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Research Article

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Experimental evaluation of a fluted feed roller metering device performance in a pneumatic grain drill for rapeseed planting

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ABSTRACT - In the present study, the application feasibility of an air-assisted centralized metering device equipped with a fluted feed roller was investigated. The performance of the proposed metering device for rapeseed planting was evaluated in the laboratory. For this purpose, effects of rotational speed (n) of the metering device shaft (at levels of 46.5, 48, 79, and 96 rpm), active roller length, L, (at levels of 1/6, 1/4, and 1/3 of the total length of the fluted roller), and number (N) of seed delivery tubes (at levels of 16, 24, and 32 outlets) on the seed weight delivery coefficient of variation (CV) and seeding rate (SR, kg ha^{-1}) were investigated. A factorial experiment arranged as a completely randomized design with three replications was used to perform the laboratory experiments. Results showed that the effects of all treatments (n, L, and N) on both SR and CV were significant. The interactions of N×L and L×n were also significant on both SR and CV. The interaction of N×n was significant only on the SR. The interaction of N×L×n was also significant on the SR. Results of mean comparisons revealed that the CV decreased as n and L increased; whereas, it increased as N increased. However, the opposite pattern was observed for the SR with changing the mentioned factors. Minimum SR value (6.1 kg ha^{-1} – in the recommended SR range for rapeseed planting) was obtained at 46.5 rpm and L_1 (1/6 of the total length of the fluted roller) with 32- outlet seed delivery tube.

INTRODUCTION

General methods such as broadcasting, drill seeding, precision planting, and hill dropping are usually used for planting crop seeds (Rebati and Zareian, 2003; Gautam et al., 2019). The choice of planting method depends on different factors like the kind of crop, type of soil, soil fertility level, and amount of moisture available.

Drill seeding is one of the most important methods in which seeds are randomly dropped in a definite furrow and then covered. Wheat, barley, and canola seeds are usually planted with this method. In this planting method, weed germination is reduced due to the short distance between planting rows (Behroozi Lar, 2016; Owen et al., 2015). Most planters use a mechanical metering device, which can damage the seeds and reduce the seed viability. Since seeds in the pneumatic planters are selected and delivered by the air pressure difference between two sides of the metering disk and do not experience any mechanical force, they experience the least damage (Maleki, 2006; Amirian et al., 2017; Li et al., 2021; Xiong et al., 2021).

Obtaining the accurate seeding rate (SR) in the field to increase crop yield is important; therefore, setting the planter to select the exact number of planted seeds to prevent re-planting is necessary. In a grain drill equipped with a mechanical metering device, the force required to rotate the feed shaft of the metering system is provided by a gauge wheel drives. Providing the mechanical power to operate the metering devices with this method is cheap and effective. Different SRs are acquired by adjusting the ratio of the planter's forward speed to the rotational speed of the metering device feed shaft (Iacomi and Popescu, 2015; Ahmad et al., 2021).

The grain drill with an integrated seed tank is less commonly used. On the other hand, seed planters are evolving towards planters with a large field operation width (Ding et al., 2021). However, a further increase in the operation width of this kind of planter (more than 4 to 6 m) is too expensive, complex, and time-consuming (Yatskul et al., 2017). A pneumatic grain drill seems to be the best alternative to solve this problem (Wang et al., 2022). In this case, with only one seed tank, an operation width of 24 m or more can be provided. However, for uniform seed planting, a precise and technical solution is needed to ensure the uniformity of seed planting along the planting rows (Yatskul et al., 2017). The pneumatic planter uses the negative air pressure to take the seeds from the tank and send them with a positive air pressure to the metering device for precision planting. However, in order to plant more rows at the same time, high air pressure is required which causes a lot of energy consumption. The seeds of Rapeseed are small in size, have lightweight, high oil content, low shear strength, good spherical shape, and a smooth surface. The pneumatic grain drill is recommended for the planting of this type of seed (Yitao et al., 2017).

Seed planting by the air-assisted centralized metering device has attracted the attention of many researchers. In centralized metering device, the efficiency can be increased by using one metering device for multiple rows instead of traditional seed planting, which performs with one metering device for one row (Lei et al., 2021; Hu et al., 2021; Wu et al., 2022).

