EFFECTS OF THE MAIN OPERATING PARAMETERS ON SEED HOLDING IN A SEEDER-PNEUMATIC METERING DEVICE WITH AN INCLINED PLATE FOR MAIZE

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ABSTRACT

Today's pneumatic sowing machines often use a seeder-pneumatic metering device with vertical seed discs. The weakness of a seeder-pneumatic metering device with a vertical disc is its low efficiency in receiving and holding seeds. In order to improve the suction and retention of seeds during sowing, the seed disc in a metering device was placed tilted compared to the vertical direction (pneumatic metering device with an inclined disc). The study was carried out according to the single-factor experimental method to determine the main working parameters of the aerodynamic sowing unit combined with the inclined disc.The results showed that an inclined seed disc is more effective than a vertical one in receiving and holding seeds during the sowing process. Specifically, the research focused on determining the effects of the main parameters - suction pressure, seed hole diameter, seed hole velocity, and angle of the seed disc - on the ability of the metering device to receive and hold seeds. The experimental results showed that an effective maize pneumatic metering device with an inclined disc has the following working parameters: 50-100mmHg vacuum pressure; 4-5.5mm seed hole diameter; a seeding hole velocity of less than 0.68 m/s; and the seed disc angled at 20-35 degrees from the vertical direction.

Keywords: Seeder-pneumatic metering device, maize sowing machine, pneumatic metering device with inclined disc.

Ảnh hưởng của một số thông số làm việc chính đối với việc giữ hạt trong bộ phận gieo ngô kiểu khí động kết hợp với đĩa nghiêng

TÓM TẮT

Ngày nay, máy gieo hạt kiểu khí động thường sử dụng bộ phận nhận hạt kiểu đĩa thẳng đứng. Hạn chế của bộ phận gieo hạt này là hiệu suất nhận và giữ hạt thấp. Để nâng cao khả năng hút và giữ hạt trong quá trình gieo, đĩa nhận hạt trong bộ phận gieo được đặt nghiêng so với phương thẳng đứng (bộ phận gieo kiểu khí động kết hợp đĩa nghiêng). Nghiên cứu đã được thực hiện theo phương pháp nghiên cứu thực nghiệm đơn yếu tố nhằm xác định các thông số làm việc chính của bộ phận gieo kiểu kiểu khí động kết hợp với đĩa nghiêng. Kết quả cho thấy trong quá trình gieo đĩa nghiêng làm việc hiệu quả hơn đĩa đặt thẳng đứng trong việc nhận và giữ hạt. Cụ thể, các nghiên cứu tập trung xác định ảnh hưởng của các thông số chính như: áp suất hút, đường kính lỗ chứa hạt, vận tốc của lỗ chứa hạt, góc quay của đĩa gieo đến khả năng nhận và giữ hạt. Kết quả thực nghiệm cho thấy bộ phận gieo ngô kiểu khí động kết hợp với đĩa nghiêng làm việc hiệu quả với các thông số làm việc chính như sau: Áp suất chân không 50 mmHg-100 mmHg; đường kính lỗ hạt 4-5,5mm; vận tốc lỗ đĩa gieo hạt nhỏ hơn 0,68 m/s và đĩa gieo tạo với phương thẳng đứng một góc 20-35 độ.

1. INTRODUCTION

A metering device is an important part of a sowing machine, and determines the quality and productivity of sowing. In Vietnam, popular maize-sowing machines use a disc or finger pick-up metering device. Sowing machines with a pneumatic metering device have also been put into application due to their outstanding advantages in accuracy and productivity. In these devices, exhaust fans creating pressure in the chamber are driven by the tractor power take-off shaft. These machines are made with 3-6 sowing rows.

Further research has led to the development of a precision pneumatic seed measuring device, and some of studies have focused on optimizing the following parameters: vacuum pressure, seed hole diameter, and velocity of the seed hole (Karayel *et al.*, 2004; Singh *et al.*, 2005; Satti *et al.*, 2012; Yu, 2014). Arzu & Adnan (2007) studied the operating variables of a vacuum precision seeder including the vacuum applied to the seed plate, the diameter of the seed holes, and the peripheral speed of the seed plate. The optimum levels of vacuum pressure and the diameter of the holes for the precision seeding of cotton seeds were reported to be 5.5 kPa and 3 mm, respectively. Yasir *et al.* (2013) designed a pneumatic precision metering unit, which had a cylindrical seed plate made up of a 2mm thick and 30mm wide aluminum sheet with a 140mm diameter and 30 equidistant cylindrical holes. Zhao *et al.* (2010) investigated the performance of a vacuum cylinder seeder for the precision sowing of rape seeds. The forces acting on the seeds in free flight were calculated using the computational fluid dynamics (CFD) software FLUENT. Using the differential equation for seed motion, seed falling trajectories using different working parameters were numerically determined. Zeliha & Aziz (2004) analyzed the effects of hole shape, peripheral velocity and hole area of the seed plate, vacuum pressure, and thousand grain weight on the seeding quality of a pneumatic single seed planter with a vertical seed plate for three maize varieties. These analyses showed that the mentioned parameters - pressure, seed hole diameter, seed hole velocity - are all related to the suctioning and holding of seeds during sowing.

