# Design and experiment of the pneumatic cylinder type precision metering system for wheat

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**Abstract:** The main goal of this study was to design a pneumatic cylindrical-type metering device with six-rows for wheat precision and to analyze its output under different rotating speeds and vacuum pressure values. The effect of the pressure, rotating speed and rows on seed suction, retention and dropping was shown inspected. Six levels of rotating speed (5, 10, 15, 20, 25 and 30 r/min.) combined with the applying of different vacuum pressures (1.8, 2.1, 2.4, 2.7, 3.0, and 3.3 kPa) were inspected to detect the optimum pressure which was adequate for seed sucking at each speed. In addition, to predict the vacuum pressure corresponding with each rotating speed, a regression model was developed. Based on seed mass analysis, statistical differences under the influence of velocities and negative pressure were found at 5 percent significance according to Duncan's Test, whereas the differences were existed between and within rows. Results revealed that the highest seed mass means of 19.02 g and 22.64 g were obtained by row1while the lowest means of 18.02 g and 21.49 g were attained by row6 under the effect of the speed and vacuum pressure, respectively. The noticeable variation between row1 and row 6, particularly under high speeds (25 and 30 r/min), might be returned to the truth that row 1 was closer to vacuum inlet, and row 6 was the farthest one. Results concluded that the multiple-row pneumatic cylinder with oblong shape seed nozzle was found to be capable for single seed picking with a small rows variation but without seed damage.

**Keywords:** Multi-rows cylinder, pneumatic metering device, wheat, precision
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## 1 Introduction

Wheat is regarded to be one of the most imperative grain crops worldwide and may be a staple food for around 1/3 of the global population[1]. It is basically utilized as a source for giving more protein than any other grain crops[2]. One aspect influencing the quality of the crop in mechanized crop production systems is the seeder operation. The greater accuracy the planting operation, the higher the quality of the crop harvested[3]. Precision planting was created by Dattain 1947 to put one seed at a desired distance within the soil[4]. Some scholars defined precision sowing as a process that locate a single seed at an exact spacing in the row[5,6]. As another meaning, precision seeding machines put cereal on the desired spacing and provide a most effective growing region consistent with seed[7]. Seeds distribute by accurate planting should accomplish the prerequisites of seed distribution between rows and within-row for each particular crop[8]. Plant spacing can influence both vegetative and reproductive growing and crop yield[9,10]. Such metering device designed exceptionally to meet the necessities of planting wheat within the recommended seed rate to increase productivity efficiency and reduce the production cost of the crop cultivation[6]. In later a long time, numerous sowing metering gadgets, the basic components of seed planters, are designed or optimized to boost their performances[9,10]. Precision planting reduces seed scattering and excessive use of seeds because of the uniform distribution of seeds and by prevent seed from bouncing inside the furrow. Uniform germination and plants growth in a regular method could make easily carry out the subsequent operations, which include removal of weeds and harvesting at a lower cost[3]. There are two main seed sowing technologies, either mechanical metering technologies or pneumatic metering technologies. Mechanical types use gravity, centrifugal force or any other typical mechanical forces, while pneumatic pattern utilizes airflow pressure as an additional pneumatic system[11,12].

Pneumatic metering technology is preferable because it meter different seed shapes and size without damage[13,14]. Several studies had been previously achieved to study the performance of precision planters. They provided a valuable information about the efficiency of the most of precision metering systems, in both laboratory and field tests. Karalyel et al.[15] identified an excellent vacuum pressure to attain a better performance of a metering device by using developed mathematical models of physical parameters for various seeds. A uniform spacing was employed to increase plant growth, seedlings emergence and yield by way of decreasing plants competition for light, water, and nutrients[16,17]. For the most of the plants at planting time, both seed population and seed distribution affect the harvested plants yield and size of stalks[18]. The effect of rotational velocity, negative pressure and air nozzles of a vacuum plate was studied and the precision indices (miss, multiple and

