape of nozzle entrance of a vacuum plate and assessed the precision indices (skip, multiple and quality of feed index) [15]. The operating parameters of a vacuum precision planter have been studied by Yazgi, specifically applied vacuum, nozzle diameter and the peripheral speed of the plate. In this trial, they involved response surface methodology (RSM) to examine seed distribution performance. Results disclosed that 5.5 kPa vacuum and of 3 mm nozzle diameter were the most appropriate values for consistent distribution of cotton seeds [16]. Seed spacing accuracy of a multi-rows pneumatic disk for precision rapeseed has been assessed. Results obtained scrutinized that quality feed index obtained was more than 89% while miss index was lower than 2% [17]. Dynamic analysis simulation on seed pick-up process of a pneumatic metering device has been conducted to show up the relationship between vacuum pressure and structural and operational parameters. A mathematical model was instituted for estimating the maximum vacuum amount and the pressure ratio coefficient (K) of the outlet and interface was also studied. The impact of the coefficient (K) had been examined through vacuum current simulation using ANSYS/CFX [18]. studied the results of seed distribution in the field and laboratory for five sowing machines at three operating speeds [1]. They utilized the seed location method which involved an opto-electronic sensor system. Some scholars determined the time intervals between successive falling seeds and their front and back positions employing a laboratory measurement system relying on an opto-electronic system designed for this purpose [19,20]. Grain precision and dropping velocity have been studied by applying high-speed camera system. The results of camera system were compared with that of the greased-belt stand. Under camera system, no missed seeds have been observed [7]. The ability of air-suction in vacuum planter for seed capturing effectiveness was inspected using axial and radial seed pick-up clearance and effective pickup area [21]. Kumar built up a complex flow rate of paddy rice grains through metering nozzles on a horizontally rotating cylinder exploiting of Artificial Neural Network and regression analysis. They stated that the cylinder was made with 36 nozzles number and 6 mm diameter each which associated with the most suitable speed of 61 rpm [22]. Zhan team carried out some studies on the performance of a pressurized planter using cylindrical type metering device for checking rapeseed precision. Computational fluid dynamics (CFD) software had been employed in these attempts for calculating forces acting on free fall seeds. They determined seed movement and dropping trajectories using a set of numerical equations [3]. Several researchers looked over seed suction by a pneumatic metering device for rapeseed, whereas some findings about nozzle diameter and number, orifice radius, and plate speed have been described [23]. utilized greased-belt stand equipped with a computerized camera system for seed capturing to investigate the performance results of a pneumatic disk [24]. Investigations results revealed that the three precision indices were obviously influenced by speed level and vacuum amount with no seed damage. A special remote-control precision planter combined with an inside-filling pneumatic centralized metering device was designed for small seeds precision. Results of field experiments exposed that rows consistency CV and stability CV of the overall seeding mass were found to be below 9.5% and 5%, respectively [25].

One of the shortcomings of recently applied pneumatic plate-type devices for seed metering is their incapability to meter more than one row of seed simultaneously [26]. These conventional disk-type devices utilize a single plate with only one row of holes and fit to a separate metering unit of seeding equipment. This is doubtless result in some complications of transmission and pneumatic systems, consumes more power, and necessitates using of several planting units which in turns brings further operation cost. In the present study, a seed metering device with a single metering plate for metering four rows concurrently was formerly designed for seed precision. The purpose was to reduce the number of metering units per each planting machine, decrease pressure and power consumption, and simplifies power transmission and pressure systems construction, as well as reducing total planter manufacturing and operating cost. However, the two rows of holes closer to the plate center of rotation resulted in more multiple seed pick-up than the other two rows which stated in previous study carried out by some scholars [12]. These results returned mainly to the variation in linear velocities of the rows and comparatively higher vacuum pressure gathering around plate center of rotation. Therefore, an attempt was tried through this study by employing a plastic device with adjustable openings for distributing and supplying vacuum pressure with right amount through each row nozzles aiming at achieving equal rows' seed pick-up. The opening size is controllable and can permit vacuum pressure separately connect to the four rows of the nozzles. Using of such a device and a like which can be able to supply pressure with a controllable amount, is definitely add a new value and significance to the device prototype applicability. The prototype assured its capability to suck and meter seeds through the four rows with little differences, but the performance was remarkably optimized by using the technique of vacuum distribution device.