In current pneumatic sowing machines, metering devices often have a vertical seed disc. To increase the ability to attract and hold seeds on the seed disc during the sowing process, a new research direction has been proposed, which is to study pneumatic metering devices with inclined discs. In a pneumatic metering device with an inclined disc, the pressure on seeds consists of the suction pressure of the air and pressure of the seeds on the inclined surface. The seeds' pressure on the inclined surface should improve the holding and dissociating process.

The study was conducted through laboratory experiments with the experimental material being a common maize variety in Vietnam. The aim of this study was to analyze the effects of some of the main technical parameters of a pneumatic metering device with an inclined disc on the abilities to suction and hold seeds. The technical parameters studied were the vacuum pressure, seed hole diameter, seed hold velocity, and inclined angle of the disc.

2. MATERIALS AND METHODS

2.1. Materials

Because of the demand for varieties, Vietnam has many diverse maize varieties, including LVN10, LVN4, LVN145, and LVN9, among others. The focus, however, is still on hybrid varieties with seeds of a relatively similar size. The mass of 1,000 seeds is about 300 to 350 grams for these varieties. In this study, the LVM10 maize variety was used and details about this variety are shown in Figure 1 and Table 1.

Table 1. Statistics of LVN10 maize seeds used in the experiments

	Length a (mm)	Width b (mm)	Thickness c (mm)	Rate of b/a	Rate of c/a
Average	8.68	7.44	5.40	0.86	0.63
Max	11.00	9.10	8.00	1.01	1.00
Min	7.00	5.50	3.50	0.60	0.35

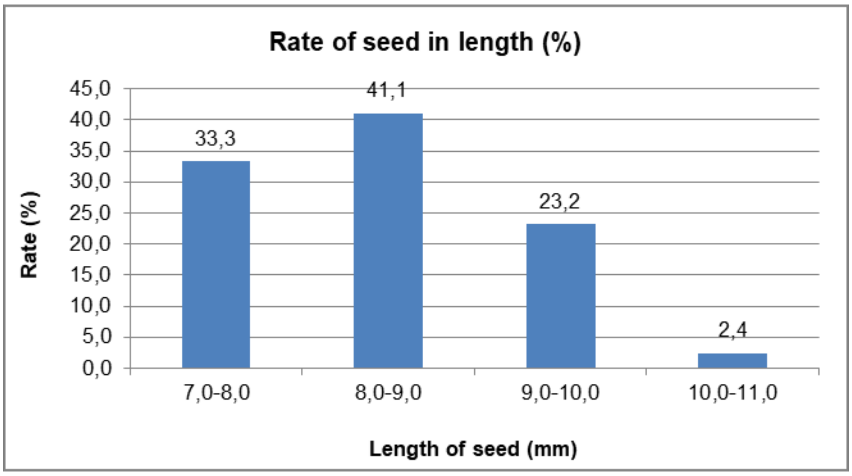


Figure 1. LVN10 maize seed length statistics by percentage

2.2. Methods

2.2.1. Working principle of a disc pneumatic metering device

Figure 2 illustrates the structure of a disc pneumatic metering device. A seed disc is made with seed holes evenly spaced along its perimeter. The disc is built with a body to create an open space only through seed holes (a vacuum chamber). The partition is called a pressure-cut wall, hence the space near the seed outlet has the same pressure as the air pressure. A vacuuming machine creates a vacuum in the chamber through a vacuum pipe. The metering device is the main working part of the sowing machine, performing three main tasks: suctioning and receiving seeds in the feeding area, separating seeds, and releasing the seeds at the seed outlet spout. When the seed disc rotates, the seed holes move through the feeding area, where under the suction pressure, a seed will be sucked and held in each seed hole. The dissociation process occurs when the disc passes through the feeding area, where the seeds held in the seed holes will continue to move with the seed disc and outer seeds will fall back to the feeding area under the effect of gravity and the dissociation device. Seeds kept in the seed holes continue to move to the seed outlet spout. When the holes go through the space, without vacuum pressure, the seeds drop through the release door due to gravity.

2.2.2. Model and setup of experiments of the disc pneumatic metering device

The experimental model was designed and arranged as shown in Figure 3. When tested, the motor sent rotating motion to the seed disc through the screw-worm gear and the belt drive. The motor ratio sent from the motor to the spindle of the sowing disc by design was 1/14. An inverter adjusted the rotational speed of the motor, thereby adjusting the rotational speed of the sowing disc. The vacuum pressure in the chamber was created by a suction fan and throttle valve. Vacuum pressure in the chamber was displayed by an indicator. The sowing component was connected to the frame by a rotating joint and holding bar so that researchers could change the angle of the disc.