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quality feed index) were measured. Furthermore, they supposed the correct nozzle diameter was 2.5 mm for precision cotton seeds. They also noted that the metering unit with rotating speed of 0.42 m/s and a vacuum of 2 kPa resulted in values of 94.7% and 8.6% as quality feed index and multiple index, respectively[5]. The working parameters of a vacuum precision planter, such as plate applied vacuum, hole diameter and the peripheral speed of the plate had been appraised. In this attempt, the reaction surface methodology was applied to discover the overall performance of seed distribution consistency. Laboratory results attained divided into three different categories to measure the values of the three indices. Results showed that about 5.5 kPa negative pressure and 3 mm hole diameter were the excellent values for cotton seeds precision[19]. A pressurized-type row planter has been assessed at 3 metering element speeds (0.16 m/s, 0.23 m/s and 0.31 m/s) with their corresponding working speeds (1.33 m/s, 2.0 m/s and 7 m/s) under field test utilizing cotton and corn seeds. Their tests showed that the variation in seed spacing was proportionally elevated with the linear speed[20]. The high-speed camera device was employed to explore seed dissemination accuracies and fall of speed. The bench test stand coupled with a computerized digital camera device was employed for seed observation to find out the output of pressurized disk for metering rapeseed. Results intimated revealed that no broken seed had been detected. Through this study, the precision indices (quality feed, multiple and miss index) have been influenced by angular speed and vacuum amount[21]. The seed distribution attained by camera system was correspond with that of greased belt test stand which taken as a reference. With all camera tests, no missed seeds were occurred[22]. An investigation of the impact of air-suction accuracy to assess seed pick-up capability. This work was carried out utilizing pivotal and radial seed capture and measure of successful pick-up region[23]. Some scholars focused on seed physical properties, structural and working parameters, and the surrounding environmental conditions. They concluded that the parameters are most important for measuring the efficiency of precision sowing machines[24]. And also reported that with the increase in pressure, the miss index value was reduced but it increased with the elevated speed. With lower vacuum pressure and at higher speeds, the metering disc does not get enough time to pick up seeds, resulting in higher miss indices. The multiple indices on the other hand are lower at higher speed but increase at higher pressure[5].

Most of the metering devices currently employed for metering wheat are of drill types. This definitely results in excessive use of seeds per unit area. Seed drilling exactly provide excessive seedlings emergence which may lead to abnormal plants competition for minerals and water. On the other hand, Seed broadcasting could also be utilized for sowing wheat but it may provide irregular seed distribution which provides random stands per unit area. In addition, these sowing methods cannot allow subsequent operations such as weed suppression, chemical application and harvesting. Recently, the metering systems used for the crop precision are inadequate, but there are two metering devices constructed for the purpose. These are namely; the external multi-row pneumatic cylinder[25,26] which requires a higher vacuum pressure to overcome the impact of centrifugal and gravity forces, and the other is the internal-filling cylinder-type centralized metering device[27], which also consume moderately higher vacuum pressure compared with the first one. The currently constructed metering device consumes comparatively lower pressure for seed sucking than that obtained by the two mentioned types. Furthermore, the metering element of the system includes an oblong-shape cut for seed pick-up and retaining that made to match the shape of wheat seed and provide convenient seed stability and sticking during metering process which provided an excellent performance. Besides, the system can perform six rows concurrently and consumes lower vacuum pressure compared to the previously designed metering device with a single row that designed for precise wheat metering.

The principal goal of this study was to design a pneumatic cylindrical-type metering device punched with a special shape of seed nozzle (oblong shape) for wheat seed precision and investigate its performance under various rotating speeds and vacuum pressure levels as to:

1) Detect the possibility of the device for seed pick-up with appropriate vacuum amount and speeds under the six rows,

2) Determine the optimum vacuum pressure value that could be sufficient for seed sucking under corresponding operating speeds,

3) Modify and optimize the device operating and designs parameters for advanced performance investigation.

## 2 Materials and methods

### 2.1 Physical characteristics of wheat seed

The physical properties of the grain are the predominant imperative basic factors in identifying out the operational parameters. During this study, the main dimensions, sphericity and thousand seed mass of wheat seed had been measured (shown as Figure 1). For dimensions' measurements, (1000 seed) of randomly selected wheat seeds of a local Chinese variety (Huamai 13) were used for measuring seed length, width, thickness and mass. A caliper with a sensitivity of 0.01 mm has been used for the dimensions check. A digital balance with an accuracy of 0.01 g was used for estimating seed mass. These characteristics are given in Table 1.

a. Caliper b. Digital balance c. Wheat seeds

Figure 1 Measurement apparatus and seeds

**Table 1 Physical characteristics of wheat kernels**

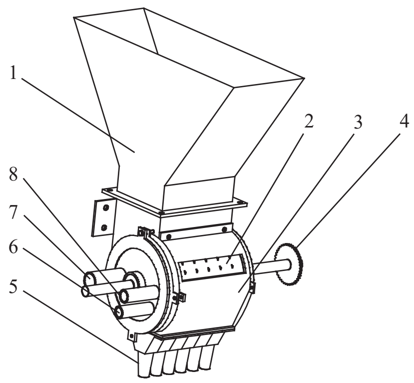
| Physical properties | mean | SE | 95% confidence limit |
|---|---|---|---|
| Length $l$/mm | 6.57 | 0.14 | 6.57 ± 0.26 |
| Width $w$/mm | 3.63 | 0.10 | 3.63 ± 0.20 |
| Thickness $t$/mm | 3.23 | 0.11 | 3.23 ± 0.20 |
| Sphericity% | 0.63 | 0.035 | 0.63 ± 0.06 |
| 1000 seed mass, g | 44.17 | 0.34 | 44.17 ± 0.66 |