The main objective of this work was to study the influence of an adjustable vacuum distribution device on rows seed pick-up similarity and consistency. The method had been employed as to:

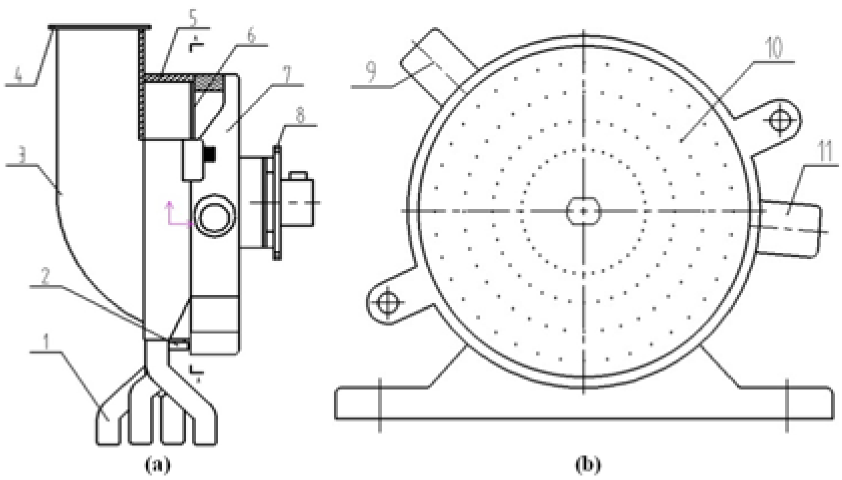
1. Study the effect of vacuum levels and plate rotating speed on rows seed pick-up results at 30˚vacuum openings angle through the four rows,
2. Investigate the influence of several vacuum opening angles on rows pick-up similarity.
3. Inspect the influence of different opening angles adjustment on rows performance.

2. Materials and Methods

2.1 Structure and Working Principle of Vacuum Distribution Device

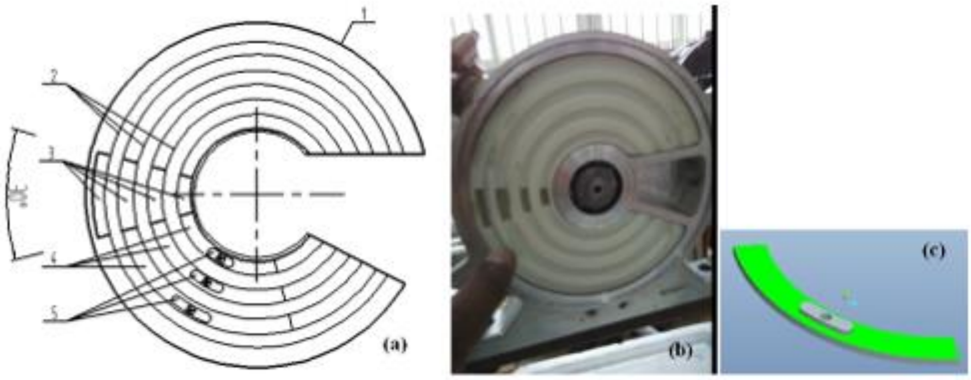
The prototype metering device comprise of a single pneumatic plate with four-rows for metering rapeseed as shown in Figure1. One side of the plate is directly connected to an air pressure source to imply vacuum at seed sucking area and positive pressure at release points, while the other face attaches to seed supply source and seed dropping tubes. Figure. 1a showing the complete metering device and its main components, while figure.1b displaying the metering plate attached to the air chamber. The pressure chamber was prepared with two cavities; one for vacuum pressure at seed sucking and retaining stages, while the other for positive pressure to blow seed off at release stage. The metering plate is rotating tightly in a groove on the pressure chamber top surface without air leakage (as shown in Figure. 1b).

The device is simply work in such a way: vacuum from pressure source flows through the inlet into the vacuum distribution device cavity. Thereafter, it runs through the openings to be in direct contact with the metering plate surface where metering nozzles receive vacuum and pick seeds opposite to the metering plate other side.



1. Seed tubes; 2. Seed discharge nut; 3. Seed box; 4. Seed box cover; 5. Metering plate shield; 6. Metering plate 7. Pressure chamber; 8. Driving sprocket; 9. Vacuum inlet; 10. Metering plate nozzles; 11. Positive pressure inlet.

Figure.1 (a) Side view showing main parts of multi-rows pneumatic plate metering device, **(b)** Front view showing the metering plate attached to the pressure chamber.



1. Vacuum distributor body; 2. Separators; 3. Vacuum openings; 4. Movable opening covers; 5. Protrusion on the covers for easy dragging.

Figure 2 (a) Vacuum distribution device structure, **(b)** Vacuum distribution device inside vacuum cavity, **(c)** Movable vacuum opening cover.

Further rotation of metering plate brings the nozzles to reach release points where seeds dropdown under positive pressure effect and gravity into seed tubes and then to the soil.