2.2.3. Experimental parameters

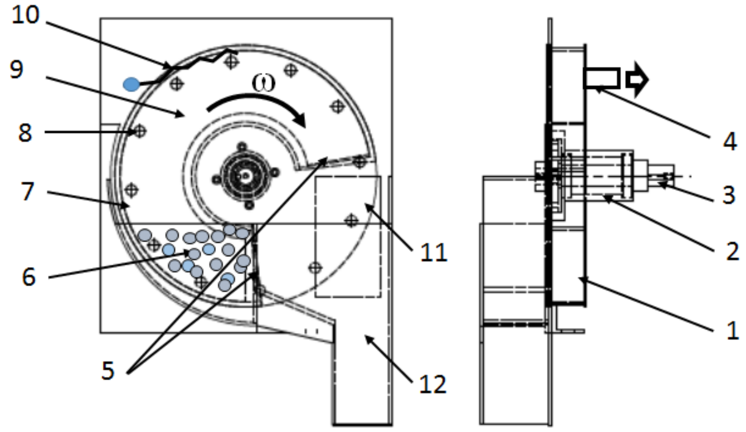
a. Input parameters

The following parameters were adjusted during the experiment (Table 2):

Vacuum pressure in chamber: One of the important factors affecting the disc's ability to attract and hold seeds is the vacuum pressure in the chamber. The higher the vacuum pressure, the greater the suction and holding force. However, the more seed holes there are on the disc, and the larger the diameter of each hole, the more power is required to create necessary vacuum pressure to suck the seeds.

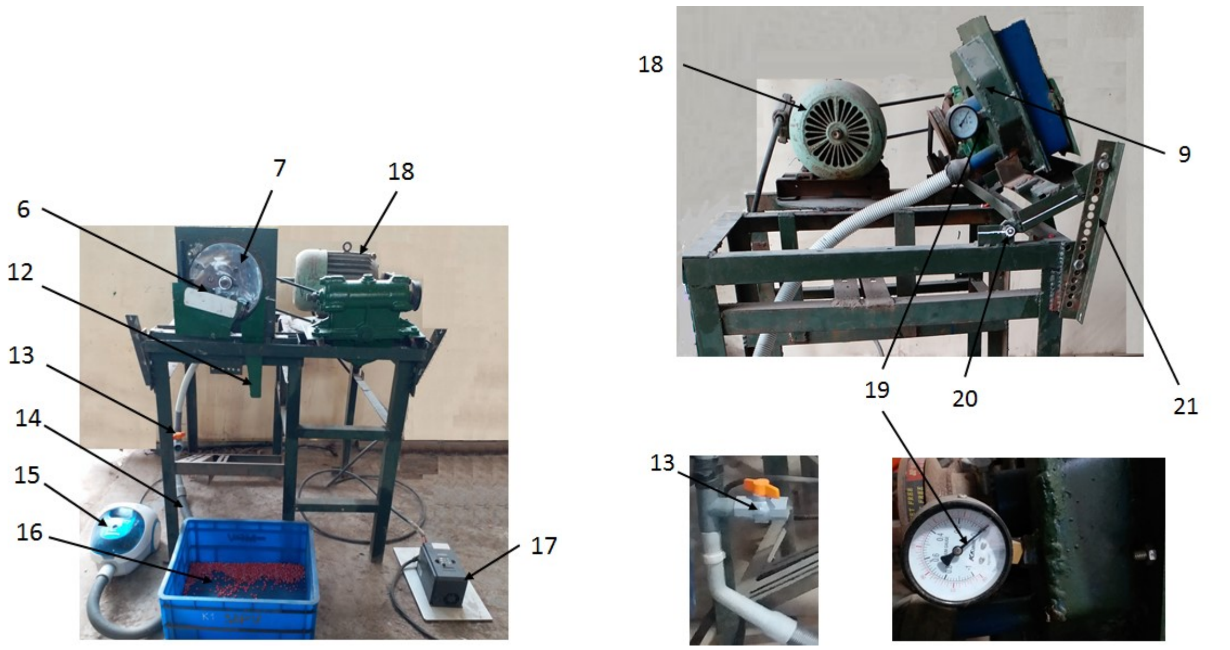
The test was performed with the pressure levels set at -1, -2, -3, and -4 in Hg (respectively: -24.5, -50.8, -76.2, and -101.6 mmHg).

Seed hole diameter: The force to suction and keep the seeds in the seed holds depends on the vacuum pressure in the chamber and the area of each hole (or the hole diameter). If the diameter of the seed hole is too small, the ability to attract and keep seeds will be poor. The diameter of the seed hole can also not be too large, which lets the seeds go through the holes. For maize, experiments were conducted with the following diameters: d3 = 3mm, d4 = 3.5mm, d5 = 4mm, d6 = 4.5mm, d7 = 5mm, and d8 = 5.5mm.



Note: 1: Body; 2: Support bearing; 3: Rotor shaft; 4: Vacuum pipe; 5: Pressure-cut wall; 6: Feeding area; 7: Sowing disc; 8: Seed hole; 9: Vacuum chamber; 10: Dissociation device; 11: Space; 12: Seed outlet spout.

Figure 2. Projection of a disc metering device



(a) (b)

Note: (a): Front view; (b): Side view; 13: Throttle valve; 14: Vacuum pipe; 15: Suction fan; 16: Seed tray; 17: Inverter; 18: Motor; 19: Air pressure indicator; 20: Rotating joint; 21: Holding bar.