Note: Sphericity, defined as the ratio of the diameter of the largest inscribed circle over the diameter of the largest circumscribed diameter of the seed. SE is a standard error.

$$Sphericity = \frac{(l \cdot w \cdot t)^{\frac{1}{3}}}{l} \times 100\% \tag{1}$$

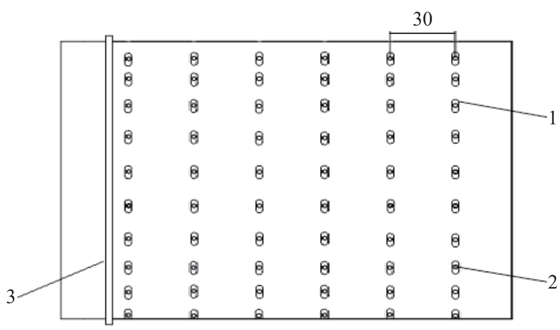
### 2.2 Structural parts and working principle of the metering device

The precision prototype of pneumatic cylindrical type metering system (as shown in Figure 2) consists of a horizontal cylinder, pressure chamber, seedbox, seed tubes and driving mechanism. The metering cylinder as the core element of the device contains six metering rows on its periphery. Figure 3 illustrating the metering cylinder component which is the crucial element of the system. The cylinder was made with 200 mm long and 140 mm diameter whereas 25 round holes were punched around its circumference with 14.4° between each adjacent two holes. The distance between each two rows of holes was 30 mm. The cylinder was prepared with two types of holes (as shown in Figure 3); one with around shape which penetrate from the cylinder outside to the inside as to carry pressure during operation, and the second one has an oblong shape cut on the cylinder surface which match the shape of wheat seed and that for making easier and single pickup of the seed. The pressure hole (for seed sucking) was made with 2 mm diameter that sufficient for securing pressure for picking. Each pressure hole was punched with mentioned oblong shape cut on the cylinder surface (as shown in Figure 3) which is similar or closer to wheat seed shape in order to provide seed rest and secure stability during operation. The dimensions of the oblong cut were derived from the measurements of the seed dimensions; therefore, they were made as 7 mm, 3 mm and 1.3 mm as length, width and depth, respectively. These dimensions were found to be appropriate and fit well the dimensions of wheat seed. The pressure hole for seed sucking was made in a round shape with 2 mm diameter. Each air hole was punched with an oblong shape cut on the cylinder surface (as shown in Figure 3) similar or closer to wheat seed shape as to provide seed rest and to secure stability during operation. The measurements of this cut were 7 mm, 3 mm and 1.3 mm as length, width, and depth, respectively, which fits the shape and dimensions of wheat seed.




1. Seedbox; 2. Metering cylinder; 3. Removable cover;4. Driving sprocket; 5. Seed tubes; 6. Positive pressure inlet; 7. Negative pressure inlet;8. cleanout pressure inlet.

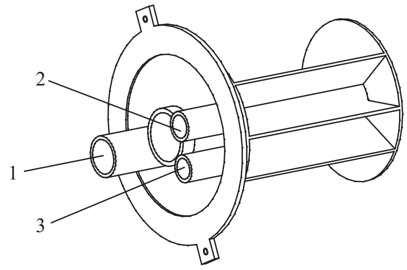
Figure 2 Schematic diagram of a pneumatic cylindrical-type metering system




1. Oblong shape cut 2. Around shape (hole diameter 2 mm) 3. Bearing barrier

Figure 3 Metering cylinder with six rows punched with air nozzle and oblong shape metering hole

Another most important part is the air chamber (as shown in Figure 4). The device has a cylindrical shape which divided into three separate cavities, each cavity creates an independent chamber. These cavities resemble vacuum cavity for seed pick-up, positive pressure cavity for seed dropping, and high positive pressure for hole clearing. The larger cavity was machined to be for vacuum pressure, while one of the other two cavities receives positive pressure to drop the seed and the other receives stronger positive pressure to clean metering nozzles before starting of the picking operation again. The device of air cavities is located inside the inner diameter of the metering cylinder as to create direct contact with metering nozzles to allow seeds sucking and sticking by vacuum through the outer surface of the cylinder among the metering process. The device is put and gets stationery where the vacuum cavity angle starts from pickup area and continues up to seed release point where seed dropping area begins. The nozzle clearing area start by the end of dropping area.

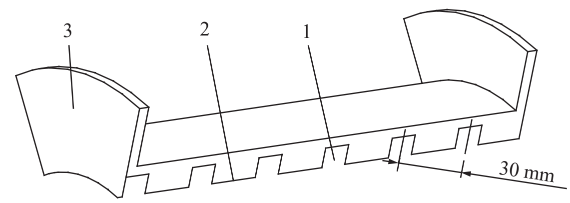



1. Negative pressure inlet 2. Positive pressure inlet 3. Clean out pressure inlet

Figure 4 Device with air press cavities

The seedbox is made with a holding a capacity of about 10kg. Its lower part was equipped with a slant metal sheet to direct the seeds into a narrow area in front of the metering cylinder to keep accessible seed level towards metering holes for easy sucking and prevent seed from jumping over the cylinder.