Due to the tendency of seed to be more multiple around plate center of rotation, a vacuum distribution device (Figure. 2) has been utilized to control the amount of vacuum pressure blow through independent rows. The device provides four outlets for the vacuum which match the four-hole rows on the metering plate, whereby each vacuum stream suck seeds through independent row opposite to plate surface. It basically composes of a hollow cylindrical chamber, cut with four curved openings on the top surface as shown in figure. 2. The openings allow vacuum to run directly and separately from the device to the rows of holes on the metering plate. These openings were made with an angle of 30 degrees from the center of the cylinder as in figure. 2a. Each opening is surrounded by two edges stretching along the area of vacuum, and open directly into the corresponding rows of metering nozzles.

The opening edges stay in direct contact with the plate surface; thus, they allow vacuum to pass only through the metering holes and prevent air overlapping with neighboring openings. Not only but also the opening size could be easily controlled by using an adjustable plastic slice cover (as shown in Figure. 2 a and c) which can be drawn over the opening in a groove between the two edges. So, the slice cover can completely close the opening or create an opening with a desired size, thus opening effect depends on the size created by the slice for vacuum passage. The cover is equipped with a protrusion on the top surface for easy dragging which coupled with an adjustable screw to carry the cover stationary. This configuration of openings has been made in such a way in order to secure vacuum blowing through separate metering rows and adjust to different desired amounts. Another round opening was punched on the periphery of vacuum distributor device to permit vacuum flow from an air source into the device. The whole vacuum distributor device is located precisely and tightly inside a vacuum chamber as presented in Figure 2b, whereas the openings are aligning with their corresponding rows of holes.

2.2 Experiment Description and Statistical Method

Firstly, the device was inspected at a completely opened angle (30 degrees), which means no slice cover was used for covering the openings. Six levels of rotating speeds, namely; 5, 10, 15, 20, 25 and 30 $r.min^{-1}$ were independently verified under five levels of vacuum pressure, specifically; 1, 1.2, 1.4, 1.6 and 1.8 kPa at an interval of 0.2 kPa to detect the influence of vacuum at each speed on seed pick-up in terms of seed mass. Vacuum amounts were adjusted to the mentioned values because it was found to be adequate to suck seeds through row4 with a little or no seed missing. Another test was conducted at six degrees of vacuum opening angles, namely; 5˚, 10˚, 15˚, 20˚, 25˚ and 30˚ as to verify the effect of angle on rows performance. Under each angle, the test was carried out at the above stated speeds with their optimum vacuum levels. Further test was conducted by inspecting rows at different opening angles under the same velocities and vacuum formerly mentioned. This was achieved through operation by setting up the opening cover slice through each row to a degree (angle) that can achieve equal or closer rows performance. Under each experiment, the test was replicated five times and means attained were compared using the Coefficient of Variance (CV). The CV method was largely used for means comparison as reported by which can be illustrated by equation (1) [27].

$$CV = \frac{S}{Z_m} 100 \quad (1)$$

where S is the standard deviation of the main seed mass and Z_m is the average of seed mass.

In this study, the CV value was used as a measure for both, rows' results consistency (CV) and stability of independent rows replicates (CV*) by using the same equation.

3. Results and Discussion

3.1 Effect of Vacuum Levels and Speed on Rows Pick-Up Results At 30° Vacuum Opening Angle

By reason of multiple seed pick-up occurred in row 1 and 2, vacuum distribution device had been tried to distribute and control vacuum pass through the four rows aiming at similar rows seed sucking. Multiple seed pick-up around plate center of rotation may basically refer to dissimilarity in peripheral speeds of the rows and /or to the higher negative pressure around the center than at the periphery; and that may due to no air leakage around its circumference. In this trial, the device was used with its four vacuum openings completely opened at 30° angle. Test results of the rows (R_1, R_2, R_3 and R_4) under the interaction of vacuum levels and angular velocities are shown in figure 3. The figure is apparently showing that rows pick-up in terms of seed mass at independent speed was noticeably improved by increase in vacuum amount as CV line explain. This might be attributed to the capability of higher pressure to reduce skip seeds which occur during lower vacuum level. These results are similar with that stated by who reported that low negative pressure generate empty nozzles, while the higher produce more multiples [28]. The figure illustrated that the best results of the rows pick-up under the six speeds were achieved at the highest vacuum levels; namely, 1.8 and 1.6 kPa as expressed by consistency CV value. It could be noticed from all figures (Figure. 3 a, b, c, d, e and f) that row 4 attained the lowest seed pick-up at all speeds and under each vacuum level compared with other rows except at 1.6 kPa vacuum, while row1 seemed to have the highest amount. This variation in rows performance may disclose that vacuum level around farther rows is inadequate to achieve the same results as the closer rows. Rows pick-up consistency CV at mentioned pressure oscillated between 2.19 and 11.57% under the six speeds. The variation in rows CV indicates the influence of the pressure and speed interaction on rows sucking performance. On the other hands, the stability CV for independent rows replicates at stated speeds coupled with vacuum pressure was found to be ranging between 0.63 and 5.99%, which may deem to be a sign for a steady vacuum for seed picking within separate rows. It could be seen from the figures that the rows seed means at the same speed and vacuum amount have little variations under low speed, but it increased with the increase in speed, particularly, between row4 and the other rows. This is mainly referred to insufficient vacuum level blow through row4 which was not matching the corresponding peripheral speed of the row level. This situation may require a decrease in vacuum opening size of inner rows with frequent multiple picking such as (R_1) as to reduce pick-up at this point and simultaneously increase it through farther row (R_4). Owing to these results, it's better to use vacuum distribution device with a little different adjustment in the size of the vacuum opening angle among the rows for attaining better output.

