Modeling and evaluation of a vacuum – cylinder precision seeder for chickpea seeds

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Abstract: In countries that agricultural fields are small, most farmers sow pea seed by scattering them by hand, which causes to decrease the yield. Thus, the objective of this study was to investigate the performance of a cylinder-type vacuum precision seeder for sowing pea seed in small fields. The effects of vacuum pressure, speed of grease belt and diameter of seed hole were evaluated by examining the mean seed spacing, quality feed index, coefficient of seed distribution uniformity, and miss and multiple indices. The main variables were vacuum pressure (40, 60 and 80 mbar), grease belt speed (2.5, 5 and 7 km h^{-1}) and seed hole diameter (3, 4 and 5 mm). The results indicated that the maximum performance of the metering device was founded at the vacuum pressure, grease belt speed and seed hole diameter of 60 mbar, 2.5 km h^{-1} and 4 mm, respectively. The miss index, multiple index, quality feed index, seed distribution uniformity coefficient and actual mean seed spacing were obtained as 10%, 5.54%, 84.46%, 79.87% and 11.94 cm, respectively. In the treatment of 3-40-7 (hole diameter (mm), vacuum pressure (mbar), and belt speed (km h^{-1}), respectively), higher miss index caused higher mean seed spacing; this is while in the treatment of 5-80-2.5, higher multiple index caused lower mean seed spacing.

Keywords: vacuum precision seeder, miss index, multiple index, performance of the seeder

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1 Introduction

Proper spacing of plants is important for maximum yields as well as for ease of care and picking. In agriculture, seeds that are sown by precision planters, offer greater precision than other traditional methods, namely broadcasting and drilling. Traditional sowing methods result in non-uniformity in distribution of seeds and poor control over depth of seed placement (Shelke, 2011; Walke, 2016). In the study that was conducted by Silim et al. (1990), the effect of seeding density and row spacing were investigated on the lentil yield. Results showed that the using of seed drill represent a potential saving in seed costs of 20% to 30% over hand broadcasting. In the study of investigating the sowing methods and seed rate on growth and yield of wheat, results showed that sowing by drilling method significantly increased the plant vigor and yield (Soomro et al., 2009). These studies indicated that traditional methods were not appropriate approaches for sowing seeds.

There are many studies conducted to investigate the performance of precision planters. Most of these studies focus on vacuum plate-type seeders. In a study investigating the performance of a plate-type vacuum seeder for sowing maize and cotton seeds, two important factors, namely forward speed (4.8, 7.2 and 9.7 km h^{-1}) with corresponding seed meter speed (0.16, 0.23 and 0.31 m s^{-1}), were investigated (Moody et al., 2003). It was concluded that the variance in seed spacing increased with the increasing ground speed. Singh et al. (2005) investigated the effect of factors such as rotational speed of seed meter, shape of seed entry and vacuum pressure on the variability in seed spacing as well as in miss and multiple indices. Appropriate diameter of disc hole, speed of seed meter and vacuum pressure were determined as 2.5 mm, 0.42 m s^{-1} and 2 kPa, respectively. In a study investigating the performance of a precision vacuum

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seeder for sowing melon and cucumber seeds, results showed that variability in seed spacing increased with the increasing ground speed. The results also revealed that the ground speed of 3.6 km h^{-1} resulted in a better seed pattern than the ground speeds 5.4 and 7.2 km h^{-1} (Karayel and Ozmerzi, 2001). Karayel et al. (2004) created mathematical models by using some physical properties of seeds. The aim of this research was to determine the optimum vacuum pressure of a precision vacuum seeder. Maize, cotton, soya bean, watermelon, melon, cucumber, sugarbeet and onion seeds were used in this study. The high and low optimum vacuum pressure was determined as 4 and 1.5 kPa for the maize and onion seeds, respectively. For the other seeds, the optimum pressure was determined between 1.5-4 kPa.

