International Journal of Scientific Research Updates

Journal homepage: https://orionjournals.com/ijsru/

ISSN: 2783-0160 (Online)

ORION SCHOLAR JOURNALS

(RESEARCH ARTICLE)

Check for updates

# Optimization of seed precision performance of a multi-rows pneumatic plate metering device using two seed ejecting methods

Elebaid Jabir Ibrahim [1,*], Abdelkarim Dafalla Elfadil [1], Anas Dafaallah Abdallah [1] and Reem Ahmed Mohammedali [2]

[1] *Department of Agricultural Engineering, Faculty of Agricultural Sciences, University of Gezira P. O. Box 20, Wad Medani, Sudan.*

[2] *Pharma D student at college of Pharmacology, Western University of Health Science, USA.*

International Journal of Scientific Research Updates, 2022, 03(02), 010–020

Publication history: Received on 24January 2022; revised on 30 March 2022; accepted on 01 April 2022

Article DOI: https://doi.org/10.53430/ijsru.2022.3.2.0034

## Abstract

This study was conducted at College of Engineering, Huazhong Agricultural University, China, 2019. It aimed to inspect theinfluence of two devices on seed precision performance of a multi-rows pneumatic disk metering device. Curved-edge and positive air blower were the two devices specifically used at four plate velocities coupled with their well-matching vacuum levels. Seed distribution of the two methods was also verified at 15 and 20 r/min incorporated with 1.2 and 1.4 kPa vacuum pressure, and 0.9 and 1.0 kPa positive pressure, respectively. Results exposed that vacuum amount utilized with mentioned speeds were adequate for attaining closer rows pick-up with consistency CV not surpassed 2.84%. The lowest quality index attained was 89.88%, while miss index not exceeded 7.1%, and rows stability CV was below 1.15%. Curved-edge device was found to be superior to air blower in quality index, miss index and rows stability. Study results concluded the appropriateness of the devices methods for precise seeding with a little variance, and more precise devices set up may generate better results.

**Keywords:** Multi-rows plate; Pneumatic metering device; Two devices; Seed precision

## 1. Introduction

Precision planting as a pattern of seed distribution operation was instituted in early1940s [1]. It defined as a placement of single seeds in their appropriate spacings. The operation posses a set of advantages; it diminishes excessive use of seeds due to regular seed allocation, prevent seed rolling which result in particular seed amount per unit length and make easy executing of subsequent field operations with lower costs [2]. It reduces stands competition by creating the optimal plants gap [3] .

Seed metering practice relies mainly on the metering mechanism which is the most essential constituent in sowing equipment [4]. Abundant types of metering units are recently implemented in precision seeding, among them are belt-type, slant plate, vertical rotor, fluted roller and pressurized plates[5,6]. The device operating principle is of either mechanical or pneumatic. Pneumatic devices are more preferable compared with mechanical types due to their perfect seed rate with lower broken ratio, better seed sucking, maintaining and dropping [7,8,9].

A variety of studies were formerly executed to study the performance of precision equipments, which made available information about precision systems whether they were of laboratory or field source. Karaye *et al* [10] set up a mathematical model relying on seed physical properties to identify the optimal vacuum amount of a planting machine.

*Corresponding author: Elebaid Jabir Ibrahim; E-mail: ebaidjabir@gmail.com
Department of Agricultural Engineering, Faculty of Agricultural Sciences, University of Gezira P. O. Box 20, Wad Medani, Sudan.

Grain suction capability by a pressurized metering system was studied to verify plate velocity, hole number, diameter and radius of air nozzle [11,12]. Singh and others checked out the impact of a disk rotational speed, negative pressure and shape of orifice entrance on cottonseed distribution and found the recently known precision indices [13]. Some endeavors exploited Response Surface Methodology (RSM) to look for seed spacing regularity of a seed planter [14]. An application of optoelectronic sensor system was engaged in seed preciseness to study distributed seed locations. Thus, kernel spacing stability was portrayed by means of the coefficient of precision [15]. The technique was also implemented to find out time intervals between successive dropped seeds, in addition to front and back locations as to view metered seeds accuracy [16,17]). High-speed camera technique was also considered to detect seed fall velocity and preciseness. Results acquired were matched with those of oily-belt stand which used as a reference. [18]. Bench test stand incorporated with a computerized camera technique for seed monitoring had been attempted to validate out precision performance. Results emerged that no damaged seed attained and precision process was plainly affected by angular velocity and vacuum level [19,20,21]. Computational Fluid Dynamics (CFD) was applied for computing forces affecting on dropped seeds, thus they illuminated seed movement and dropping trajectories by employing a set of numerical formulas [22].

Due to the properties of most seeds, it's not easy to realize sowing requirements by employing mechanical types, whereas some cereals may expose to damage and hence plug up metering orifice [23,24]. Accordingly, scholars implemented three pneumatic manners along the optimization of seed precision. They utilized positive air only for seed dropping, singling or combination of the two factors [25]. Positive pressure for kernel conveying incorporated with mechanical feeding [26]. Others exploited vacuum pressure for grain picking and positive for dropping and blowing off undesired particles [27,28].