Different types of metering devices have been used in planters and it has been reported that the fluted feed roller metering device is widely used and the most common in seed drills (Maleki, 2006; Yasir, 2012; Minfeng et al., 2018; Huang et al., 2018; Xi et al., 2020; Xi et al., 2021). The main purpose of this study was to investigate the feasibility of implementing the fluted feed roller metering device in a pneumatic centralized system for rapeseed planting. For this purpose, the effects of the rotational speed of the metering device shaft, the active roller length, and the number of divider seed delivery tubes on SR and uniformity of seed distribution between planting units were investigated.

MATERIALS AND METHODS

The performance of the proposed metering device (fluted feed roller – Fig. 1) in an air-assisted centralized system (Murray et al., 2006) was evaluated in the laboratory of the Biosystems Engineering Department, School of Agriculture, Shiraz University, Iran.

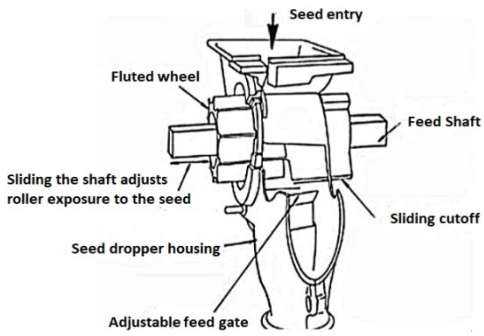
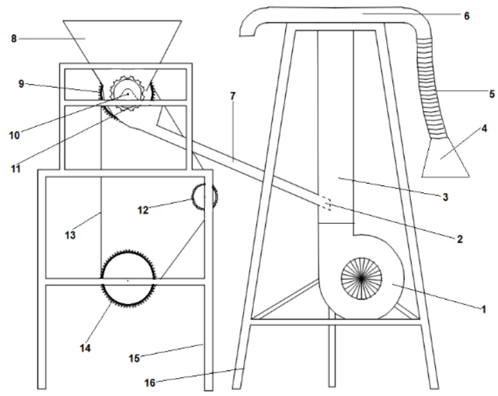
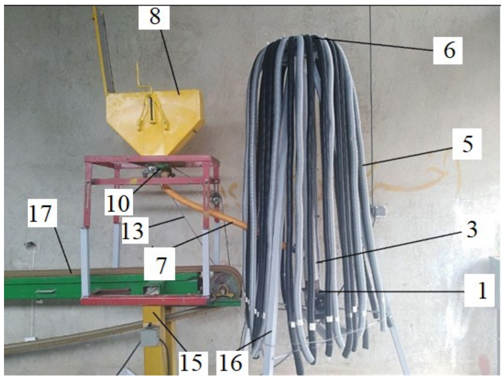


Fig 1. A fluted feed roller metering device (Murray et al., 2006)

A schematic (Fig. 2a) and real setup (Fig. 2b) of the proposed air-assisted centralized seed-metering device are shown. After turning on the single-phase centrifugal fan (FTP 92-2E-35-133) (1), air flows through the vertical tube (3), carries the seeds to the pneumatic divider (6) and then to the seed delivery tubes (5). The feed shaft of the metering device (11) rotates and carries the seeds from the tank (8) to the inclined tube (7) by the flute grooves which are exposed to the seeds. The created suction at the junction of the connecting (2) and vertical tubes (3) causes the seeds to be unloaded from connecting tube into the vertical tube.



(a)



(b)

Fig 2. (a) Schematic and (b) real setup of the air-assisted centralized seed-metering device used in this study; 1- Centrifugal fan, 2- Seed suction region, 3- Vertical tube under air flow pressure, 4- Seed collecting bag, 5- Seed delivery tube, 6- Pneumatic divider, 7- Seed transfer tube, 8- Seed tank, 9- Sprocket connected to the feed shaft of the metering device, 10- Bearing, 11- Fluted feed roller, 12- Idler sprocket, 13- Power transmission chain, 14- Sprocket connected to grease belt, 15- Grease belt chassis, 16- Pneumatic unit chassis, 17- Grease belt.