Modification, test and evaluation of a manually operated drum type seeder were conducted to investigate its field capacity. The field capacity of the seeder was lower than that of hand broadcasting; however, the partial budget analysis revealed that by using a rotary type seeder and a rotary type weeder, a farmer could earn a net benefit of US$55.06 per hectare compared to hand seedling followed by hand weeding (Islam and Ahmad, 1999). This kind of planter is very appropriate for the farmers who want to acquire the maximum profit and yield on the small lands. Besides, due to the small size of lands, the investment in purchasing this type of planting machines could have proper economic justification.

Zhao et al. (2010) investigated the performance of a vacuum-cylinder seeder for precise sowing of rapeseeds. In this study, positive differential pressure was used to release seeds. The main purpose of this study was to compare the numerical analysis and laboratory test of seed spacing uniformity. The forces acting on the seeds were calculated using the computational fluid dynamics (CFD). The fall time and horizontal displacement of the seeds were predicted by the numerical analysis and also, were measured and compared by a high-speed camera system. Results showed that the optimum levels for positive differential pressure and release angle for the precision seeding of the rapeseeds were in the range of 1-2 kPa and -10˚-0˚, respectively. Although the positive pressure has an effective role in the delivery of seeds into a furrow, but its especial sealing mechanism increase its cost and reduce its lifetime and reliability.

Yazgi and Degirmencioglu (2007) optimized the seed spacing uniformity performance of a vacuum-type precision seeder using reply surface methodology. The vacuum level, diameter of seed holes and rotational speed of the seed plate were considered as variables. In this study, the optimum level of vacuum pressure and seed hole diameter were found to be around 5.5 kPa and 3 mm for cotton seeds, respectively. The maximum performance was obtained at the lowest rotational speed of the seed plate.

Pea seed are the most widely produced seeds that have been planted in most countries and are the main source of protein for humans. In countries like Iran that agricultural fields are small, most farmers sow seeds by scattering them by hand. Thus, developing cheap and easy-to-use seeders seems to be necessary. Although there are many studies carried out to investigate the performance of plate-type seeders for various products (Singh et al., 2005; Zhao et al., 2010; Zhao et al., 2015), no studies were found to report the performance of vacuum-cylinder seeders for pea seed. Therefore, the main objectives of this study were to develop a simple and inexpensive seeder for small fields, and to investigate the effect of important factors on the planting precision of this seeder.

2 Materials and methods

In this research, the pea seeds were prepared from the farmers growing this native product for many years in Kermanshah, Iran. The seeds were healthy, vigorous, well matured and free from other materials. Some important physical characteristics of pea seed are shown in Table 1. The geometric mean diameter (d_s) of the seed was calculated by the following equation.

$$d_s = \sqrt[3]{lwt} \tag{1}$$

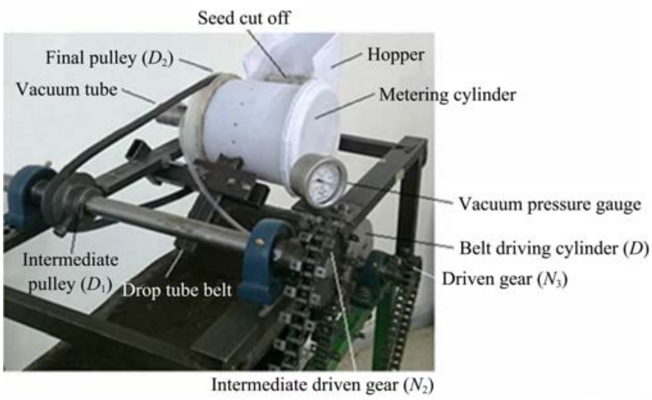
where, l (mm), w (mm) and t (mm) are the mean length, width and thickness, respectively.

According to the results of Table 1, the dimension of geometric diameter was used to determine the maximum hole seed diameter. To prevent entering of the seeds to the cylinder, the biggest diameter of the seed hole was assumed as 70% of the geometric diameter of the pea seeds.