3.2 Effect of vacuum opening angle on rows pick-up similarity

A uniform seed capture of the rows depends mainly on the exact amount of negative pressure needed by a specific row level for attaining seed picking without multiple or missing. Six vacuum opening angles have been investigated through this attempt at the same formerly mentioned angular velocities and their matching vacuum magnitudes to verify opening angle influence on rows performance.

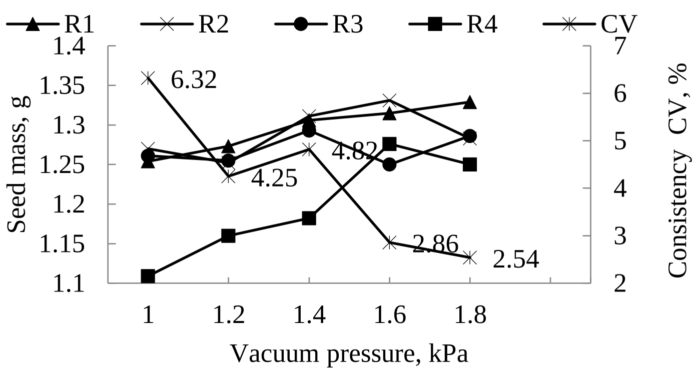


Figure 3a. Results of 30° vacuum opening angle on rows seed pick-up at 5 r.min^{-1}.

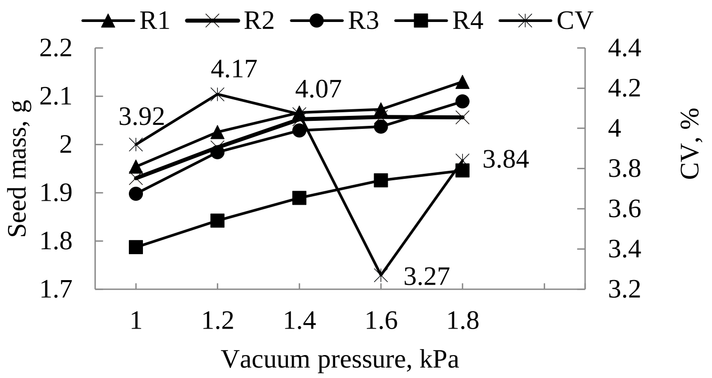


Figure 3b. Results of 30˚ vacuum opening angle on rows seed pick-up at 10 r.min^{-1}.

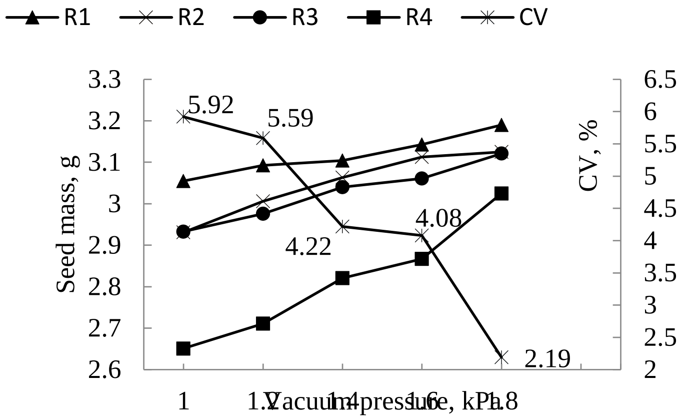


Figure 3c. Results of 30˚ vacuum opening angle on rows seed pick-up at 15 r.min^{-1}.