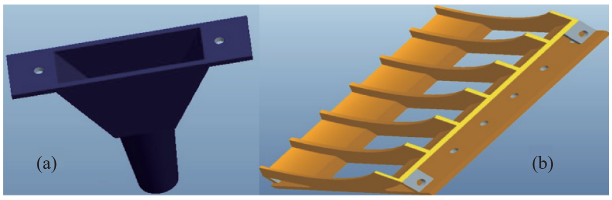
The seed guide device (as shown in Figure 5) is a plastic device with six groves could be designed using three-dimension printing machine to direct the seeds to pass only through the line of metering holes and prevent side creeping of seeds under rotating dynamic force of the metering cylinder as to reduce multiple seed pick-up. The device has a curve-shaped where its lower surface is located to be in direct contact with the cylinder outer surface. The seed passing grooves on the device were cut at the same clearance that provided between the metering rows in the cylinder (30 mm). The dimensions of each groove were made to permit seed passing smoothly and easily through the groove. Their width and height were made to be equal with 10 mm of each as to allow seed to move without obstruction if either they are on a vertical or horizontal level. Seed guide device comprises of two rigid parts at the two ends (as labeled 2 in Figure 5) to hold the device stationary with the seedbox body.




1. Seed pass grove. 2. barrier for removing excessive seeds 3. part for holding the device stationery

Figure 5 the component of seed guide device

The seed tubes were made of a rigid plastic by using a three-dimension printing machine (3D printer). Each seed tube was made in two shapes; the upper part was built in a tapered shape in order to be wide enough to collect dropping seeds from the row planting. The lower end of this shape have been converted in to a round tube (as shown in Figure 6a) with an internal diameter of 15 mm as to allow seed easily fall down. The six seed tubes were collectively attached to a holder which could be easily install to the metering device system. The holder (Figure 6b) upper side has a curve shape as the same as metering cylinder shape, while the lower part (rectangular) use to fix the seed tubes. This way provides a direct contact of the device with the metering cylinder and aligning of the seed tubes with the cylinder metering holes which permit smooth falling of seeds.

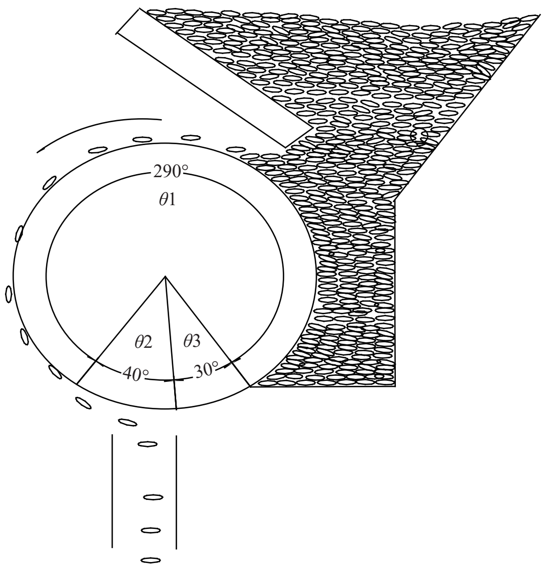



a. Seed tube shape b. Seed tubes holder

Figure 6 Seed tubes and holder

### 2.3 Theory of seed metering operation

The cylindrical type metering device operation could be achieved under three basic stages of air pressure aiming at accurately place seeds at the required spacing. The first stage is the grain pickup from pickup area by using vacuum pressure without seed losing, doubling or damage. The second stage is the seed holding and retaining stage which requires sticking of seeds on the nozzle at metering cylinder rotation until arrives at the falling points. The final stage is the release of seeds from the cylinder and drop them down and before start first stage again receive stronger positive pressure for cleaning metering nozzles before pickup seeds again. Figure 7 shows the three stages and corresponding angles according to the system structure.




Note: $\theta 1$: Picking and retaining angle; $\theta 2$: Dropping angle; $\theta 3$: Clearing angle

Figure 7 Sketch diagram for seed metering process.

### 2.4 Dynamic analysis of the seeding process

The metering processes are mainly composed of three stages; absorbing under vacuum effect, holding and retaining, and dropping of seed under gravity and positive pressure. The corresponding angles coupled with these stages are: absorbing and the retaining angle ($\theta_1$) is 290°, the dropping regional angle ($\theta_2$) is 40° and free angle ($\theta_3$) is 30°, this area was prepared with high positive pressure inlet for cleaning the nozzles as shown in (Figure 7).