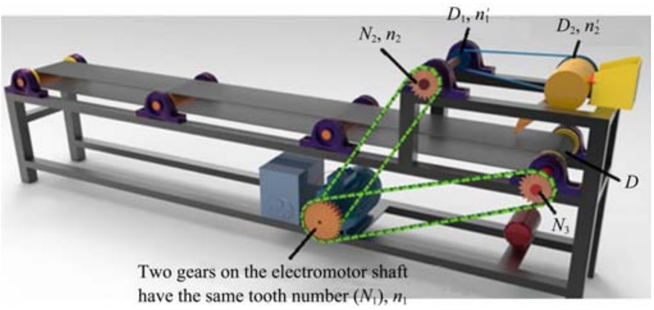
Table 1 Physical characteristics of pea seed

Physical properties	Minimum	Maximum	Mean	Mean of Std. Error	95% confidence limit
Length *l*, mm	8.61	10.24	9.70	0.10	9.70±0.20
Width *w*, mm	6.36	8.36	7.33	0.11	7.33±0.22
Thickness *t*, mm	6.83	8.10	7.28	0.09	7.28±0.18
Geometric diameter, mm	7.27	8.54	8.03	0.08	8.03±.15
Thousand seed mass, g	432.33	438.04	435.85	0.48	435.85±0.95

The precision planter used in this study was a vacuum type planter consisting of a rotating cylinder where the vacuum was supplied in the inner side of the cylinder and the seeds were held by the vacuum in the seed cells. When the seeds reached a point where the seed tube was located, they fell into the tube by a tangential metal sheet. A general view of the metering cylinder is shown in Figure 1.



(a) Real



(b) Schematic views

Figure 1 The metering mechanism of the precision vacuum seeder

The seeder performance was determined using greased belt stand. The length and width of the belt were 4 and 0.3 m, respectively. Seed-metering mechanism having a plastic cylinder of 200 mm outside diameter and 5 mm thickness was used. As Figure 1 shows, the metering cylinder was mounted on the final pulley of 250 mm diameter. This pulley can rotate freely about fixed vacuum metal tube. After choosing the appropriate size of pulleys (Pulley 1 and 2 in Figure 1) and gear 2 (N_2), and assuming the nominal seed distance of S as 10 cm (Siahkohian et al., 2009), the number of gear teeth (N_3) was calculated using the following relationships:

$$\frac{N_3}{N_1}=\frac{n_1}{n_3} \tag{2}$$

$$\frac{N_2}{N_1}=\frac{n_1}{n_2} \tag{3}$$

$$\frac{D_2}{D_1}=\frac{n_1'}{n_2'},\ n_1'=n_2 \tag{4}$$

$$S=\frac{\pi D n_3}{\lambda n_2'}=\frac{\pi D}{\lambda}\frac{N_1 n_1}{N_3}\frac{D_2}{D_1 n_1'} \tag{5}$$

$$N_3=\frac{\pi D}{\lambda}\frac{N_2}{S}\frac{D_2}{D_1} \tag{6}$$

where, S is the nominal seed distance (cm); N_1 is the number of teeth on the electromotor shaft; N_2 is the number of teeth on the intermediate driven gear; N_3 is the number of teeth on the gear, which is fixed to the shaft of belt-driving cylinder; D_1 is the diameter of intermediate pulley driven by the intermediate gear (cm); D_2 is the diameter of final pulley (cm); D is the diameter of belt-driving cylinder (cm); λ is the number of seed holes and $n_i(n'_i)$ is the number of rotation.

Vacuum pressure and belt surface speed were the important variables that affected the seeder performance. A vacuum pressure gauge (Instrumate, Slovenia) with a scale range of 0-100 mbar was used to measure the vacuum pressure. To provide a range of belt surface speeds, grease belt was driven by electric motor and its surface speed was controlled by using Starvert-iG5 inverter (LG Industrial System Co., Korea). To prevent rolling and bouncing of the seeds on the belt surface, the belt was coated with grease sufficient to catch the seeds as they were released from the seed tube.

In this study, 3^3 factorial design (three levels and three factors) was used in order to evaluate the performance of the seeder. The main variables were pressure (three levels of 40, 60 and 80 mbar), speed of grease belt (three levels of 2.5, 5 and 7 km h^{-1}) and seed hole diameter (three levels of 3, 4 and 5 mm) with three authentic replications. Twenty-five seed distances with misses and multiples were measured on the grease belt. Given the smaller length of belt than the standard, to measure the distance between the seeds, firstly, the conveyor belt was allowed to turn for 10 min and, then, after turning on the suction pump, the distances between the seeds were measured for each treatment using the camera.