One of the limitations related to recently applied pneumatic plate metering systems is their shortage to perform more than one row concurrently [29]. These conventional types are commonly utilizing an individual disk drilled with a single row of holes on its circumference and attached to a separate planting unit of seeding equipment. That means, a separate sowing unit necessitates using of a detached metering plate for seeding process. This in turns results in quite heavier seeding machine, complicated seeder's transmission and pneumatic systems, more power will be needed, and requires employing a set of sowing units per planter which definitely generates further cost. Accordingly, the recently invented multi-rows pneumatic plate metering device had been designed for reducing metering units per seeding machine and removing any inessential parts, and hence averting unnecessary costs. The device had been formerly investigated under a set of angular velocities combined with vacuum pressure. Unluckily, the rows of holes nearby the plate center of rotation (row1 and 2) picked-up more multiple seeds compared to the outer two rows. This condition requires using of an efficient method that capable of realizing same rows seed picking. For this reason, two devices have been exploited through this study for ejecting multiple seeds around air nozzles of mentioned two rows as an attempt for keeping single seed per nozzle. These devices were namely; curved-edge seed ejector and positive air blower device.

The main goal of the study was to examine the influence of two devices on seed precision performance of a multi-rows pressurized plate metering device. The work was conducted to:

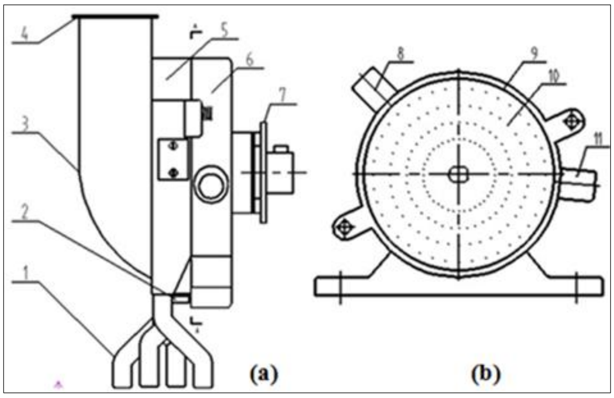
- Inspect the effect of the two devices on rows pick-up similarity performance under a set of plate rotating speeds and vacuum pressures,
- Detect the appropriate vacuum pressure that match the corresponding plate speed,
- Investigate seed distribution accuracy of the rows depending upon precision indices (Quality of Feed Index, Multiple Index and Miss Index),
- Study rows stability and consistency performance.

## 2. Material and methods

### 2.1 Structure and working principle of the prototype

The device employing a pressurized vertical plate with four-rows formerly developed for sowing several small seed-types. One face side of the plate connects to vacuum pressure at seed sucking stage and positive pressure at release points, while the other side attach to seed supply source and seed release tubes. Figure 1(a) present the essential components of the prototype, while figure 1(b) displays the plate with four rows of holes mounted to the pressure cavity. The pressure chamber was fabricated with two air cavities; one is attached to vacuum source for seed sucking and the other receives positive air pressure for dropping.

The most paramount element of the device is the metering plate; it was made with four rows of holes around its center of rotation as to perform four planting rows concurrently. Each row composed of 40 round holes drilled with 1.2 mm each. The gap between each neighboring two rows is 14 mm, while its 30 mm from the disk center to the first row as to make easy installing driving shaft. According to the physical properties of tested seeds (rapeseed) and to the test and investigation, it was found that 1.2 mm was the most appropriate hole diameter for better pick-up as declared also by [30]. For other seeds shape and size, it's requisite to drill the hole with a proper diameter for attaining perfect pick-up.




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

**Figure 1** (**a**): a schematic diagram of the multi-rows pneumatic plate metering device; (**b**) showing the metering plate on its groove in pressure cavity

## 2.2 Two devices used for seed singling

The two devices applied in this study were namely; a device with cured-edge for seed ejecting (fig.2 a) and a device employ positive pressure blow against seeds in the holes (fig.2 b). Figure (2a) display a plastic device with four curved-edges made with the same arcs of the rows of holes and at the same gap between the rows (14mm). The edges made in a curved-shape in order to avoid single seed obstruction or damage but permit smooth contact only with multiple seeds. The device could be set up where the edges are close enough to the rows as to give a little contact with seeds and then discard undesired multiples. As a result, the edges influence relies upon their clearance from seed rows and number of seeds per metering hole.

In figure (2b) a device exploiting positive pressure to throw away multiple seeds from metering orifice. The device is a hollow tube; with its lower part (cylinder shape) used as an inlet for positive pressure which connects the device to the pressure source, while its upper part (conical shape) is closed but equipped with two different size of small air nozzles on the top. The bigger one was prepared to be in an oblong-shape (1.5mm width and 4 mm length), while the smaller orifice was made in a form of three circular nozzles with 1mm diameter each. Due to this configuration, the device is positioned where the larger nozzle blows the air through row1 and the smaller blow towards row 2. This was made in such a way as to secure separate air blow through the two rows with rather different amount because of quite different pick-up of the two.