During operation, the travel wheel of the planter rotates which in turn carry a shaft connected to the actuating shaft of the planter which transmits the power to the metering device operating gear that holds the metering cylinder to rotate inside a pressure chamber/cavity. Under the influence of pressure generated by the air pump, the vacuum suck and hold the seeds, and positive pressure releases them to the seed tube and then to the ground.

The operation of seed suction through the hole is an important issue. The vacuum runs in the radial direction through the hole, whereas, airflow lines represent a semi-sphere envelope. Pressure velocity rises up as the radius of the envelope decrease. The speed of air ($Vr$) at a space of ($r_1$) from hole center could be estimated by Equation (2).

$$v_{r_1} = \frac{r_2^2}{r_1^2}\cdot\frac{\propto\sqrt{\frac{2gp}{r}}}{2} \tag{2}$$

where, $r_2$ is the metering hole radius, m; α is the flow coefficient (assume to be 0.7); $\gamma$ is the specific weight of air (11.2 N/m$^3$ at 20°C and 96 kPa); $p$ is the vacuum pressure, N/m$^2$; $g$ is gravity acceleration, m/s$^2$. The air velocity through the center of the hole ($vr2$) could be computed by Equation (2).

$$v_{r_2} = \propto\sqrt{\frac{2gp}{\gamma}} \tag{3}$$

Vacuum plate peripheral speed of $V_p$ and the forward speed of the planter $V_f$ could be measured using Equations (3) and (4).

$$V_p = \frac{\pi d n_p}{60} \tag{4}$$

$$V_f = \frac{n_p}{60} k Z_t \tag{5}$$

where, $d$ is the plate diameter, m; $n_p$ is rotating speed of the plate, r/min; $k$ is holes' number in the plate, and $Z_t$ is the theoretical seed spacing, m. If $k$ is replaced by $\pi d/l$ into Equation (3), the value of $V_f/V_p$ becomes as shown in Equation (5).

$$\frac{V_f}{V_p} = \frac{Z_t}{I} \tag{6}$$

where, $l$ is arc distance between adjacent holes in the plate and m is the velocity ratio. Under the situation of zero-slippage, forward speed ($V_f$) is equal to drive wheel peripheral speed ($V_w$). Accordingly, theoretical seed distance ($Z_t$) is calculated due to travel wheel ($D$), transmission ratio ($i$) and hole number in the plate ($k$) as shown in Equation (7).

$$Z_t = \frac{\pi D}{ik} \tag{7}$$

### 2.5 Experiment description and statistical method

In this study, six levels of both rotating speeds (5 r/min, 10 r/min, 15 r/min, 20 r/min, 25 r/min, and 30 r/min) and vacuum pressure (1.8 kPa, 2.1 kPa, 2.4 kPa, 2.7 kPa, 3.00 kPa, and 3.3 kPa) have been separately investigated to examine the influence of each variable on seed pick-up in terms of seed mass. The levels of speeds were investigated to provide the prototype performance under low speed (5 r/min) and follow the output gradually up to the higher speed (30 r/min). In regard to the vacuum pressure, an initial test provided that (1.8 kPa) was found to be enough for pick-up without miss at lower speed. The impact of speed on rows results had been inspected at a constant vacuum pressure, while the influence of pressure was examined at constant rotating speed. In vacuum pressure effect, a value of 0.3 kPa was used as an interval in order to employ pressure amount not a little to make insignificant difference or too much to create excessive influence. In addition, negative pressure (NP) was adjusted under each rotating speeds (RS) to a value that was sufficient to attain seed picking without missing and linear regression was built to predict the vacuum amount which match the corresponding speed. Through all tests, the prototype was operated for one minute and seed weight through separate rows per each discharge tube was obtained. The experiment was repeated five times and then the means were attained. SAS statistical software package was used for data arrangement and analysis, while Duncan's multiple range test was utilized to recognize the mean separation of the variables through seed pick-up under the six rows and their significant level.

## 3 Results and discussion

### 3.1 Effect of rotating speed (RS) on seed pick-up

The impact of rotating speed on seed pick-up of the multi-row pneumatic cylinder metering system under fixed vacuum quantity is shown in Table 2. The table indicates that as the cylinder velocity increase, the pick-up seed mass of the rows also increases. In other words, when the cylinder rotating speed increases, the number of dropping seeds also increases through all rows. However, under the mentioned vacuum amount (2.4 kPa), an increase in speed resulted in increased were insignificantly different between rows seed suction. According to this fact, a specific vacuum is able to suck seeds under certain speed properly and if any more increase in speed vacuum will result in more missing or will be insufficient to suck more seed. This means that every speed requires a particular quantity of vacuum pressure to suck seed uniformly. This result is the resemblance to previously studied pneumatic seed-metering unit[4].