2.1 Multiple index

When one seed hole of a metering cylinder delivers more than one seed, the distance between seeds fall less than 0.5 times the nominal seed distance; thus, the seed-to-seed distance is found to be less than nominal seeding distance. Low level of this index indicates a good and acceptable performance of the seeder as it does not affect the yield (Bakhtiari and Loghavi, 2010; Kachman and Smith, 1995). Pressure value, seed hole diameter and seed size are variables that can cause multiple index. The multiple index was calculated using the following relationship:

$$I_{multi}\% = \frac{n}{N}\times 100 \qquad (7)$$

where, I_{multi} is the multiple index, n is the number of seed spacing less than 0.5 times the nominal seed distance; N is total number of measured spacing.

2.2 Miss index

Miss index is the percentage of spacing greater than 1.5 times the nominal seeding distance. This can be created when seed hole cannot deliver seeds to the drop tube. Pressure value, level of hopper vibration, height of seed level in hopper and diameter of seed hole are the important variables that can affect the miss index. Since, in this study, the hopper was fixed, for decreasing its effect in the miss index, the height of seed level was controlled every time. Equation (8) was used for calculating the miss index (Singh et al., 2005).

$$I_{miss}\% = \frac{m}{N}\times 100 \qquad (8)$$

where, I_{miss} is the miss index; m is the number of seed spacing greater than 1.5 times the nominal seeding distance.

2.3 Quality feed of feed index

The quality feed of feed index (I_{qf}) is the percentage of spacing that are less than 1.5 times but more than half the set planting distance S in mm. The quality feed of feed index is a measurement of how often the spacings were close to the nominal spacing (Yasir et al., 2012).

$$I_{qf}\% = 100-(I_{miss}+I_{multi}) \qquad (9)$$

2.4 Coefficient of seed distribution uniformity

The coefficient of seed distribution uniformity (S_e) is the main factor that was used to measure the variability in seed spacing. This coefficient was calculated by using Equation (9) (Senapati et al., 1992).

$$S_e = (1-\frac{S_d}{S})\times 100 \qquad (10)$$

where, S_e is the coefficient of seed distribution uniformity (%); S_d is the mean absolute difference of actual seed spacing with respect to mean seed spacing (cm), and S is the nominal seed spacing (cm). Statistical software of SPSS (SPSS Inc., Chicago, IL, Version 16) and Matlab (The Mathworks, Inc., Natick, MA, USA, Version 15) were used to analysis and find the least significant difference (LSD) of effective variables.

3 Results and discussion

3.1 Effect of the vacuum pressure, belt speed and seed hole diameter on the mean seed spacing

Figure 2 showed that there were significant differences among the mean seed spacing at the three levels of pressure and the lowest mean seed distance was found at a vacuum pressure of 80 mbar. At this pressure, the mean seed spacing was obtained 15.54 cm. As the vacuum pressure increased, the amount of seed holding force also increased. Therefore, with the increase of the vacuum pressure, the mean seed spacing decreased.

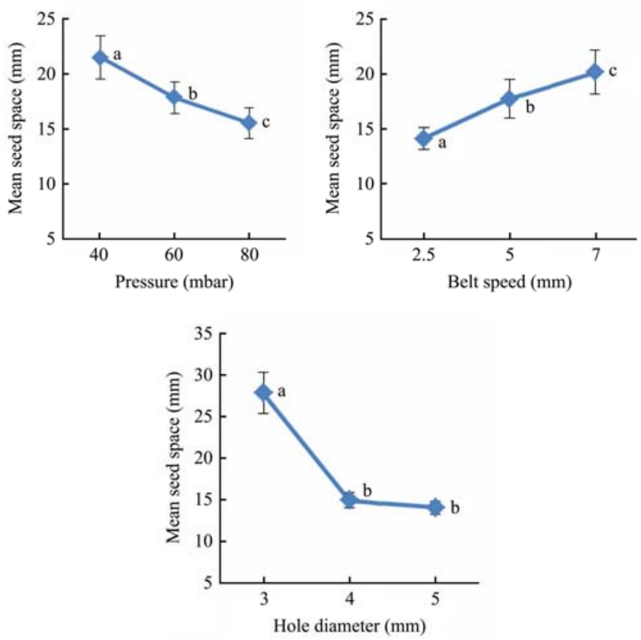


Figure 2 Effect of vacuum pressure, belt speed and hole diameter on mean seed spacing, means with the same letter are not significantly different at p=0.05