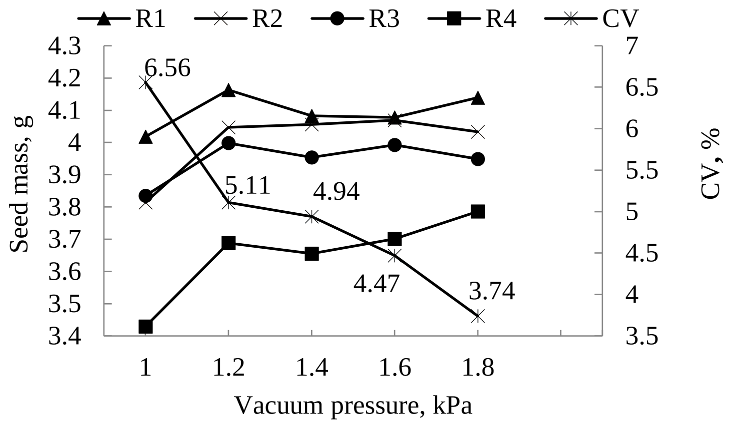


Figure 3d. Results of 30◦ vacuum opening angle on rows seed pick-up at 20 r.min^{-1}.

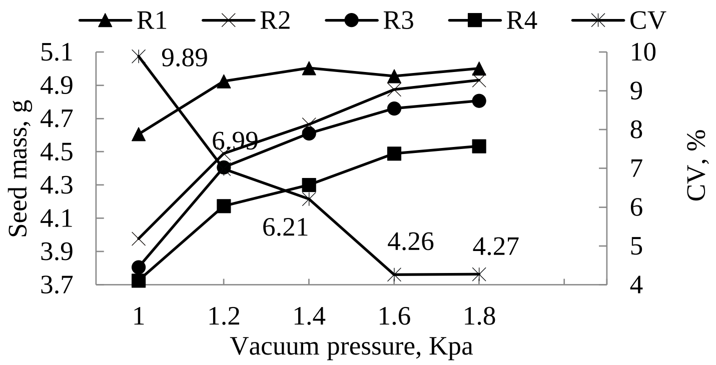


Figure 3e. Results of 30˚ vacuum opening angle on rows seed pick-up at 25 r.min^{-1}.

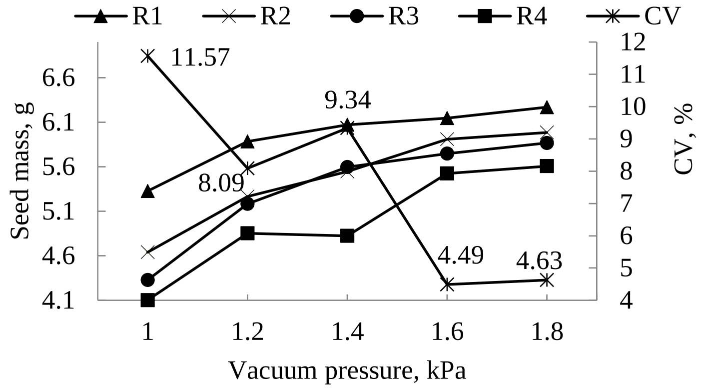


Figure 3f. Results of 30˚ vacuum opening angle on rows seed pick-up at 30 r.min^{-1}

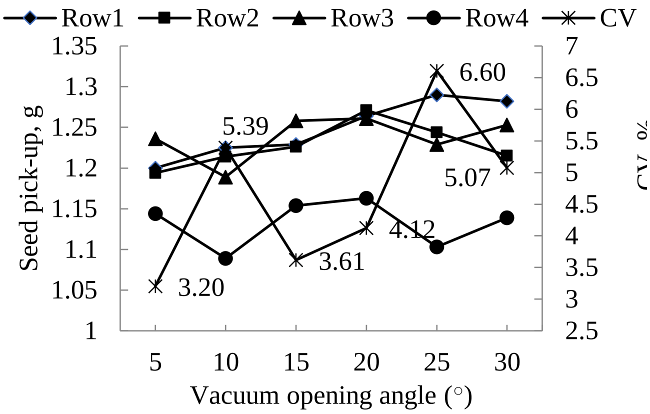


Figure 4 a. Results of opening angle on rows picking performance at 5 r.min^{-1} and 1kPa.