Experiments were arranged as a factorial based on a completely randomized design with three replications to investigate the effects of the rotational speed of the feed shaft of the metering device (at four levels of 46.5, 48, 79, and 96 rpm), the active roller length (at three levels of 1/3, 1/4, and 1/6 of the total length of the fluted roller), and the number of seed delivery tubes (at three levels of 16, 24, and 32 outlets) on the CV of seed weight (delivered by each seed delivery tube) and the SR. The main and interaction effect of treatments on dependent variables were evaluated by analysis of variance. Also, mean comparisons were carried out with Duncan's test. Statistical analyses were performed using SAS 9.1 software.

Since the 32-outlet divider was available in the laboratory of the Biosystems Department of Shiraz University, 16 and 8 numbers of the outlets divider were blocked to create 16 and 24-outlet divider configurations, respectively. Fig. 3 shows a typical schematic setup of the 24-outlet divider.

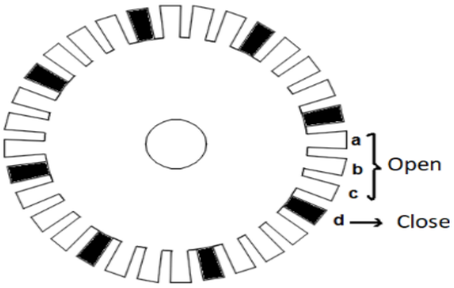


Fig 3. A typical schematic setup of a 24-outlet divider

In this study, the seed of rapeseed (Neptune cultivar) with a 1000-seed weight of 4.1 g was used. Similar experimental (Jafari et al., 2011; Yatskul et al., 2017; Minfeng et al., 2018; Gierz and Markowski, 2020) and numerical (Lei et al., 2018; Hu et al., 2021) studies were conducted to measure the CV of delivered wheat and rapeseed seeds weight from each delivery seed tube. They reported that the CV could be an important indicator in evaluating the planter performance. It should be noted that the lower CV indicates more uniformity in the planting rows. Equation (1) was used to calculate the CV (Jafari et al., 2011; Yatskul et al., 2017; Huang et al., 2018; Hu et al., 2021; Xi et al., 2021).

$$CV = \frac{\sigma}{\mu} \times 100 \quad (1)$$

where σ and μ denote the standard deviation and mean mass of samples, respectively. The SR was calculated using the weight of seeds consumed in a given area.

In the present study, the weight of delivered grains by each seed delivery tube in 30 seconds was measured. Collected samples were weighted by a digital scale (A&D, Japan, Tokyo) with an accuracy of ± 0.001 g. The range of grain drill forward speed for the planting of three seeds (wheat, barley, and sorghum seeds) was reported as 5.28-7.26 km h^{-1} by Al-Hamed et al. (2015). The forward speeds for the rapeseed planting were considered as 3, 5, 8, and 10 km h^{-1} and also at 4 and 6 km h^{-1} by Ahmadi, et al. (2008) and Mohammad-Ghasemnejad Maleki (2019), respectively. In the current study, the forward speed of the grease belt was considered as 4 km h^{-1} through all experiments.

RESULTS AND DISCUSSION

The variance analysis results, considering the effects of metering device rotational speed (n), the active roller length (L), and the number of seed delivery tubes (N) on the CV of seed weight delivered by each seed delivery tube are shown in Table 1. The effects of n, L, and N were significant on the CV at probability level of 1%. Also, the interactions of N × L and n × L on the dependent variable were also significant at probability levels of 1% and 5%, respectively.

The Effect of the Number of Seed Delivery Tubes on the Coefficient of Variation (CV)