In the evaluation of the effect of belt speed on the mean seed spacing, the results (Figure 2) showed that the mean seed spacing at a belt speed of 2.5 km h^{-1} was close to the nominal seed spacing. Bouncing of the seeds at high speed was the main reason for the increase of seed spacing. Also, this figure indicated that the lowest mean seed spacing was obtained at a seed hole diameter of 5 mm and there was no significant difference between the hole diameters of 4 and 5 mm. The lowest mean seed spacing was found 14.03 cm at the diameter of 5 mm. At the hole diameter of 3 mm, the mean spacing dramatically increased. Decrease of the exerted force on the seeds can be the main reason for the increase in the mean spacing at this diameter. These results are in agreement with the previous findings by Singh et al. (2005) and Moody et al. (2003).

Figure 3 showed the interaction effect of seed hole diameter and vacuum pressure on the mean seed spacing. This figure showed that, with the increase in the diameter size of the holes and vacuum pressure, the mean distance of seeds approached the nominal value of 10 cm. Comparison of the mean using LSD test revealed that at the belt speed of 2.5 km h^{-1} there were no significant differences in the mean seed spacing among the treatments which have the hole seed diameter of 4 and 5 mm and the vacuum pressure of 60 and 80 mbar. The comparison of the means indicated that the three treatments of 5-80-2.5, 5-60-2.5 and 4-60-2.5 had a minimum difference of 15%, 18% and 19% from the nominal seed spacing, respectively.

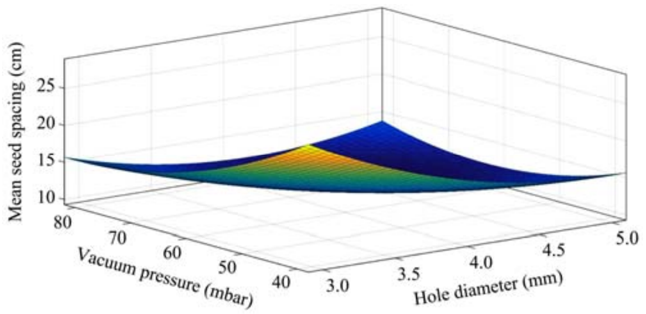


Figure 3 Effect of hole seed diameter, and vacuum pressure changing on the mean seed spacing (belt speed, 2.5 km h^{-1})

3.2 Effect of vacuum pressure, belt speed and hole diameter on the performance indices

As the vacuum pressure and seed hole diameter increased, the miss index decreased, while with the increase of the belt speed, this index increased (Figure 4). When the belt speed increased, the metering drum did not have enough time for picking the seeds; also, at lower vacuum pressure and smaller seed hole diameter, the holding force was low, resulting in higher miss indices.

Figure 4 showed that there was none potential difference in the quality feed of feed index between the seed hole diameter of 4 and 5 mm and there is no significant difference in quality feed index between 60 and 80 mbar vacuum pressures. Lowest values of this index was obtained at the seed hole diameter of 3 mm and 40 mbar vacuum pressure. In examining the effect of belt speed on the quality feed index, results indicated that the highest value of this index was found at 2.5 km h^{-1}. Figure 4 revealed that with the increase in vacuum pressure, the multiple index increased while with increasing the belt speed, this index decreased. Figure 4 showed that there were none significant differences in the seed distribution uniformity under different levels of vacuum pressure, belt speed and seed hole diameter