Figure 4 display the results of the six opening angles at six plate rotating speeds associated with their optimal vacuum levels. Rows results under separate velocities were compared using the CV measure. Figure 4a presenting the results of the six angles at 5 r.min^{-1} coupled with 1kPa pressure. Results stated that seed picking -in terms of seed weight- resulted in some differences between rows, but it was generally increased with vacuum opening angle increase, except among row4. The row showed inconsistent performance under regular increase of vacuum opening angle, while the remaining rows showed to some extent a linear increase of mass with increasing vacuum angle. However, row4 resulted in the lowest seed mass under all opening angles. These might be attributed to the lower and instable vacuum among this row, which may produce some skip seeds. The figure also displaying that rows seed mass was swinging between 1.08g to 1.28g. It could be noticed from the figure that rows seed pick-up consistency CV was fluctuating between 3.20% and 6.6%, where it was slightly declining as the opening angle increase. Variation in rows seed mass capture increases to some extent with the increase in metering plate speed. These results are similar to those attained by, who mentioned that the performance of the metering device was apparently affected by the rotational speed and vacuum level [27]. At 5° vacuum opening angle, the rows achieved the best CV (3.20%) compared to other openings.

Figure 4b showing rows results at 10 r.min^{-1} coupled with 1.2kPa vacuum pressure. Results exposed that rows seed pick-up mass under all angles was not more than 2.16g and not less than 1.85g. As the same results achieved at 5r.min^{-1}, row4 resulted in the lowest seed mass -except at 5˚ opening angle- compared to other rows. It seems that rows results were relatively better than that attained at 5r.min^{-1}. Rows consistency CV ranged between 2.38% and 4.70%, whereas the lowest and highest CV values were attained at 10˚ and 20˚ vacuum angle, respectively. It could be observed from the figure that the CV value tend to increase as the opening angle increase. Figure 4c displayed results of 15r.min^{-1} coupled with 1.4kPa vacuum pressure. It clarifies that rows seed mass was changing in a range between 2.81g and 3.35g at all opening angles. The consistency CV was ranging between 1.33 and 5.42% as the lowest and highest values, which occurred at 10˚ and 20˚ angles, respectively. Like the same results of formerly mentioned speeds, 15 r. min^{-1} provided the lowest and highest seed mass among row4 and row1, respectively, except through 5˚ vacuum angle. Figure 4 d exposed results of 20 r.min^{-1} joined with 1.6 kPa vacuum pressure. Rows seed weight was oscillating between 3.69g and 4.46g for all opening angles. The CV obtained was found to be between 2.08% and 6.92% as the best and worst values which took place at 10˚ and 20˚ opening angles, respectively. At 15˚, 20˚, 25˚ and 30˚, row1 gained relatively higher pick-up compared with other rows. Figure 4e visualized rows results at 25 r. min^{-1} associated with a negative pressure of 1.8 kPa. Seed pick-up of the rows fluctuated between 4.45g and 5.67g for the six opening angles. Consistency CV obtained for all opening angles ranged between 2.70% and 6.90%, with the best CV value gained at 10-degree angle. In this situation, row1 acquired the highest mass at 10˚, 15˚, 20˚, 25˚ and 30˚ and in the same time attained the lowest result at 5˚. This indicates the effect of the smallest angle (5˚) on rows results, which generated by the critical size near row1 and expands towards remaining rows. Figure 4f exhibit rows result at 30 r.min^{-1} connected to the corresponding vacuum of 1.8 kPa. Rows seed mass was found to be ranging between 5.63g and 6.88g. The speed performance resulted in consistency CV of 1.94% and 7.20 % as minimum and maximum values for all opening angles, where the most consistent CV value was attained at 5˚ angle. Results of row1 and row4 seemed to be similar to that formerly stated at 15˚, 20˚ and 25˚ speeds.

Generally, it could be noticed from all figures of vacuum opening angles that rows seed pick-up increase as the opening angle increase but the variation between them was also increased, particularly between row1 and 4. This situation is simply needs more adjustment of opening angle through individual rows in order to provide an adequate vacuum amount that sufficient for seed sucking without missing or multiple.

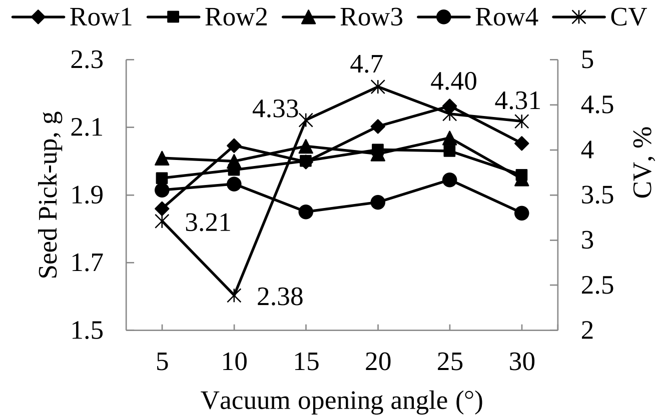


Figure 4b. Results of opening angles on rows picking performance at 10 r.min^{-1} and 1.2 kPa