**Table 2 Effect of rotating speed on seed pick-up mass under the six rows**

| Rotating speed/ $r \cdot min^{-1}$ | Constant vacuum/ kPa | Seed mass means/g Row 1 | Row 2 | Row 3 | Row 4 | Row 5 | Row 6 | DMRT | SD | CV |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 2.4 | 8.01 | 7.95 | 7.62 | 7.6 | 7.45 | 7.38 | 7.668f | 0.258 | 3.37 |
| 10 | 2.4 | 13.44 | 13.17 | 13.24 | 13.22 | 13.21 | 12.39 | 13.112e | 0.366 | 2.79 |
| 15 | 2.4 | 16.13 | 16 | 15.93 | 15.94 | 15.88 | 15.47 | 15.892d | 0.223 | 1.41 |
| 20 | 2.4 | 22.16 | 21.8 | 21.78 | 21.73 | 21.59 | 20.74 | 21.633c | 0.476 | 2.201 |
| 25 | 2.4 | 25.3 | 25.19 | 25.15 | 25.09 | 25.07 | 24.31 | 25.0183b | 0.356 | 1.421 |
| 30 | 2.4 | 29.06 | 28.78 | 28.62 | 28.5 | 28.59 | 27.83 | 28.563a | 0.409 | 1.431 |
| DMRT | | 19.017 A | 18.815 B | 18.723 B | 18.68 C | 18.632 C | 18.02 D | | | |

Notes: Capital and small letters were used for describing means significance under the collective speeds and collective rows effects, respectively. Means with the same letters are not significantly different at the 5% level, by Duncan's Multiple Range Test (DMRT).

As it will be seen from Table 2, the seed mass was considerably differing due to the variation in cylinder rotational speeds. Based on the seed mass, there were massive differences at 5% significance among seed weight mean at various speeds. The highest value (28.563 g) was obtained from the highest speed (30 r/min), while the lowest amount (7.668 g) attained by the slowest speed (5 r/min). It could also be noticed that there were important differences between rows means under collective vacuums due to Duncan's multiple range test, whereas, 19.02 g, 18.82 g, 18.72 g, 18.68 g, 18.63 g and 18.02 g were obtained by row 1 to row 6, respectively. Row 2, and 3, showed no significant difference with the means of 18.82, 18.72. Also row 4 and 5 resulted in no significant difference with the means of 18.68 g, 18.63 g, respectively. Means variations were also found within and between rows with the same or different rotating speed. The variation in rows seed weight at lower speeds (5 r/min, 10 r/min or 15 r/min) is probably referred to different multiple seed pick-up via the rows, and that may return to inconsistent vacuum pressure. However, at higher speeds the variation can be attributed to both multiple pickups which frequently occur coupled with missing seeds. The increase in speed negatively affected rows pick-up consistency as could be clearly observed from the rotating speed of 20, 25 and 30 r/min (Table 2). The reason for that may be returned to insufficient interaction time between the metering hole and seeds within the vacuum zone which may result in missing or non-sucking seeds. This result is similar to other seed-metering devices[24,28]. The coefficient of variation for rows means at different speed levels ranged from 1.41% to 3.37% which indicates acceptable results.

### 3.2 Effects of negative pressure (NP) on seed pick-up

Table 3 showed an impact of vacuum pressure (when the speed held constant) on seed pick-up regularity of the rows and their variation coefficients. It was found that the negative pressure under constant rotating speed affected seed mass at 5% significance. The difference in seed weight means at diverse vacuum levels was significant according to the results of Duncan's test as showed in the table 3. The vacuum pressure was proportionally affected seed pick-up mass; therefore, an increase in vacuum pressure produced a rise in seed pick-up. This result agreed with that obtained by a single-row vertical disk metering device and inside-filling seed-metering cylinder[4,24,27]. Generally, a decrease in vacuum pressure decreased the number of seeds stick on the hole, while an increase resulted in greater seeds adhere to the nozzle entrance. The amount of the vacuum that meets the corresponding rotating speed was found to be quite lager than single-row vertical disk and quite lower than inside-filling seed-metering cylinder[9,29]. Once again, Table 3 showed that seed pick-up persisted to increase when the rotating speed held constant and vacuum pressure gradually increased by the rate of 0.3 kPa. The table revealed that changing of vacuum amount had greater effect on seed mass in separate rows with different vacuum pressure, between rows under collective vacuum (as gave in capital letters), under collective rows with same vacuum (as presented by using small letters) and between rows with the equal vacuum amount. As the vacuum regularly increased, the seed pick-up also increased, whereas the highest amount of seed means (25.23 g) under collective rows was carried out at 3.3 kPa vacuum amount, while the lowest mean (18.75 g) was attains at 1.8 kPa. However, under collective vacuum pressure the highest value (22.643 g) had been attained by row 1, while the lowest value (21,493 g) was acquired by row6.