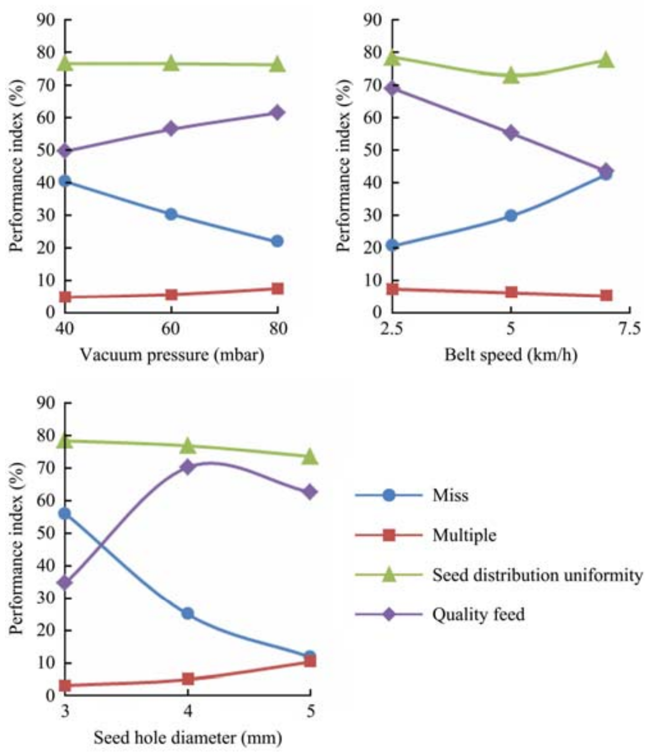


Figure 4 Effect of vacuum pressure, belt speed and hole diameter on the performance indices

Figurer 5 showed the interaction of the effective variables on the miss index. The results showed that as the seed hole diameter increased, the miss index decreased. Results indicated that the lowest value of the miss index was obtained in the 5-80-2.5 treatment followed by 4-80-2.5 and 4-60-2.5. These results are in agreement with the previous findings by Karayel and Ozmerzi (2001) and Yazgi et al. (2007). However, the results of investigating hole diameter effect on the miss index were observed to be the opposite to the findings of Shaaban et al. (2009) on the onion seeder performance. The opposite results may be explained by the differences in the type of metering devices (plate vs. drum) or the size of seed hole diameters.

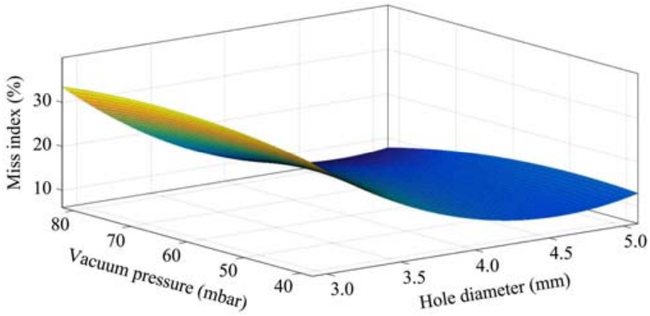


Figure 5 Miss index as a function of hole diameter and vacuum pressure (belt speed, 2.5 km h^{-1})

The results of interaction analysis (Figure 6) indicated that, like the miss index, the multiple index was proportional to the size of the seed hole diameter. At the smallest seed hole diameter, the multiple index was the lowest. The minimum and maximum values of this index were obtained in the 3-40-7 and 5-80-2.5 treatments, respectively.

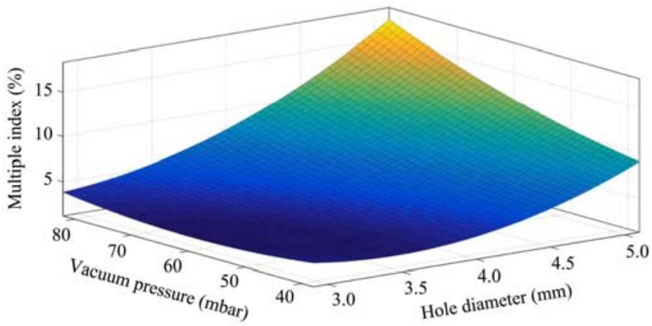


Figure 6 Multiple index as a function of hole diameter and vacuum pressure (belt speed, 2.5 km h^{-1})

A comparison of the miss and multiple indices indicated that the values of these indices at the seed hole diameters of 3 and 5 mm were inversely proportional. Figures 5 and 6 showed that at the hole diameter of 3 mm, the miss index was high but the multiple index was low; at the hole diameter of 5 mm, this relationship was reversed. Moreover, at the hole diameter of 4 mm, these indices were moderate.