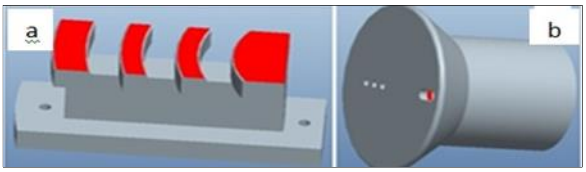
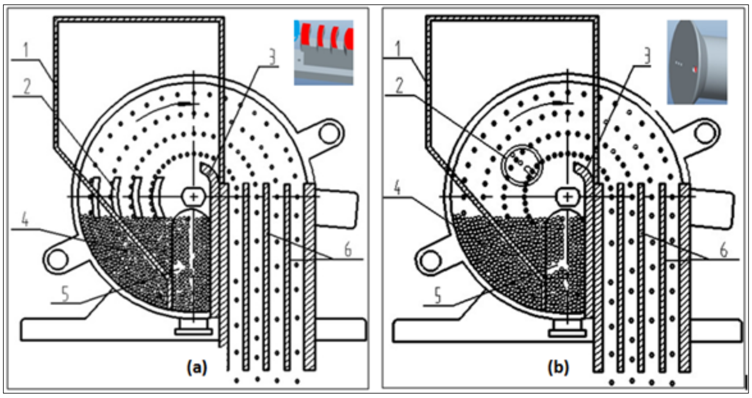



**Figure 2** Displays the two devices: (a) Curved-edge seed ejector; (b) Positive air blower

Using of the two devices in seed metering process could be seen from figure 3, which is a transparent cut view of the device shield showing how seed metering operation is simply take place. The cereal from gathering region is absorbed by vacuum, at times a set of seeds is sucked by metering holes. As grains passing nearby curved-edge device (Fig. 3 a) they touch the edges which eject multiples down and keep individual seeds per hole. Figure (3b) show positive air blower which is located inside vacuum cavity near and opposite to the metering holes where the two type of nozzles blow against their corresponding rows of holes. In the same manner, seeds are picked by vacuum and through their passing opposite to the air blowing area they exposed to pressure force. Depending upon pressure magnitude, the device can blow-off multiple seeds stick to the nozzles and may keep only single seed. At release point, seeds are detachedly fall down by means of separators built in side seed tube device.




1. Seed box; 2.Curved-edge singling device/Positive air blower; 3.Seed barrier; 4.Seeds area; 5.Seed flow opening; 6.Separators

**Figure 3**Transparent cut of metering plate shield displaying: (a) Curved-edge device and (b) Positive air blower as apart in seed metering process

## 2.3 Test methods

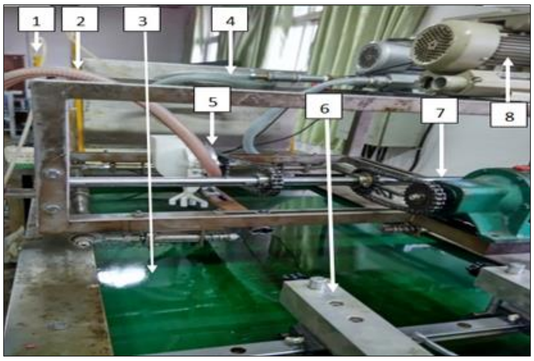
### *2.3.1 Seed pick-up uniformity of the rows*

This work was carried out at the College of Engineering, Huazhong Agricultural University, China in 2019. Under the two test methods, the experiments were conducted at four plate angular velocities, namely; 5, 10, 15 and 20r/min.coupled with their corresponding optimal vacuum pressure levels. Vacuum pressure magnitude at each speed was adjusted to a value that was sufficient to suck up seeds through the holes of row 3 and 4 without any missing. The best vacuum values found to be accurately corresponding with mentioned speeds were, 0.8, 1.0, 1.2 and 1.4 kPa, respectively. The influence of each device method on rows pick-up uniformity -in terms of seed mass- was independently studied.

In cured-edge method, the edges were adjusted to be as closer as possible to single seeds, but in a little contact with multiple seeds as to expel them out. Under positive air blower, the air was gradually adjusted at each speed until multiple seeds were removed from row 1 and 2 without creating any skip seeds.

### *2.3.2 Seed precision evaluation*

After rows pick-up uniformity investigation, the two devices have been utilized for detecting seed distribution accuracy on a sticky belt stand as shown in figure 4. The test was carried out at two plate rotating speeds (15 and 20 r/min) incorporated with their matching negative pressure (1.2 and 1.4 kPa), while 0.9 and 1.0 kPa positive pressure were provided by positive air blower under the two speeds, respectively.




1. U-tube manometer; 2. Positive pressure line; 3. Greased belt; 4. Vacuum pressure line; 5. Metering device; 6. Oil supply device; 7.Variable speed motor; 8. Air pump.