Important variations have been existed also among rows under collective vacuum amounts, whilst, the values of 22.64 g, 22.48 g, 22.30 g, 22.34 g, 22.22 g and 21.49 g had been attained by row 1 to row 6, respectively. Means differences also happened between a few rows under the same vacuum amounts; where some of them appreciably diverge while others had not (as shown indicated by CV). This may be attributed to unequal rows seed pick-up due frequent multiple seeds. As a truth that row1 resulted in the highest seed weight under all vacuum levels compared with the other rows. That may be returned to the fact that the row is closer to vacuum inlet which could produce relatively higher vacuum pressure passed through this row holes. On the contrary, the lowest seed mean was acquired by row 6 (21.493 g), and that the row is the farthest one from the vacuum inlet which may not secure enough vacuum pressure for seed sucking. According to the test and analysis using the CV value, it was found that the vacuum pressure of 3.3 kPa was the best value which corresponds with the rotating speed of 20 r/min more than other values.

**Table 3 Effects of vacuum pressure on seed pick-up mass under the six rows**

| Negative pressure/ kPa | Constant rotating speed/ r·min$^{-1}$ | Seed mass means/g Row 1 | Row 2 | Row 3 | Row 4 | Row 5 | Row 6 | DMRT | SD | CV |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.8 | 20 | 19.13 | 18.99 | 18.73 | 18.71 | 18.53 | 18.41 | 18.75f | 0.271 | 1.45 |
| 2.1 | 20 | 21.3 | 21.12 | 20.61 | 20.96 | 20.8 | 19.45 | 20.71e | 0.660 | 3.185 |
| 2.4 | 20 | 22.25 | 21.91 | 21.83 | 21.85 | 21.74 | 21.2 | 21.80d | 0.341 | 1.645 |
| 2.7 | 20 | 23.46 | 23.2 | 23.18 | 23.14 | 23.11 | 21.91 | 23c | 0.548 | 2.385 |
| 3.00 | 20 | 24.19 | 24.18 | 24.19 | 24.14 | 24.01 | 23.33 | 24.01b | 0.338 | 1.41 |
| 3.3 | 20 | 25.53 | 25.49 | 25.31 | 25.28 | 25.13 | 24.66 | 25.23a | 0.317 | 1.255 |
| DMRT | | 22.643 A | 22.482 B | 22.308 B | 22.347 C | 22.22 C | 21.493 D | | | |

Notes: Capital and small letters used for describing means significance under collective negative pressure and collective rows effects, respectively. Means with the same letters are not significantly different at the 5% level, by Duncan's Multiple Range Test (DMRT).

### 3.3 Effects of rotating speed (RS) and negative pressure (NP) on seed pick-up

Figure 8 showed the interplay of negative pressure and the rotating velocity of the metering device on seed pick-up performance. To scrutinize the specified vacuum pressure versus each cylinder rotating velocity, a lot of attempts had been made for verifying the further favorable value of negative pressure which may be sufficient for seed pick-up. The optimum vacuum amount was determined under each rotating speed according to seed sucking and holding capacity. It was found that the required vacuum for seeds sucking under the six rows was proportional with the rotating speed. This result agrees with previous studies[4,24,29]. Accordingly, an increase in rotating speed required an increase in the vacuum amount and vice versa. Thus, a simple regression model was created for predicting wheat seed pick-up pressure which matches different device operating speeds. The figure is clearly showing the optimal values of vacuum that corresponds well with the rotating speed. It was observed that during operation negative pressure lower than the optimal value under each speed resulted in some empty nozzles, while higher than these levels produced more multiples, this was agreed with that stated by Searle et al.[30] The regression manner result was also found to be in line with the results of a multi-row pneumatic precision metering system that previously utilized for rapeseed precision[31].

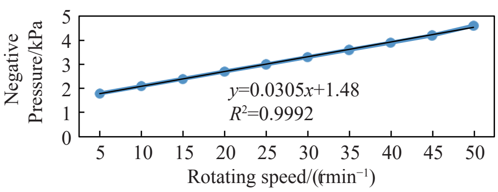



Figure 8 Relationship between rotating speed and corresponding negative pressure for seed pick-up under the six rows

Table 4 displaying seed mass obtained from the six rows under different rotating speeds and corresponding optimum negative pressure. Analysis of results detected that seed pick-up under the 6 rows was affected by rotating speed and vacuum pressure, in addition to the rows of the cylinder. Some statistical variations between rows with the same vacuum and the same velocity were occurred. As could be observed from the Table, seed suction and maintaining under the six rows were affected by higher rotating speeds (20 r/min, 25 r/min, and 30 r/min) and vacuum pressure around the nozzles more than the lower speeds (5 r/min, 10 r/min and 15 r/min), particularly through the hole row farther from the vacuum inlet (row 6) compared with the closer ones. The variation in means of rows under the same vacuum pressure and the same speed might be attributed to inadequate negative pressure resulted from air leakage at any unclearly closed point that may produce an insufficient amount for seed retaining which results in a few sticking or missing seeds. Furthermore, more than one seeds occur due to variation in seed size (ungraded seeds) or if none of them is successful to entirely close the metering hole. In some cases, no seeds were picked up by the nozzles, whilst, other nozzles lift up more than one seed simultaneously. This result was identically similar to that reported by Barut et al.[32]