It is sometimes needed to close some outlets of the seed metering device divider head during planting, such as adjusting the planting row space according to the plant species, machine configuration, soil type and conditions, seed delivery tube outlet clogging, and other agricultural practices management (Yatskul et al., 2017). Fig. 4 shows the effect of the number of seed delivery tubes (N) on the CV of seed weight delivered by each seed delivery tube. As can be seen, the CV for the N_1 = 16 outlets was less than N_2 = 24 and N_3=32 outlets. In the case of N_3 = 32 outlets, all the outlets of the divider were symmetrically open; therefore, the seeds were uniformly distributed between the seed delivery tubes and the CV, in this case, was lower than that of N_2 = 24 outlets. In the case of N_1 = 16 outlets, the divider had a good symmetry (one open and one blocked) and the number of outlets was also less than the others; therefore, enough seeds entered the outlets, which reduced the CV. The arrangement of the divider outlets in the case of N_2 = 24 outlets is shown in Fig. 2. Since there was a blocked outlet next to each three open outlets, the seeds were thrown around by colliding with the blocked outlets and collected in front of the middle open outlets (i.e., outlet b), and finally, they entered the middle outlet by air flow pressure. As a result, more seeds entered the middle outlet. This might be one of the reasons for the increase in the CV in this case in comparison to the other two cases.

The obtained results also were in close agreement with the findings of Yatskul et al. (2017). They investigated the influence of the outlet closing on the CV. They reported that the CV were increased due to closing the outlets of the divider head; therefore, closing variations were unfavorable. They recommended providing the "interchangeable heads" with the different outlet numbers. Furthermore, they found that statistically, the less number of outlets, the more likely it is to distribute the seeds with the high accuracy during a random seed distribution.

Table 1. Variance analysis of the seed weight delivery CV

Source of variation	Df	Mean squares	F-value
Number of seed delivery tubes (N)	2	1881.48	197.71**
Active roller length (L)	2	120.55	12.67**
Rotational speed of the metering device feed shaft (n)	3	74.82	7.86**
N×L	4	175.61	18.45**
N×n	6	17.27	1.82^{ns}
L×n	6	21.65	2.28*
N×L×n	12	10.71	1.13^{ns}
Error	72	9.51	

** and * refer to significant differences at probability levels of 1% and 5%, respectively; "ns" refers to non-significant differences.

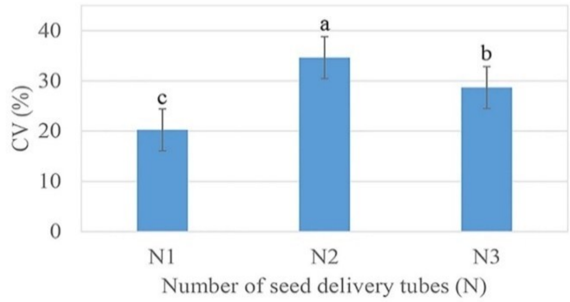


Fig 4. The effect of the number of seed delivery tubes on the coefficient of variation (CV). Different letters show significant differences at probability level of 1%.

The Effect of Active Roller Length on the Coefficient of Variation (CV)

Fig. 5 shows the effect of active roller length (L) on the

CV. As can be seen, the CV related to the active roller length of L_3 (1/3 of the total length of the fluted roller) was lower than for L_2 (1/4 of the total length of the fluted roller) and L_1 (1/6 of the total length of the fluted roller). The amount of feeding rate in the case of L_3 was the most. Therefore, for this treatment more seeds entered the pneumatic divider. This caused a sufficient number of seeds to enter all the outlets and hence the lowest CV was achieved. The difference between the CV values for the L_1 and L_2 was not statistically significant. Other researchers also reported that the CV decreased by increasing the active roller length of the metering device (Guler, 2005; Kara, 2010; Huang et al., 2018).

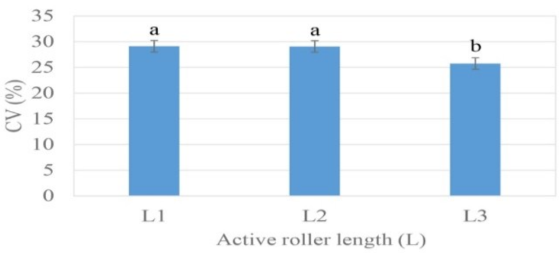


Fig 5. The effect of active roller length on the coefficient of variation (CV). Different letters show significant differences at probability level of 1%