**Figure 4** Belt test stand for seed precision evaluation of a multi-rows plate.

In this test, the prototype was positioned over the sticky belt and actuated by the system driving motor to give the selected theoretical spacing. The belt was operated at a constant speed of 2.75 km/h. The seeds drop down from the device and stick on the oil provided on the belt surface with less rolling. Thereafter, released gains pass under the monitoring area of the system camera. A computer software system combined with belt test calculates seed spacing on the belt according to equation (1) and view the results as illustrated in fig. 5.

$$Theoraticalspacing(mm) = \frac{beltspeed(km.h^{-1})x10^{6}}{60xrotatingspeed(rpm)xnumberofholes} \text{.................} (1)$$

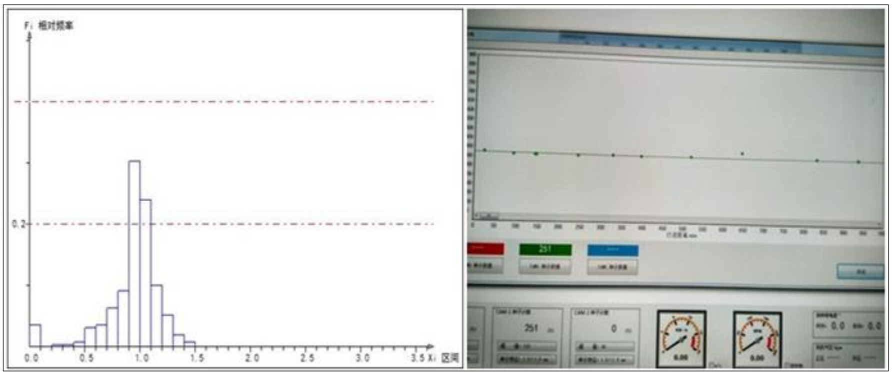


**Figure 5** Seed distribution performance and graphical layout.

Since the metering device plate is vertical, the four rows release seeds simultaneously in the same line which does not allow precise distribution. For this reason, each row was independently inspected while seeds drop from other rows were thrown out using a special ejector for this purpose. At each speed, the experiment was replicated five times and then the mean value of each index was attained. The coefficient of variance (CV) as clarified by formula (2) had been utilized to examine the stability and the consistency of quality index [31,32]:

$$V(\%) = \frac{S}{Z_m}\ 100\text{.................} (2)$$

where$S$: is the standard deviation of distributed seeds mean; $Z_m$ : is the mean of seed spacings.

As stated by Singh *et al.* [13], the precision measurement indices can be determined as follows:

**Miss Index:** is the ratio of spacings larger than 1.5 times theoretical grain distance (S) which expressed by formula (3):

$$I_{Miss} = {}^{n_1}/_{N}\, X100\text{.................} (3)$$

where, $n_1$ : is the spacing number larger than 1.5 $S$; $N$: is the total number of measured spacings.

**Multiple Index:** is the ratio of spacings smaller than or equal to the half of the theoretical kernels gap ($S$) and elucidated by formula (4):

$$I_{Mult} = {}^{n_2}/_{N}\, X100\text{.................}(4)$$

where, $n_2$: *is* the number of spacings ≤ 0.5 $S$.

**Quality of feed index (QFI):** is the percentage of spacings more than half but not more than 1.5 times theoretical distance ($S$). It is presented by formula (5):

$$I_{QF} = 100 - (I_{Miss} + I_{Mult})\ \text{.................} (5)$$

## 3. Results and discussion

### 3.1 Effects of the two devices on rows pick-up regularity

Table 1 exhibits the influence of the two devices on rows seed pick-up results at four rotating speeds coupled with their optimal matching vacuum pressure. Vacuum magnitudes were accurately applied for seed picking and retaining without missing. Additionally, positive air blowing values have been gradually and precisely adjusted through each speed to eject multiples with no occurrence of kernel skipping. It was found that the perfect positive pressure values which kept single seeds per holes were 0.8, 0.9, 0.9 and 1.0 kPa at mentioned four speeds, respectively. The amount of (0.9 kPa) was reused with the speed of 15 r/min, because it was found to be corresponding also with this speed, and when the value was increased to more than this level it produced some empty nozzles through row1. The table displayed that curved-edge method resulted in higher rows seed pick-up than positive air blower under the inspected velocities. This may give a sign that some multiple seeds have been occurred with curved-edge or some missing has been generated by positive air blower. Some multiple or miss are frequently happening in seed metering process; identical results correspond with those attained by some scholars who stated that seed sucking is largely varied at high or low pressure and plate speeds [32,33]. The table also showed that seed pick-up of the rows associated with positive blower (row 1 and 2) were found to be lower than those achieved by curved-edge, which apparently indicate the effect of air blowing method on seed ejection. Furthermore, the two rows under air blowing effect at same speed were frequently produced lower seed pick-up while rarely sucked up higher grain than the other two rows. These results may attributed to combined two factors; namely, inconstant effect of positive air pressure and/or linear velocities of rows levels. However, it could be clearly noticed that row 1 obtained lower seed pick-up at all speeds compared with row 2, which reveal that the air nozzle of row1 blow out comparatively higher air pressure than nozzles of row 2. According to the coefficient of variation, the results of the two applied methods were not considerably different, whereas rows consistency CV values were fluctuating between 0.99% and 2.84%.