Figure 3. Experiment model of the pneumatic metering device with inclined disc

Table 2. Symbols and values of the input parameters

Vacuum pressure in the chamber		Seed hole diameter		Seed hole velocity		Inclined angle of the seed disc	
Code	Values (mmHg)	Code	Values (mm)	Code	Values (m/s)	Code	Values (deg)
p1	- 24.5	d3	3.0	h1	0.38	α1	0
p2	- 50.8	d4	3.5	h2	0.48	α2	12
p3	- 76.2	d5	4.0	h3	0.58	α3	24
P4	- 101.6	d6	4.5	h4	0.68	α4	36
		d7	5.0	h5	0.78	α5	48
		d8	5.5				

Experiment code: $\alpha_i d_j p_n h_m$ - Experiment with input parameters: Angle of the seed disc α_i; Seed hole diameter d_j; Vacuum pressure in the chamber p_n; and Seed hole velocity h_m. For example, 12d1p1h1 means: Angle of the seed disc is 12°; Seed hole diameter is 3 mm; Vacuum pressure in the chamber is -24.5 mmHg, and Seed hole velocity is 0.38 m/s.

Speed of the seed hole: The velocity of a seed hole is proportional to the moving speed of the machine; but at the same time, it has a great influence on its ability to suction and receive seeds. When the seed hole passes through the feeding area to attract and detach the seeds from the seed mass in the feeding area, the holding force needs to overcome resistance forces such as the resistance force of the seed mass, the inertial force, and gravity. A large velocity can increase the machine's operating speed but decrease its ability to receive seeds. In the experiment, to change the speed of the holes we used an inverter when adjusting the speed of the motor. The experiment was conducted with a seed disc with a center diameter of 200mm, and the rotation speed of the disc was at five levels from 36 to 75rpm, hence the hole velocity ranged from 0.38 to 0.78 m/s (These values were selected from preliminary test results), specifically shown in Table 2.

Inclined angle of the seed disc in comparison with the vertical direction: The inclined angle of the sowing disc was adjusted by means of a rotating joint and holder bar. The experiment was conducted with the angles of 0, 12, 24, 36, and 48 degrees.

b. Metrics to evaluate the quality of the metering device

The quality of the metering device was evaluated by its ability to receive and separate seeds accurately. With the required accuracy being 1 seed per hole, the experiments' results were collected by counting the empty holes (no seed), and holes with 1, 2, 3, or more than 3 seed(s).

2.2.4. Experiment process

Every experiment was conducted with these steps: First, materials were input into the feeding area. Second, the experimental conditions were set up by setting the seed hole velocity via the inverter and setting the pressure in the chamber through the throttle. Third, the motor was started, followed by the suctioning fan. Each experiment ran for 120 seconds, during which each experiment was recorded and saved. Finally, the videos were analyzed and data recorded.

2.2.5. Data analysis and evaluation

In the experiments, the receiving and separating seeds processes of the disc were recorded with a slow-motion camera. The videos were then examined, and all the data were analyzed and evaluated in Excel.

3. RESULTS AND DISCUSSION

3.1. Effects of the vacuum pressure on the seed holding ratio

Experimental results showed that the lower the pressure in the chamber, the better the ability of the metering device to receive seeds, as shown in Figure 4. At pressure levels higher than -50mmHg, the percentage of holes receiving seeds was low and dependent on the seed hole diameter, seed hole velocity, and the inclined angle of the seed disc. At pressure levels lower than -50mmHg, the ability of the disc to receive seeds was better. None of the holes were empty at low pressure levels when the seed hole diameter was large, seed hole velocity was small, and the inclined angle was large. To be specific, all holes received seeds when the pressure was at -24mmHg, the seed hole diameter was bigger than 5mm, the seed hole velocity was lower than 0.48 m/s, and the inclined angle was greater than 24 degrees. At a pressure level of -50.8mmHg, and an inclined angle of 36 degrees, the diameter only needed to be 4 mm while the velocity could be as large as 0.58 m/s. At a vacuum pressure smaller than -50.8mmHg, an inclined angle larger than 36 degrees and a seed hole diameter greater than 4.5mm, the seed hole velocity could be increased to 0.68 m/s with no holes left empty (i.e. all holes received seeds).