3.3 Effect of hole diameter and vacuum pressure on quality feed of feed index and coefficient of seed distribution uniformity

The quality feed of feed index and coefficient of seed distribution uniformity are the important factors that are affected by miss and multiple indices. Figure 7 showed the quality feed index at 2.5 km h^{-1} speed of grease belt. This figure revealed that the quality feed of feed index was the highest at the vacuum pressure of 60 mbar and hole seed diameter of 4 mm. At low pressure of 40 mbar and small hole diameter of 3 mm, the high miss index lead to low quality feed of feed index, and at high pressure of 80 mbar and large small diameter of 5 mm, the high multiple index cause low quality feed index. However, at the vacuum pressure of 60 mbar, the effect of hole diameter on the quality feed index is not distinguishable as the values obtained at 4 and 5 mm diameters are statistically the same at 95% level of confidence. Coefficient of seed distribution uniformity values increased as the pressure increased (Figure 8). Its maximum value is obtained at the vacuum pressure of 60 mbar and the hole diameter of 4 mm. However, the hole diameter of 3 mm and vacuum pressure of 40 mbar produced the lowest values of this coefficient. Results of the distribution uniformity showed that the vacuum pressure of 60 mbar gave the highest values of the precision in spacing. However, there was none potential difference in the coefficient of seed distribution uniformity between 60 and 80 mbar.

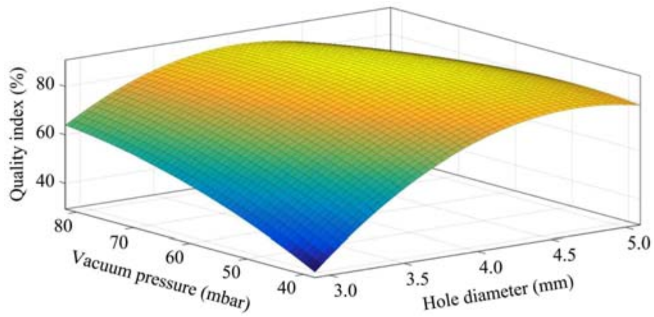


Figure 7 Quality feed index as a function of hole diameter and vacuum pressure (belt speed, 2.5 km h^{-1})

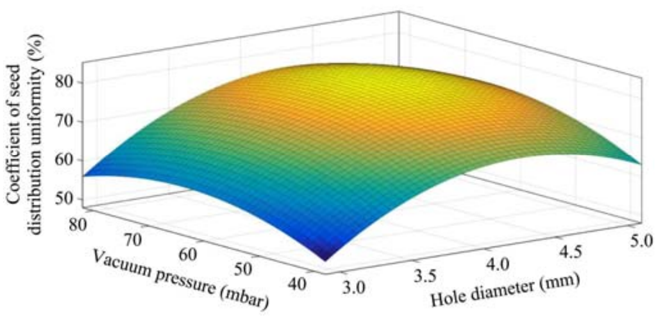


Figure 8 Seed distribution Uniformity as a function of hole diameter and vacuum pressure (belt speed, 2.5 km h^{-1})

As Table 2 showed the acceptable mean seed spacing, coefficient of the seed distribution uniformity, quality feed, miss and multiple indices were obtained in the treatments with the belt speed of 2.5 km h^{-1}. These results indicated that the time of picking up the seed had a more pronounced effect on these indices. At higher speed, lower vacuum pressure and smaller seed hole diameter, the miss index value was higher. In addition, at lower speed, higher vacuum pressure and larger hole diameter, the multiple index was also higher. These results are in agreement with the early findings by Singh et al. (2005). For the pea seed, the minimum value of the miss and multiple indices was obtained in the treatment of 4-60-2.5, in which the quality feed index and coefficient of seed distribution uniformity were 84.46% and 79.87%, respectively. Although the quality feed index of 4-80-2.5 treatment is higher than that of 4-60-2.5, there is no significant difference between the 4-60-2.5 and 4-80-2.5 treatments. Considering the mean seed spacing, multiple and miss indices, there is no significant difference between the treatments of 4-80-2.5 and 4-60-2.5. As shown in Table 2, the highest coefficient of the seed distribution uniformity was found in the 4-60-2.5 treatment and the Statistical analysis shows a significant difference between the 4-60-2.5 and 4-80-2.5 treatments at the 5% level of significance.