**Table 1** Rows performance under the two devices effect

| RS*NP (rpm*kPa) | Positive air blower(kPa) | Two Devices | Rows seed pick-up, g | | | | Mean, g | SD | CV, % |
|---|---|---|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | R4 | | | |
| 5 *0 .8 | - | Curved- edge | 1.0 | 1.02 | 1.04 | 1.02 | 1.02 | 0.0163 | 1.60 |
| | 0.8 | Positive air blower | 0.98 | 1.01 | 1.02 | 1.05 | 1.015 | 0.0288 | 2.84 |
| 10*1.0 | - | Curved- edge | 2.11 | 2.14 | 2.21 | 2.13 | 2.147 | 0.0434 | 2.03 |
| | 0.9 | Positive air blower | 2.06 | 2.09 | 2.1 | 2.06 | 2.077 | 0.0206 | 0.99 |
| 15*1.2 | - | Curved- edge | 3.3 | 3.26 | 3.4 | 3.39 | 3.337 | 0.0684 | 2.05 |
| | 0.9 | Positive air blower | 3.11 | 3.16 | 3.2 | 3.05 | 3.13 | 0.0648 | 2.07 |
| 20*1.4 | - | Curved- edge | 4.4 | 4.26 | 4.32 | 4.3 | 4.32 | 0.0588 | 1.36 |
| | 1.0 | Positive air blower | 3.94 | 4.03 | 3.97 | 3.9 | 3.96 | 0.0547 | 1.38 |

RS*NP: Combined Rotating Speed (RS) and Negative Pressure (NP); SD: Standard Deviation; CV: Coefficient of Variance.

### 3.2 Effects of the two devices on seed precision

The influence of the two devices on seed distribution was verified relying on quality feed index (IQF) of the rows and their consistency CV. Results procured by the greased-belt stand were presented in table 2 to explicate the variability between the two methods, and hence between the rows. The table displaying the impact of the methods on rows seed preciseness at 15 and 20 r/min coupled with 1.2 and 1.4 kPa vacuum pressures, respectively. The table clarified that the highest mean quality index secured by the rows under both speeds was not exceeded 91.92%, and the lowest was around 89.88%, while rows consistency CV values were below 1.0%. Results visualized that curved-edge device generated highest quality index (91.92 and 91.89 %) at both speeds compared to positive blower. This may refer to better performance of curved-edge device which may diminish miss seeds and produce little multiples. It could be perceived that row 1 and 2 under positive air blower acquired the lowest quality index at both angular velocities matched to other two rows. This may extremely attributed to the influence of air blow through these rows nozzles which decrease pick-up pressure force acting on the seeds which in turns created frequent missing. Figure 6 display some results of seed distribution obtained via belt test stand.

**Table 2** Effect of the two devices on seed quality feed index

| RS*NP (rpm*kPa) | Two devices | Positive air blower(kPa) | Rows Quality Feed Index, % | | | | Mean, % | SD | CV, % |
|---|---|---|---|---|---|---|---|---|---|
| | | | R1 | R2 | R3 | R4 | | | |
| 15*1.2 | Curved- edge | - | 91.56 | 91.92 | 91.35 | 91.05 | 91.47 | 0.36 | 0.399 |
| | Positive air blower | 0.9 | 90.49 | 90.45 | 91.11 | 90.57 | 90.65 | 0.30 | 0.339 |
| 20*1.4 | Curved- edge | - | 90.67 | 91.42 | 90.98 | 91.89 | 91.24 | 0.53 | 0.582 |
| | Positive air blower | 1.0 | 89.88 | 90.29 | 90.5 | 91.12 | 90.44 | 0.52 | 0.571 |

RS*NP: Combined Rotating Speed (S) and Negative Pressure (NP); SD: Standard Deviation; CV: Coefficient of Variance.

**Figure 6** Seed distribution results on belt test stand

On the other hands, the three indices of seed precision integrated with the stability CV of independent rows quality index were illustrated in figure 7. Figure 7 (A and B) highlight the results of curved-edge device at 15 and 20 r/min. Results were visibly showing that miss index and multiple index occurred at acceptable levels. However, multiple indexes were more frequent than miss which point out that the device was appropriately employed for achieving seed distribution with a few multiples. Rows results expound that miss index was below 4%, while multiple index not exceeded 6% at both speeds. It could be observed from the figures that 15 r/min was more stable than 20 r/min according to the stability CV curve. As a fact, multiple index increase with high vacuum amount and low speed, while miss index is inversely affect by the two factors. Such results are agreed with those reported by [34]. The highest miss and multiple indices attained at 15 r/min were 3.84% and 5.72%, while at 20 r/min were 3.88% and 5.94%, respectively. The stability CV for each row replicates under the two speeds (which was generally not exceeded 1%) indicates a steady performance of the rows under the method. The figure stated also that multiple index was higher than miss, which obviously indicate that vacuum pressure was sufficient for seed pick up with a little skip rate.