According to Fig. 6, with 16-outlet seed delivery tubes (N_1) and the active roller length of L_3, enough seeds entered all outlets; therefore, a lower CV was achieved as compared to other treatments. In this case (16-outlet), by changing the active roller length from L_3 to L_2 or L_1, the active roller length decreased; hence, the CV of seed weight increased because of decreasing the feed rate. For N_3 = 32 outlets, the feed rate to the pneumatic divider increased as the active roller length increased. However, due to decreasing the air flow pressure of outlets, this large volume of seed was not well distributed between outlets. Therefore, for both active roller lengths of L_1 and L_2, better seed distribution occurred as compared to L_3. As a result, the active roller length of L_3 had a higher CV. In the case of N_2 = 24 outlets, by changing the active roller length from L_1 to L_2, the SR increased. Therefore, the most of seeds entered the middle outlet from the three outlets that were next to each other (i.e., outlet b in Fig. 2), which increased the CV. However, by changing the active roller length from L_2 to L_3, the SR increased and the middle outlet could not support and transfer this volume of seeds. Therefore, the extra seeds entered the two outlets on the right and left, which reduced the CV.

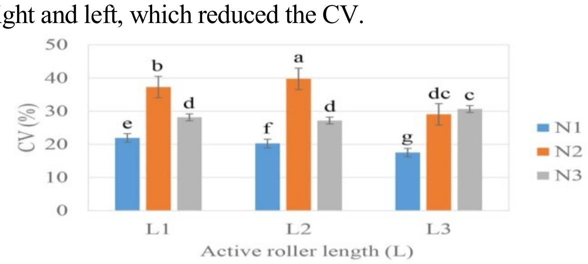


Fig 6. Interaction between the number of seed delivery tubes and active roller length on the coefficient of variation (CV). Different letters show significant differences at probability level of 1%

The Effect of Rotational Speed of the Metering Device Feed Shaft on the Coefficient of Variation (CV)

The influence of the rotational speed of the metering device feed shaft at four levels (n_1= 46.5, n_2= 48, n_3= 79, and n_4= 96 rpm) on the CV is shown in Fig. 7. The CV of seed weight for each seed delivery tube decreased with increasing the rotational speed of feed shaft. As the rotational speed of the feed shaft increased, more seeds entered the pneumatic divider and consequently, enough seeds fell into the seed delivery tubes. Therefore, a minor difference was observed between the weight of the collected seeds from each tube. Hence, the CV was decreased with increasing rotational speed of the feed shaft. In a similar study, Minfeng et al. (2018) evaluated the performance of a fluted feed roller metering device for wheat planting. They evaluated the metering device at nine levels of feed shaft rotational speed (i.e., 2, 4, 6, 8, 10, 15, 20, 25, and 30 rpm) and three levels of SR (i.e., 225, 300, and 375 kg ha^{-1}). The results showed that by increasing the feed shaft rotational speed, the CV of seed weight for each seed delivery tube was decreased. In another study, Al-Hamed et al. (2015) evaluated the performance of a mechanical seed drill in a laboratory at four levels of the rotational speed of ground wheels and three types of seeds (wheat, barley and sorghum). They reported that for all three seed samples, increasing the wheel rotational speed, reduced the CV of seed weight of each seed delivery tube. Similar results have been found in the relevant conducted researches (Guler 2005; Kara, 2010; Ozturk et al., 2012; An et al., 2017; Huang et al., 2018; Emrah and Yildirim, 2022).

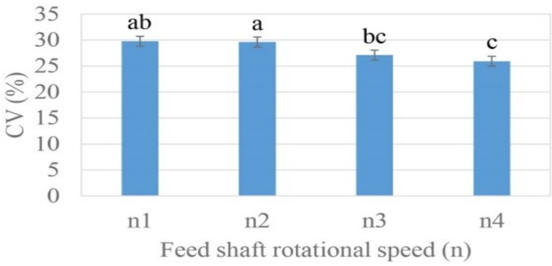


Fig 7. The effect of feed shaft rotational speed on the coefficient of variation (CV). Different letters show significant differences at probability level of 1%.

At all four levels of feed shaft rotational speed, changing the active roller length from L_1 to L_3 increased the seed discharge towards the divider (Fig. 8). Therefore, enough seeds entered the outlets and the CV was reduced. The rotational speed of n_1 was minimum; therefore, due to the increase in the active roller length (i.e., changing active roller length from L_1 to L_2), the seeds entered the pneumatic divider with a discrete rate and the CV was increased. By changing the active roller length from L_2 to L_3, more seeds entered the feed tube than previous case (i.e., L_1 to L_2); hence, the seeds accumulated inside the feed tube and were sucked into the air flow continuously. This factor caused the seeds to enter the divider continuously and as a result, the CV decreased.