Table 2 Impact of seed hole diameter, pressure and belt speed on mean seed spacing, coefficient of seed distribution uniformity and Mean of miss and multiple indices

Treatments d(mm)-p(mbar)-v (km h^{-1})	Mean seed spacing (cm)	Coefficient of seed distribution uniformity (%)	Quality feed index (%)	Miss index (%)	Multiple index (%)
3-40-2.5	25.42	53.02	35.88	61.29	2.83
3-40-5	47.83	61.50	12.23	85.71	2.05
3-40-7	51.34	50.28	8.41	89.47	2.12
3-60-2.5	15.43	62.52	64.54	32.43	3.03
3-60-5	23.22	44.41	52.52	44.44	3.04
3-60-7	44.97	56.00	13.39	84.62	2.00
3-80-2.5	15.77	62.41	65.46	29.73	4.81
3-80-5	23.71	42.15	66.74	28.88	4.38
3-80-7	31.50	40.70	48.00	47.67	4.33
4-40-2.5	12.97	73.97	80.24	14.29	5.47
4-40-5	16.19	46.74	68.68	25.81	5.51
4-40-7	19.43	53.08	47.60	47.06	5.34
4-60-2.5	11.94[a]	79.87[b]	84.46[a]	10.00[a]	5.54[a]
4-60-5	15.91	60.92	71.35	24.24	4.41
4-60-7	15.47	59.39	54.12	42.94	2.94
4-80-2.5	12.15[a]	71.35[a]	84.72[a]	9.63[a]	5.65[a]
4-80-5	12.64	72.06	70.66	24.39	4.95
4-80-7	12.16	64.81	69.35	25.62	5.03
5-40-2.5	14.71	64.34	82.22	9.56	8.22
5-40-5	12.40	62.32	81.09	12.66	6.26
5-40-7	13.42	62.75	75.76	17.50	6.74
5-60-2.5	11.84	73.14	77.59	10.24	12.17
5-60-5	14.76	58.27	77.81	12.68	9.51
5-60-7	13.66	63.35	78.43	11.94	9.63
5-80-2.5	11.59	74.37	74.81	7.64	17.55
5-80-5	11.94	65.23	76.29	9.07	14.63
5-80-7	12.99	67.56	77.87	14.56	7.57

Note: [a–b] Different letters for each column indicate statistically significant differences at the 95% confidence level.

4 Conclusion

In this study, performance of a cylinder-type meter was investigated using pea seed. Results showed that the highest performance of the vacuum metering device was obtained at the vacuum pressure, belt speed and seed hole diameter of 60 mbar, 2.5 km h^{-1} and 4 mm, respectively. At the hole diameter of 3 mm, vacuum pressure of 40 mbar and speed of 7 km h^{-1}, higher miss index resulted in higher mean seed spacing. However, at the vacuum pressure of 80 mbar, hole diameter of 5 mm and speed of 2.5 km h^{-1}, higher multiple index caused lower mean seed spacing and lower quality feed index. Results of the research showed that the obtained quality index and seed distribution uniformity value were slightly lower than the values reported for the plate type metering device. One of the main causes for reduction in these indices could be the stability and lack of vibration on the hopper. Considering the lack of vibration in the hopper wall, the probability of seed placement next to the holes was reduced; as a result, the value of miss index was increased that reduced the value of quality feed index and seed distribution uniformity. Thereupon, the metering performance in the current situation was almost appropriate; but, to achieve the acceptable values, it is necessary to add a reservoir vibrational system or accept the device operation at the speed less than 2 km h^{-1}.

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