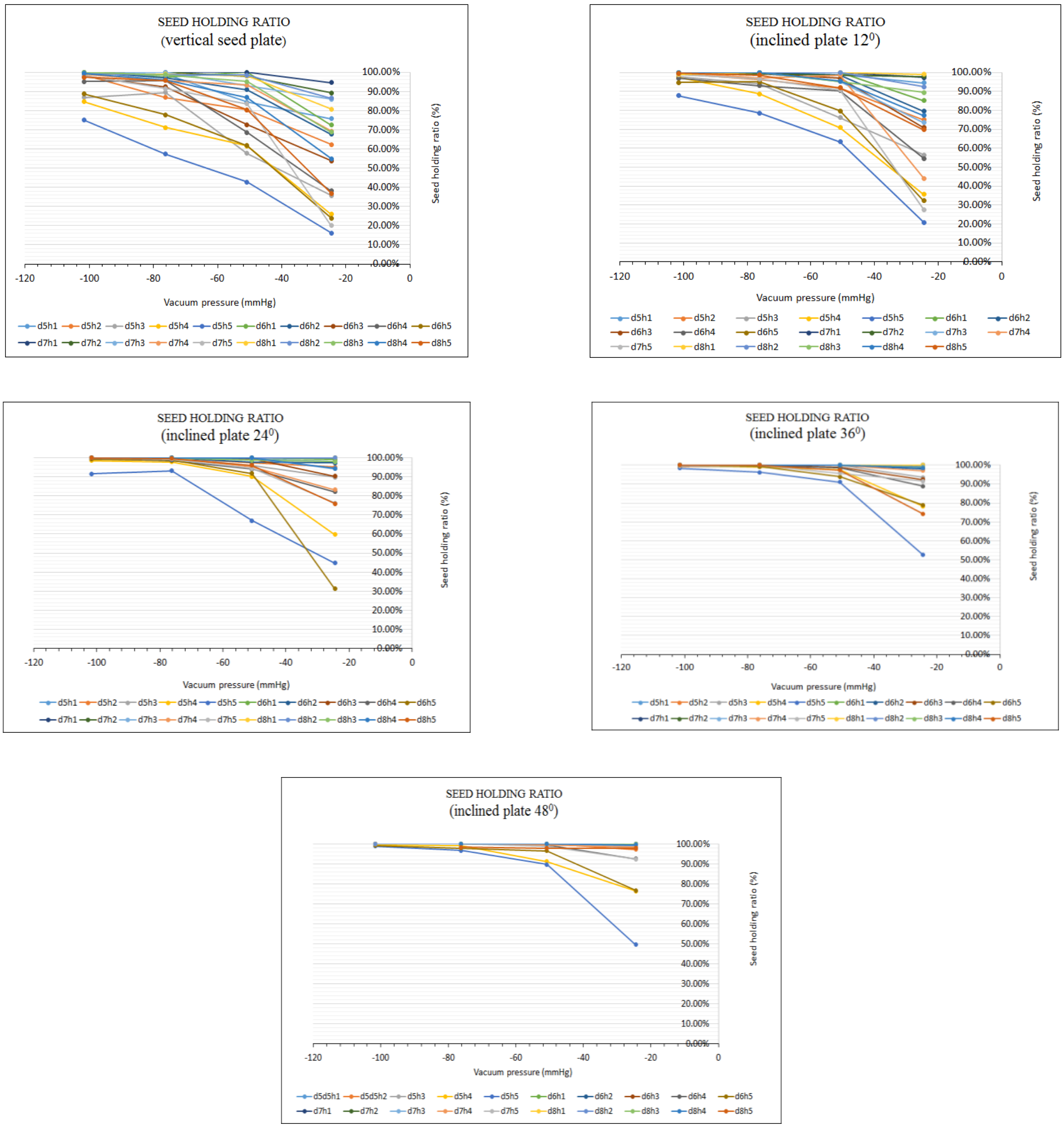


Figure 4. Effects of vacuum pressure on the seed holding ratio

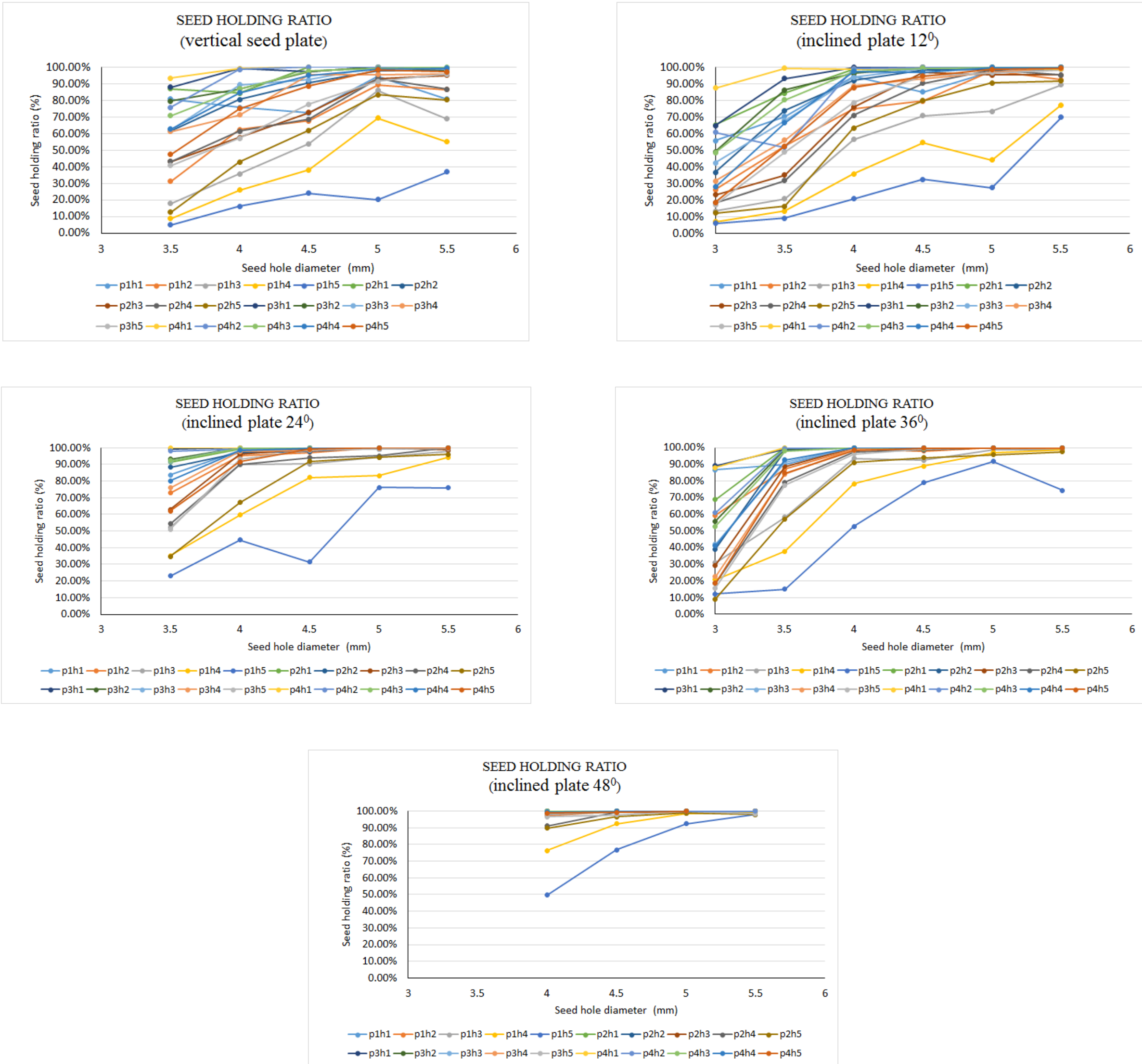


Figure 5. Effects of the seed hole diameter on the seed holding ratio

3.2. Effects of the seed hole diameter on the seed holding ratio

The suction and holding force on seeds depended not only on the vacuum pressure in the chamber but also on the diameter of the seed holes. At the same pressure, the larger the diameter of the seed holes, the greater the percentage of holes receiving seeds. Figure 5 shows the analyzed effects of the seed hole diameter on the ability of the metering device to receive seeds. According to the results, when the diameter of the seed holes was less than 4mm, the percentage of holes not receiving seeds was particularly high when using the vertical seed disc. When the seed hole diameter increased, the percentage of holes receiving seeds increased. At diameter d5 = 4mm, 100% of the holes received seeds when the inclined angle of the disc was greater than 24 degrees, the seed hole velocity was smaller than 0.58 m/s, and the vacuum pressure was less than -76.2mmHg. When the diameter of the seed holes was larger than 4 mm, at a pressure of -50.8mmHg, 100% of the holes received seeds when the disc was tilted at an angle greater than 24 degrees and the hole velocity could be increased to 0.68 m/s.

3.3. Effects of the seed hole velocity on the seed holding ratio

Increasing the seed hole velocity decreased the receiving ability of the holes, especially when the seed hole diameter and the pressure level in the chamber was large, as shown in Figure 6. This can be explained by the receiving ability's dependency on drag resistance caused by friction in the seed mass and inertial force when the seeds change from stationary to moving with the seed disc. When the seed hole diameter is large enough and the vacuum pressure in the chamber is small enough, the suctioning and holding forces will be large enough to overcome the resistance forces generated during the seed-receiving process of seed disc. In the series of experiments performed, the experiments with a seed hole velocity of 0.78 m/s (level h5), despite reducing the chamber pressure and increasing the seed hole diameter, still had a high percentage of holes not receiving seeds.