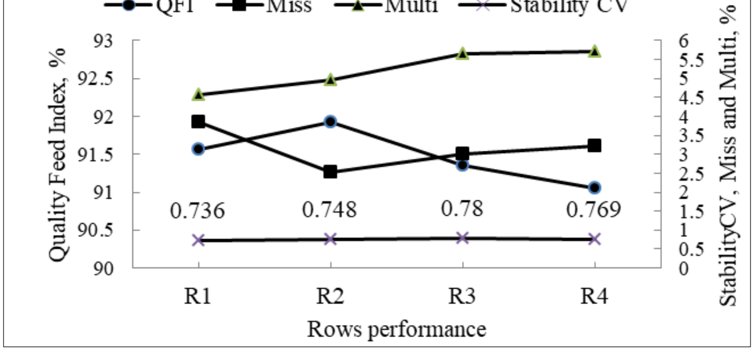



**Figure 7A** Results of Curved-edge device at 15 r/min and 1.2 kPa vacuum pressure

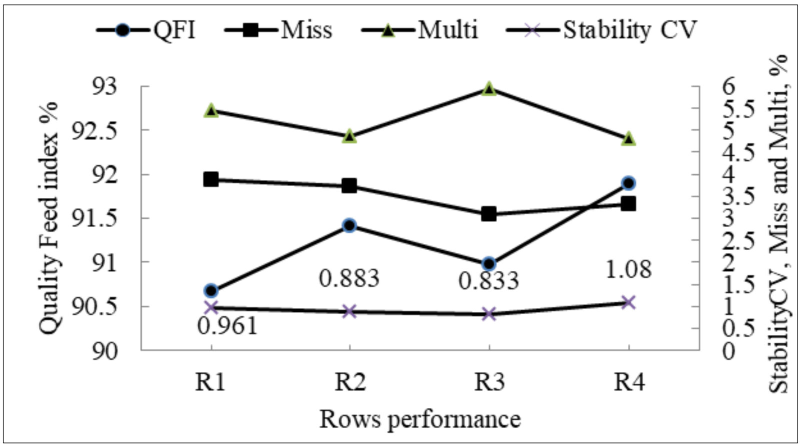



**Figure 7 B** Results of curved-edge device at 20 r/min and 1.4 kPa vacuum pressure

Figure 7(C and D) reflects the effect of positive air blower device on rows seed precision indices at the two mentioned speeds and vacuum pressure incorporated with 0.9 and 1.0 kPa positive air pressure, respectively. The figures elaborated that the lowest quality index under the two velocities were obtained by row 1 and row 2. This might be referred to the influence of positive air blow towards these rows which generated more skip seeds and hence affected directly on quality index. Miss and multiple factors are changeable through the rows; however miss index was higher through row1 and row2 than multiple under both speeds. This is doubtless disclosing the impact of positive air blower on seed ejecting off and in turns on seed precision. It could be clarified from all figures that miss indices achieved by positive air blower were higher compared to the curved-edge device, particularly, through row 1 and 2. The factor acquired the highest values of 7.05% and 6.54% at 15 and 20 r/min by row 2 and row1, respectively. Rows stability CV under the two speeds seemed to be inferior to those attained by curved-edge. Rows stability values under air blower device were not noticeably varied under the two rotating speeds, where it was oscillating between 0.52% and 1.15%.

Results achieved by the two methods explain that the two devices could be acceptably applied in multi-rows plates and such devices for attaining precise seeding which may guide researcher to carry out further advance studies. There was some tendency of curved–edge device to be more stable and consistent in quality index. Through all rows and under the two methods, the mean quality index was over 89%, while miss index was less than 7.1%. Rows quality index were fluctuating within a little range not surpassed 2.1%. According to the results attained, it seemed that 15 r/min. was more consistent than 20 r/min.