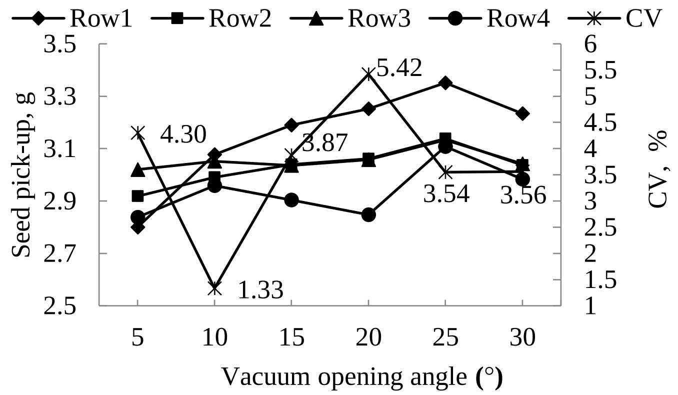


Figure 4c. Results of opening angles on rows picking performance at 15r.min^{-1} and 1.4 kPa.

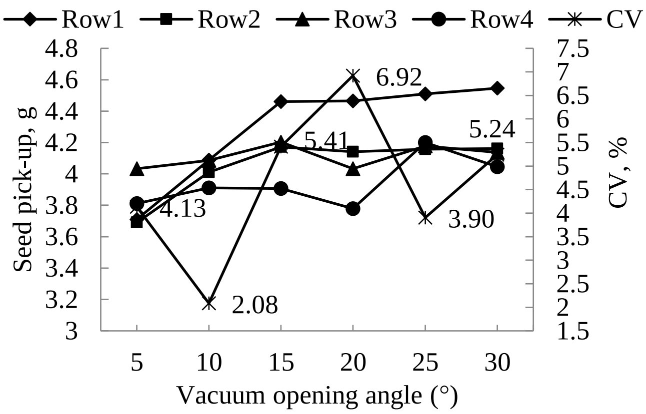


Figure 4d. Results of opening angles on rows picking performance at 20 r.min-1 and 1.6 kPa.

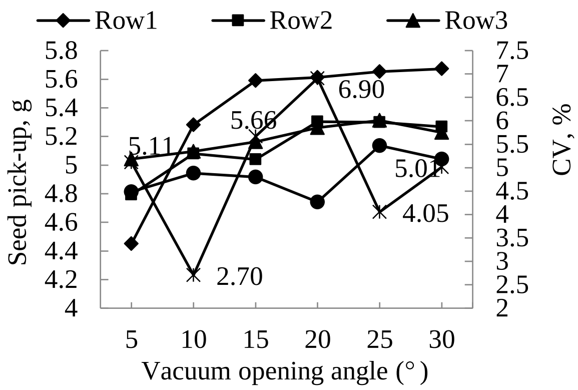


Figure 4e. Results of opening angles on rows picking performance at 25r.min^{-1} and 1.8 kPa.

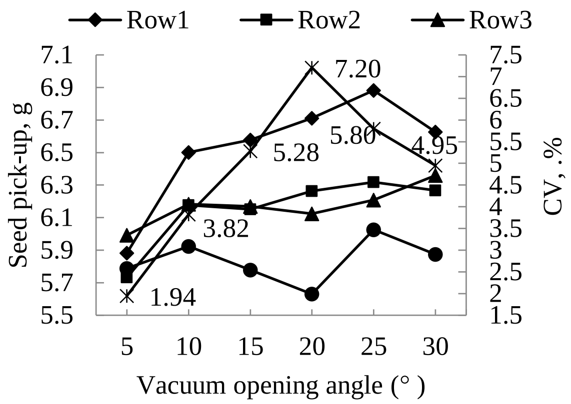


Figure 4f. Results of opening angles on rows picking performance at 30r.min^{-1} and 1.8 kPa.

For all opening angles under investigated speeds, the consistency CV was fluctuating between 1.33% and 7.20%. The best rows consistency CV acquired was found to be coupled with 10˚ angle more than the other opening angles. In more details, the values of 3.20%, 2.38%, 1.33%, 2.08%, 2.70%, and 1.94% were estimated for opening angles of 5˚, 10˚, 10˚, 10˚, 10˚and 5˚ under speeds of 5, 10, 15, 20, 25 and 30 r.min^{-1}, respectively. This may give a sign to the suitability of this angle for offering an optimal vacuum to produce most regular rows seed suction. In some cases, row1 attained the lowest seed mass under 5˚ angle compared with other rows; this may denote the influence of the opening angle on seed sucking performance by affecting on vacuum pressure blowing through this row section.