The results of variance analysis, considering the effects of the N, L, and n on the SR are shown in Table 2. According to data from Table 2, the effects of N, L, and n were significant on the SR at probability level of 1%. Also, the interaction effects of N × L, N × n, and L×n were significant on the dependent variable at probability level of 1%.

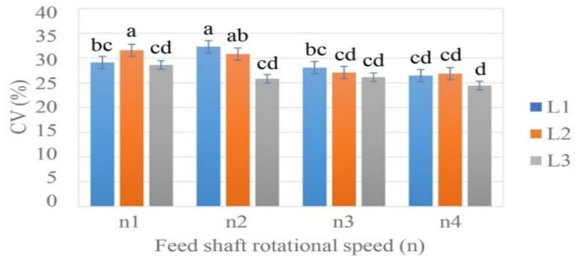


Fig 8. Interaction between the active roller length and feed shaft rotational speed on the coefficient of variation (CV). Different letters show significant differences at probability level of 5%.

Table 2. Variance analysis of the seeding rate (SR)

Source of variation	Df	Mean squares	F-value
Number of seed delivery tubes (N)	2	1479.4	1053.3^{**}
Active roller length (L)	2	682.51	485.94^{**}
Rotational speed of the metering device feed shaft (n)	3	691.12	492.06^{**}
N×L	4	89.17	63.49^{**}
N×n	6	31.8	22.64^{**}
L×n	6	13.14	9.36^{**}
N×L×n	12	3.43	2.44^{*}
Error	72	1.40	

** and * refer to significant differences at probability levels of 1% and 5%, respectively.

The Effect of the N, L, and n on the Seeding Rate (SR)

According to Fig. 9, the arrangement of seed delivery tubes with N_1=16 and N_3=32 outlets had the maximum (24.42 kg ha^{-1}) and minimum (11.73 kg ha^{-1}) SR values, respectively. It is cleared that the SR decreased as the number of seed delivery tubes increased. It should be noted that for the case of N_3=32 outlets, since the seeds were divided into a larger number of outlets; therefore, fewer seeds reached the outlets, which made the rate of seeds per hectare lower than the other two cases (i.e., N_1=16 and N_2=24 outlets).

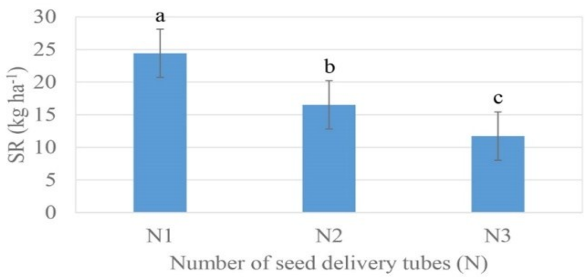


Fig. 9. The effect of number of seed delivery tubes on the seeding rate (SR). Different letters show significant differences at probability level of 1%.

It is shown from Fig. 10 that the SR increased as the active roller length increased. It was revealed that the SR had the minimum and maximum values in the cases of L_1 and L_3, respectively.

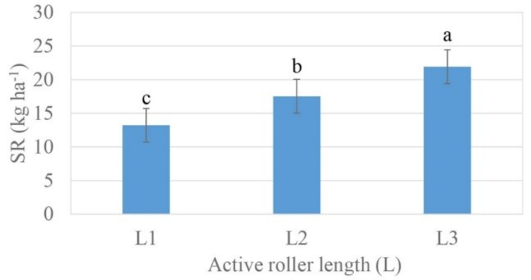


Fig 10. The effect of active roller length on the seeding rate (SR). Different letters show significant differences at probability level of 1%.

As can be seen from Fig. 11, as the rotational speed of the metering device feed shaft increased, the SR had been also increased. The maximum and minimum values of SR were associated with the n_1=46.5 and n_4=96 rpm, respectively. The obtained results (Figs. 9 and 10) also agreed with the findings of Guler (2005) and Huang et al. (2018). They reported that the SR increased as the active roller length and rotational speed increased.