**Table 4 Effect of rotating speed (RS), negative pressure (NP) and rows on seed pick-up mass**

| RS*NP | Mean Seed weight /g Row 1 | Row 2 | Row 3 | Row 4 | Row 5 | Row 6 | *Theoretical seed mass/g | SD | CV | MSE |
|---|---|---|---|---|---|---|---|---|---|---|
| 5*1.8 | 6.934 | 6.797 | 6.678 | 6.665 | 6.619 | 6.524 | 5.156 | 0.143 | 2.133 | 0.767 |
| 10*2.1 | 12.227 | 12.144 | 12.146 | 12.218 | 12.190 | 12.081 | 10.312 | 0.055 | 0.452 | 1.126 |
| 15*2.4 | 16.160 | 16.054 | 16.055 | 16.071 | 15.926 | 15.189 | 15.468 | 0.361 | 2.265 | 0.831 |
| 20*2.7 | 23.464 | 23.203 | 23.186 | 23.140 | 23.113 | 21.91 | 20.624 | 0.549 | 2.390 | 1.025 |
| 25*3.0 | 27.375 | 27.28 | 27.221 | 27.216 | 27.210 | 26.132 | 25.780 | 0.465 | 1.717 | 1.060 |
| 30*3.3 | 33.448 | 33.092 | 33.098 | 33.026 | 33.021 | 31.408 | 30.936 | 0.723 | 2.202 | 0.862 |

Note: MSE is for means comparison between rows. *Theoretical seed mass is the weight of seeds calculated according to the number of holes in the cylinder and its rotating speed, assuming that each hole carries only one seed each revolution and their weight was predicted according to the thousand seed mass (44.17 g).

Figure 9 is clearly illustrating that the mean of seed mass between rows appeared to be regular under low speed and began fluctuating as the speed increase, but it was observed to be significant at higher speeds. A theoretical weight method was utilized to compare the actual seed pick up with the theoretical one. Theoretical weight is the weight of seeds in accordance to the thousand seed mass gained by multiplying the rotating velocity by the cylinder holes number assuming that each hole holds an individual grain each time. Results revealed that, seed mass per each row under all speeds was more than the theoretical weight. These outcomes indicated that some holes were-from time to time-picking up more than one grain.

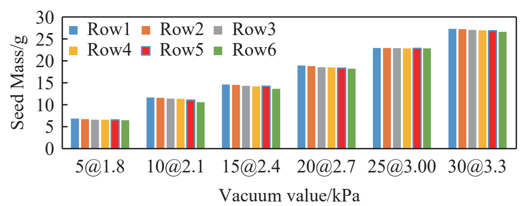



Figure 9 Effect of combined rotating speed and corresponding vacuum on seed pick up under the six rows

## 4 Conclusions

This study was conducted to investigate the performance of a multi-rows pneumatic cylinder for wheat metering incorporated with the effects of rotating speed, negative pressure and hole rows on seed sucking consistency. Research results were concluded as follows:

1) Seed pick-up of the rows in terms of seed mass was not

largely different under the effect of the same speed or vacuum, whereas they resulted in CV value not reached 4% under all tests.

2) The row of holes that was more distant from the vacuum inlet, generated to some extent lowest seed pick-up compared with the adjacent ones;

3) The statistical analysis revealed that the speed and pressure factors have direct effect on rows pick-up capacity.

4) It's strongly recommended that further study on an oblong-shape metering hole and a like are of most important to be studied for realizing better nozzle shape that match wheat seed pick-up and precise metering.

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## Nomenclatures

| Symbol | Definition |
|---|---|
| $d$ | Cylinder diameter, m |
| $D$ | Travel wheel diameter, m |
| $g$ | Gravity acceleration, m/s$^2$ |
| $i$ | Transmission ratio |
| $k$ | Holes number in the metering cylinder |
| $l$ | Arc distance between adjacent holes, mm |
| $m$ | Cylinder velocity ratio |
| $n$ | Rotating speed of the cylinder, r/min |
| $p$ | Vacuum pressure, N/m$^2$ |
| $r_2$ | Metering hole radius, mm |
| $Vf$ | Speed of the planter, km/h |
| $Vp$ | Vacuum plate peripheral speed forward, m/s |
| $Vr_1$ | Air velocity at distance $r1$ from hole center, m/s |
| $Vr_2$ | Air velocity through-hole center, m/s |
| $\alpha$ | Air flow coefficient (0.7) |
| $\gamma$ | Specific weight of air (11.2 N/m$^3$ at 20°C and 96 kPa) |
| $Zt$ | Theoretical seed spacing, m |

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