3.3 Effect of Different Rows' Vacuum Opening Angle set up

Due to results obtained from previous investigations by applying same vacuum opening angles through the rows, further attempts were tried by providing different opening angle adjustment on the rows as to achieve further closer rows seed suction. This test aimed to reduce multiple pick-ups and keep consistent seed picking among row1 and at the same time increase seed sucking through row4. Based on the test and investigation for rows picking similarity and consistency, the most convenient opening angles found were 4˚, 7˚, 10˚ and 30˚ which set up through row1, row2, row3, and row4, respectively. Thus, the angles have been studied under the same six mentioned speeds combined with their corresponding vacuum levels as formerly clarified. Investigation results attained are shown in table 1. The table showing the influence of independent angle adjustment through the row combined with the speed and vacuum on rows performance. Owing to the CV measure, rows results under all speeds were visibly improved compared with that obtained at the same vacuum angle set up, whereas the worst CV value was not exceeded 2.45%. It could be noticed from the table that rows seed mass was quite closer, but there was a tendency of row3 to attain the highest value under all speeds. This may return to the angle size adjustment on row1 and 2 which may generate sufficient pressure through these rows and direct more vacuum through row3, and hence produced more pick-up than in other rows. These agreed with the results stated by [29]. who declared that an increase in negative pressure produces more multiple seeds? Results of different rows angle reflects that each row level requires a specific vacuum amount to math its linear velocity. If more decrease is provided on vacuum angle size of rows closer to plate center such as row1, a decrease in seed sucking will be the result, because vacuum will not be enough to suck and hold seeds and then result in empty nozzles and irregular pick-up of the rows.

Table 1. Effect of different opening angle adjustment on rows seed sucking performance

Speed*Vacuum(r/min*kPa)	Rows pickup (g)				SD	CV,%
	Row1	Row2	Row3	Row4		
Opening angle	4°	7°	10°	30°		
5*1.0	1.21	1.215	1.252	1.194	0.024	2.014
CV*	2.91	3.01	2.01	2.27		
10*1.2	1.948	1.972	2.014	1.935	0.035	1.784
CV*	1.63	0.88	2.32	1.02		
15*1.4	3.004	2.956	3.055	2.926	0.056	1.893
CV*	1.7	1.95	1.39	1.52		
20*1.6	4.057	3.978	4.085	3.98	0.054	1.347
CV*	1.13	1.30	1.25	0.96		
25*1.8	5.021	4.906	5.121	4.99	0.088	1.776
CV*	0.57	1.93	1.29	1.65		
30*1.8	5.64	5.633	5.934	5.767	0.141	2.456
CV*	3.70	1.49	1.67	0.71		

CV: the coefficient of variance for rows consistency.
CV*: the coefficient of variation for the stability of independent rows replicates.
*: means combined speed and vacuum pressure.

It could be perceived from the table that there was no considerable effect of combined speed-vacuum on rows consistency CV, which may ensure the suitability of vacuum to the corresponding speed. For more clarification, 2.01%, 1.78%, 1.89%, 1.34%, 1.77% and 2.45% were found to be the CV values acquired at speed of 5, 10, 15, 20, 25 and 30 $r.min^{-1}$, respectively. Furthermore, the lower values of rows stability (CV*) under all speeds indicate a stable vacuum value at independent rows which provided regular rows seed pick-up. Rows stability (CV*) was oscillating between 0.57 and 3.70%, where the highest value was obtained by row1 at 30 $r.min^{-1}$ coupled with 1.8 kPa vacuum pressure. Looking closely at the results of all investigated parameters, the adjustment of rows with different angles generated superior results compared with 30° and the six vacuum opening angles due to closer rows pick-up and better consistency CV obtained.

4. Conclusions

Investigation results of this study concluded the following points:

(1) Results obtained by the four rows at 30° angle combined with the interaction of vacuum and speed ensured that the performance improved by the increase in vacuum level under same speed. At all speeds, rows seed pick-up resulted in the lowest and highest seed capture for row4 and row1, respectively.

(2) An increase in vacuum opening angle provided an increase in rows seed pick-up accompanied with an increase in variation between rows. Under the six vacuum opening angles and investigated velocities, the consistency CV was found to be oscillating between 1.33% and 7.20%, with the best CV values occurred at 10° angle compared with other angles.

(3) the most suitable vacuum opening angles were found to be 4°, 7°, 10° and 30° which adjusted through row1, row2, row3, and row4, respectively. Rows results at different angles were quite similar with some tendency of row3 to be the highest under all speeds. The highest CV value was not exceeded 2.45% at all speeds accompanied with the most stable rows pick-up (stability CV*). Rows performance was considerably improved, but further studies are required to develop such a device with an outside-control method that can easily adjust opening angle or vacuum level or both.

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Conflict of interest

The Authors has no conflicts of interest to declare that they are relevant to the content of this article.

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