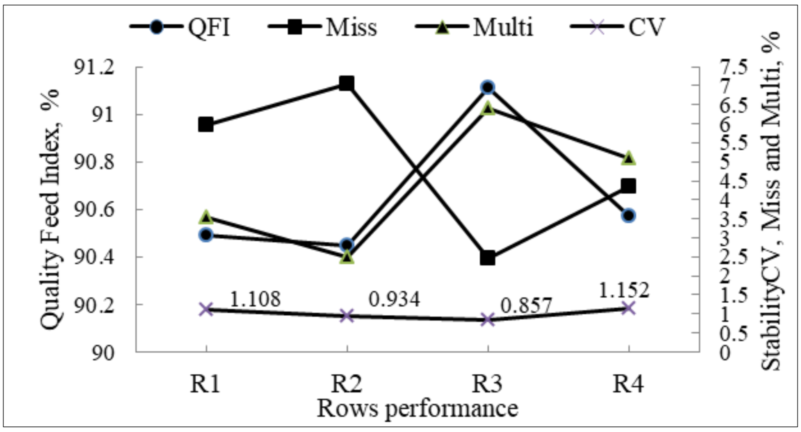



**Figure 7**C Results of positive air blower device at 15 r/min, 1.2 kPa vacuum pressure and 0.9 kPa positive pressure

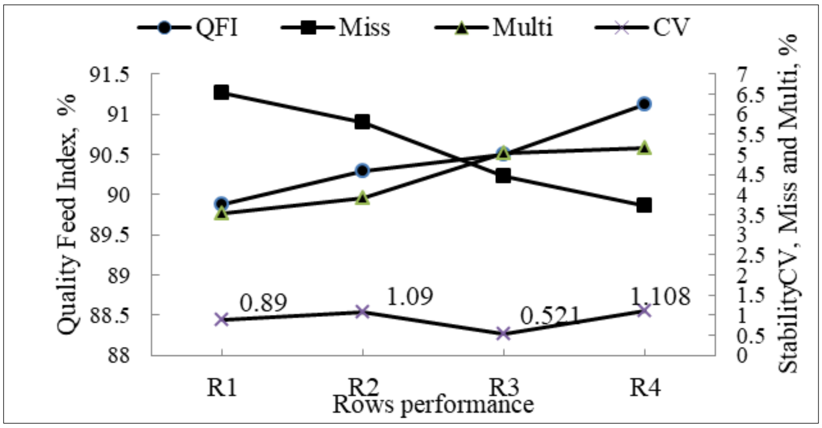



**Figure 7** D Results of positive air blower device at 20 r/min, 1.4 kPa vacuum pressure and 1.0 kPa positive pressure

## 4. Conclusion

The research findings concluded the following points:

- The two device methods were capable to precisely distribute seeds among the four rows with a little variance,
- The values of 1.2 and 1.4 kPa negative pressures under the two methods were found to be adequate for seed precision at 15 and 20 r/min, respectively.
- Rows' precision indices were found to be more than 89.8% with little differences between the two methods. Curved–edge device realized the highest quality index at both velocities. The highest miss and multiple indexes attained at the two methods were 7.05% and 6.41%, respectively.

Research results visualize the appropriateness of the two methods on seed distribution performance, but more innovative method with easy setup is strongly recommended for further studies.

## Compliance with ethical standards

### *Acknowledgments*

The study was conducted at Huazhong Agricultural University, College of Engineering, China. Deepest appreciations are extended to Prof. liaoQingXi the dean of the college for providing me the opportunity to carry out this work. Sincere gratitude also goes down to the laboratory colleagues for unlimited assistance and cooperation.

### *Disclosure of conflict of interest:*

The authors hereby declared that there is no conflict of interest in this manuscript.

## References

[1] Yasir SH, Liao Q, Yu J, He D. Design and test of a pneumatic precision metering device for wheat. Agricultural Engineering International Journal (CIGR). 2012; 14(1):16-25.

[2] Domier KW. Determination of the optimum seedbed conditions for canola. An overview of canola agronomic and varietal development research.1991; 10: 8-10).

[3] Heege HJ. Seeding methods performance for cereals, rape and beans. Transaction of Chinese Society of Agricultural Engineering. 1993; 36(3): 653-661.

[4] Yang L, Yan BX, Cui T, Yu YM, He XT, Liu QW. Global overview of research progress and development of precision maize planters. International Journal of Agricultural and Biological Engineering. 2016; 9(1): 9-26.

[5] Guler IE. Effects of flute diameter, fluted roll length and speed on alfalfa seed flow. Applied Engineering in Agriculture. 2005; 21:5-7.

[6] Boydas MG, Turgut N. Effect of vibration, roller design and seed rates on the seed flow evenness of a studded feed roller. Journal of Applied Engineering in Agriculture. 2007; 23: 413-418.

[7] Searle C L, Kocher M F, Smith J A, Blankenship E E. Field slope effects on uniformity of corn seed spacing for three precision planter metering systems. Applied Engineering in Agriculture. 2008; 24(5): 581–58.

[8] Guozhong Z, Ying Z, Xiwen L, Zaiman W, Qiang Z, Shasha Z. Design and indoor simulated experiment of pneumatic rice seed metering device. Int J Agric Biol Eng. 2015; 8(4): 10-18.

[9] Liu LJ, Yang H, Ma SC. Experimental study on the performance of pneumatic seeding system. Int J Agric Biol Eng. 2016; 9(6): 84-90.

[10] Karayel D, Barut Z B, Özmerzi A. Mathematical modeling of vacuum pressure on a precision seeder. Biosystems Engineering. 2004; 87(4): 437–444.

[11] Deng X, Li X, Shu C, Hang HD, Liao QX. Mathematical model and optimization of structure and operating parameters of pneumatic precision metering device for rapeseed. International Journal of Food, Agriculture and Environment. 2010; 8(1): 318–322.

[12] Ibrahim J E, Liao Q, Wang L, Liao Y, Yao L. Design and experiment of multi-row pneumatic precision metering device for rapeseed. Int J Agric Biol Eng. 2018; 11(5): 116–123.