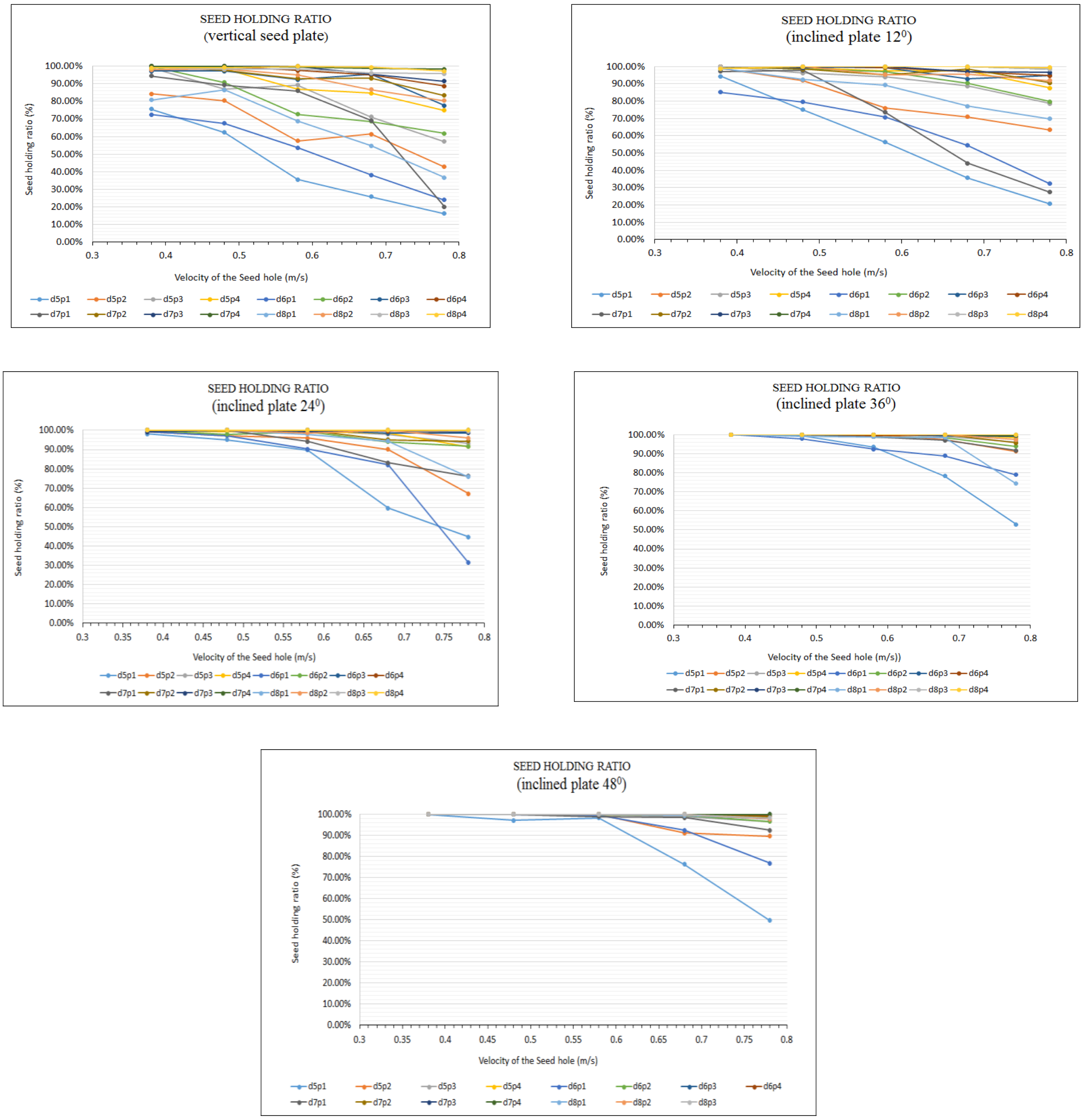


Figure 6. Effects of the seed hole velocity on the seed holding ratio

3.4. Effects of the inclined angle of the seed disc on the seed holding ratio

The inclined angle of the sowing disc plays an important role in the process of suctioning, holding, and dissociating the seeds of the seed disc. The holding force on the inclined disc was better than that on the vertical disc. Shown in Figure 7 are the analysis results of the rate of holes receiving seeds in the experiments corresponding to different pressure levels, seed hole diameters, and seed hole velocities. The results showed that when the disc was placed vertically, the percentage of holes not receiving seeds was high while under the same experimental conditions, the percentage decreased sharply as the seed disc became more tilted. With the same experimental conditions of d5h4p1, the percentage of holes not receiving seeds for the vertical disc was 74% while that of the 36-degree inclined disc was 22%. Similarly, with the d5h3p2 test conditions, the corresponding values were: vertical disc 42%, 24-degree inclined disc 4%, and 36-degree inclined disc 0%. However, experiment observations with tilted angles larger than 48 degrees showed that the dissociating process for the seeds outside the holes was poor. In these experiments, the percentage of holes receiving two seeds increased. In testing conditions where the pressure level was as high as -24.5mmHg, the hole velocity 0.38 m/s, and hole diameter 4 mm, when the disc was tilted to a 36 or 48-degree angle, the percentage of holes receiving seeds was 100%. When the pressure of the chamber was low (smaller than - 50.8mmHg) and the diameter of the holes was 4 mm or wider with an angle larger than 24 degrees, there were runs of the experiment with the percentage of holes receiving seeds to be 100%.

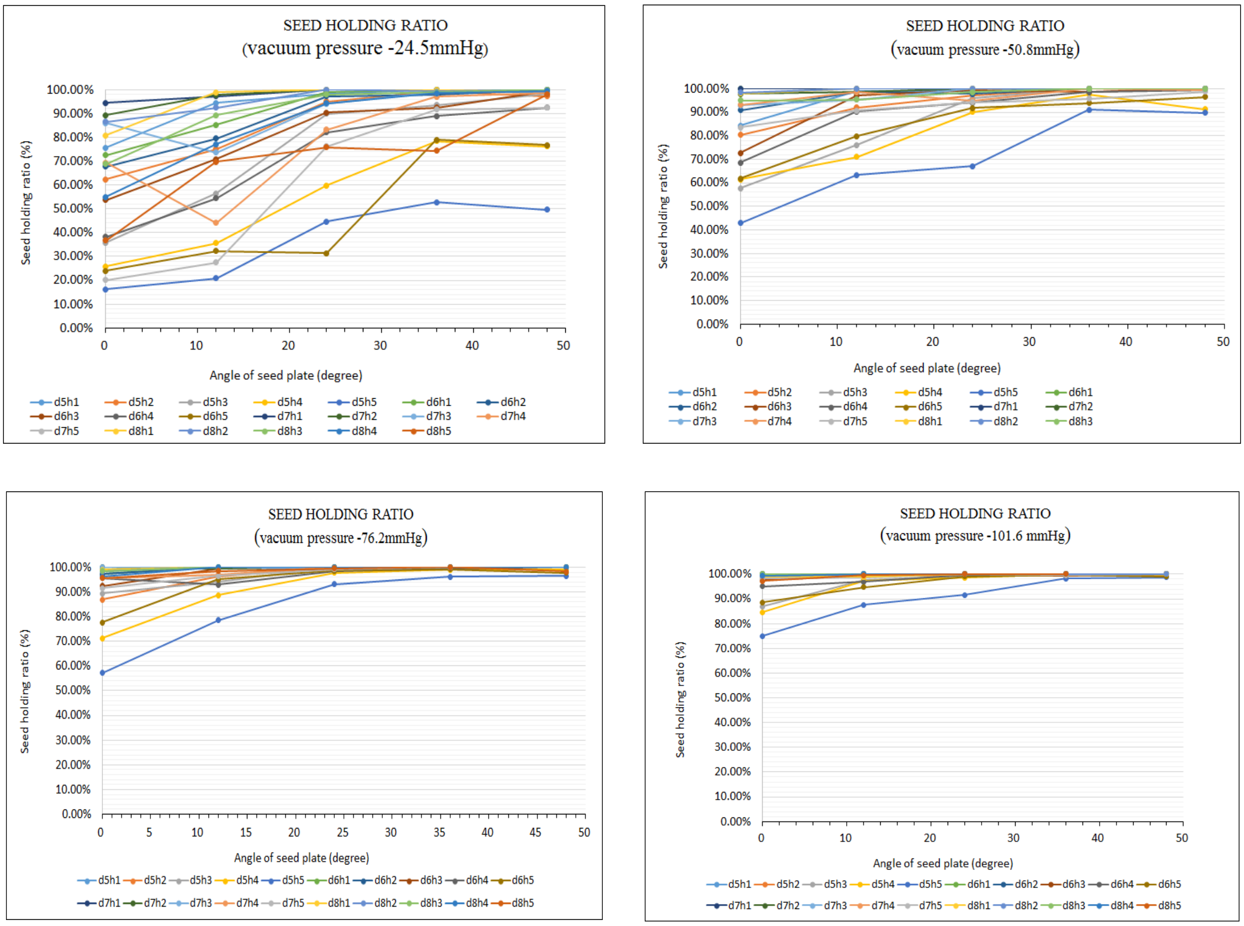


Figure 7. Effects of the inclined angle of the seed disc on the seed holding ratio

4. CONCLUSIONS

Experiments with a pneumatic metering device with a tilted disc showed better efficiency of the seed disc in receiving and holding seeds compared to that of a vertical disc device.

If the seed hole velocity is large, seeds are easily separated from the seed holes, which increases the percentage of holes not receiving seeds. When the vacuum pressure in the chamber is high and the seed hole diameter is small, the connection between the seeds and seed disc is weak; therefore, the percentage of holes not receiving seeds is higher as the seed hole velocity increases. To maintain the receiving ability of the seed disc, the velocity of the seed holes should be kept smaller than or equal to 0.68 m/s.

Under the same pressure in the chamber, the larger the seed hole diameter, the better the attracting and holding forces of the disc. However, increases in the seed hole diameter correspond to increases in the loss of pressure in the chamber. To ensure that all holes receive seeds, the pressure in the chamber needs to be increased.

When the disc is tilted, the pressure of seeds on the disc is comprised of the pressure of the seeds on the tilted surface and the air pressure, thus the force attracting and holding the seeds increases.

Studies have shown that the parameters influencing the quality of the metering device include: the vacuum pressure in the chamber, the seed hole velocity, and the seed hole diameter. The effective values of these parameters are: a vacuum pressure of -50 to -100mmHg; a seed hole diameter of 4-5.5mm; a seed hole velocity smaller than 0.68 m/s; and an inclined angle of the seed disc of 24-38 degrees.

REFERENCES

Arzu Y. & Adnan D. (2007). Optimization of the seed spacing uniformity performance of a vacuum type precision seeder using response surface methodology. Biosys. Engg. 97: 347-356.

Ismett O., Adnan D. & Arzu Y. (2012). An evaluation of seed spacing accuracy of a vacuum type precision metering unit based on theoretical considerations and experiments. Turkey J. Agric. and For. 36: 133-144.

Karayel D., Barut Z.B. & Ozmerzi A. (2004). Mathematical modeling of vacuum pressure on a precision seeder. Biosys. Engg. 87(4): 437-444.

Satti H.Y., Qingxi L., Jiajia Y. & Dali H. (2012). Design and test of a pneumatic precision metering device for wheat. Agril. Engg. Int. CIGR J. 14(1): 16-25.

Singh R.C., Singh G. & Saraswat D.C. (2005). Optimization of design and operational parameters of a pneumatic seed metering device for planting cotton seeds. Biosys. Engg. 92(4): 429-438.

Yasir H.S., Qingxi L., Jiajia Y. & Dali H. (2013). Dynamic analysis for kernel picking up and transporting on a pneumatic precision metering device for wheat. Agril. Engg. Int. CIGR J. 15(2): 95-100.

Yu J., Liao Y., Cong J., Yang S. & Liao Q. (2014). Simulation analysis and match experiment on negative and positive pressure of pneumatic precision metering device for rapeseed. Int. J. Agric. Biol. Engg. 7(3): 1-12.

Zeliha B.B. & Aziz O. (2004). Effect of different operating parameters on seed holding in the single seed metering unit of a pneumatic planter. Turkey J. Agric. Forestry. 28: 435-441.

Zhao Z., Li Y., Chen J. & Xu L. (2010). Numerical analysis and laboratory testing of seed spacing uniformity performance for vacuum cylinder precision seeder. Biosys. Engg. 106: 344-351.