[13] Singh R, Singh G, Saraswat D. Optimization of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. Biosystems Engineering. 2005; 92(4): 429–438.

[14] Yazgi A, Degirmencioglu A. Optimization of the seed spacing uniformity performance of a vacuum-type precision seeder using response surface methodology. Biosystems Engineering. 2007; 97(3): 347–356.

[15] Panning J, Kocher M, Smith J, Kachman S. Laboratory and field testing of seed spacing uniformity for sugarbeet planters. Applied Engineering in Agriculture. 2000; 16(1): 7–13.

[16] Kocher M, Lan Y, Chen C, Smith J. Opto-electronic sensor system for rapid evaluation of planter seed spacing uniformity. Transactions of the ASAE. 1998; 41(1): 237–245.

[17] Lan Y, Kocher M, Smith J. Opto-electronic sensor system for laboratory measurement of planter seed spacing with small seeds. Journal of Agricultural Engineering Research.1999; 72(1): 119–127.

[18] Karayel D, Wiesehoff M, Özmerzi A, Müller J. Laboratory measurement of seed drill seed spacing and velocity of fall of seeds using high-speed camera system. Computer and Electronics in Agriculture. 2006; 50(2): 89–96.

[19] Qingxi L, Jibo L, Guoliang Q. Experiment of pneumatic precision metering device for rapeseed. Transaction of Chinese Society of Agricultural Mechanization. 2009; 40(8): 44–48.

[20] Onal O, Onal İ. Development of a computerized measurement system for in-row seed spacing accuracy. Turkish Journal of Agriculture and Forestry. 2009; 33(02): 99-109.

[21] Elebaid JI, Liao QX. An Evaluation of Seed Spacing Accuracy of a Multi-Row Pneumatic Plate for Precision Rapeseed. Research Journal of Applied Sciences, Engineering and Technology. 2018; 15(8):306–315.

[22] Zhan Z, Yaoming L, Jin C, Lizhang X. Numerical analysis and laboratory testing of seed spacing uniformity performance for vacuum-cylinder precision seeder. Biosystems Engineering. 2010; 106(4): 344–351.

[23] Jiajia Y, Yitao L, Jinling C, Song Y, Qingxi L. Simulation analysis and match experiment on negative and positive pressures of pneumatic precision metering device for rapeseed, Int J Agric Biol Eng. 2014; 7(3): 1–12.

[24] Li X, Liao Q, Yu J, Shu C, Liao Y. Dynamic analysis and simulation on sucking process of pneumatic precision metering device for rapeseed. Journal of Food, Agriculture and Environment. 2012; 10(1): 450–454.

[25] Li Z D, Li S S, Cao XY, Lei X L, Liao YT, Wei Y P. Seeding performance experiment of pneumatic-typed precision centralized metering device. Transaction of The Chinese Society of Agricultural Engineering. 2015; 31(18):17-25.

[26] Lei X, Liao Y, Liao Q. Simulation of seed motion in seed feeding device with DEM-CFD coupling approach for rapeseed and wheat. Computers and Electronics in Agriculture. 2016; 131: 29-39.

[27] Cong J J, Yu J J, Cao X Y, Liao Y, Liao Q X. Design of dual-purpose pneumatic precision metering device for rape and wheat. Transactions of the Chinese Society of Agricultural Mechanization. 2014a; 45(1): 46–52.

[28] Li M, Qingxi L, Yitao L, Caixia S, Lei L. Analysis on seeding process of pneumatic cylinder-type centralized rapeseed precision metering device. Transaction of The Chinese Society of Agricultural Engineering. 2014; 30(23): 17–27.

[29] Cong J, Liao Q, Cao X, Liao Y, Yu J, Wang L. Seed filling performance of dual-purpose seed plate in metering device for both rapeseed & wheat seed. Transaction of Chinese Society of Agricultural Engineering. 2014; 30(8): 30-39.

[30] Lü JQ, Yang Y, Li Z H, Qin S Q, Li J C, Liu Z Y. Design and experiment of an air-suction potato seed metering device. Int J Agric Biol Eng. 2016; 9(5): 33-42.

[31] Wang L, Liao Y, Liao Q. Design and experiment of remote control precision planter for Chine cabbage. International Journal of Robotics and Automation. 2018; 33(2): 208–214.

[32] Liao QX, Jibo L, GuoLiang Q. Simulation analysis on air current field of pneumatic precision metering device for rapeseed. Transaction of The Chinese Society of Agricultural Mechanization. 2009; 40(7): 78–82.

[33] Yazgi A, Degirmencioglu A. Measurement of seed spacing uniformity performance of a precision metering unit as a function of the number of holes on vacuum plate. J. Measurement. 2014; 56: 128-135.

[34] Liao YT, Wang L, Liao Q X. Design and test of an inside-filling pneumatic precision centralized seed-metering device for rapeseed. Int J Agric Biol Eng. 2017;10(2): 56-62.