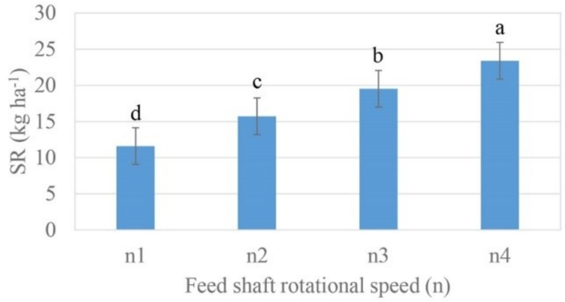


Fig 11. The effect of rotational speed of the metering device feed shaft on the seeding rate (SR). Different letters show significant differences at probability level of 1%.

Statistical analysis revealed that the interactions of N×L, N×n, and L×n were also significant on the SR. Furthermore, the interaction of N×L×n was significant on the SR. Also, it was cleared that the minimum SR value (6.1 kg ha^{-1}) was achieved at n_1 (46.5 rpm) and L_1 (1/6 of the total length of the fluted roller) with N_3=32 outlets. The obtained value of SR was in the recommended SR range for the rapeseed planting.

CONCLUSIONS

It was found that the effects of all treatments including the rotational speed (n) of the metering device shaft, the active roller length (L), and the number (N) of seed delivery tubes were significant on the SR and seed delivery CV. With increasing N and L, the CV was increased and decreased, respectively. The SR was also decreased and increased with increasing N and L, respectively. Increasing the rotational speed of the metering device, decreased the CV and increased the SR. The interactions of N×L and L×n were also significant on both SR and CV; whereas, the interaction of the N×n was significant only on the SR. The interaction of N×L×n was also significant on the SR. According to the triplet interaction analysis, it was revealed that the lowest CV (16.43% - acceptable CV range) was related to n_4 (96 rpm) and L_2 (1/4 of the total length of the fluted roller) with N_1=16 outlets. Also, it was cleared that the minimum SR value (6.1 kg ha^{-1} - recommended SR range for rapeseed planting) was achieved at n_1 (46.5 rpm) and L_1 (1/6 of the total length of the fluted roller) with N_3=32 outlets.

To generalize the application of the proposed seed metering device in a pneumatic centralized system for rapeseed planting, further studies are needed. It is also recommended to evaluate the metering device in the field in order to determine other performance parameters of planters equipped with this metering device like its energy consumption, the coefficient of uniformity, miss-seeding index, field efficiency, and percentage of seeds damaged during planting.

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ارزیابی آزمایشگاهی عملکرد موزع غلتکی شیاردار در خطی‌کار نیوماتیک برای کشت کلزا

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نرخ کاشت بذر

چکیده - در پژوهش حاضر، امکان‌سنجی بکارگیری یک خطی‌کار هوایی با موزع مرکزی، مجهز به موزع غلتکی شیاردار، مورد بررسی قرار گرفت. کارآیی موزع پیشنهادی برای کشت کلزا، در آزمایشگاه ارزیابی شد. برای این منظور، اثر تیمارهای سرعت دورانی محور موزع غلتکی (در سطوح ۴۶/۵، ۴۸، ۷۹ و ۹۶ دور بر دقیقه)، طول مؤثر موزع (در سطوح $\frac{1}{3}$، $\frac{1}{4}$ و $\frac{1}{6}$ از طول کل موزع استوانه شیاردار) و تعداد لوله‌های سقوط (در سطوح ۱۶، ۲۴ و ۳۲ عدد)، روی ضریب تغییرات وزن بذر و میزان بذر ریخته شده (کیلوگرم در هکتار) مورد بررسی قرار گرفتند. این پژوهش به صورت آزمایش فاکتوریل در قالب طرح کاملاً تصادفی و در سه تکرار، انجام گرفت. نتایج نشان داد که همه تیمارها، اثر معنی‌داری بر ضریب تغییرات وزن بذر و میزان بذر ریخته شده در هکتار دارند. اثر متقابل بین تعداد لوله‌های سقوط و موقعیت کشوئی موزع و بین سرعت دورانی و موقعیت کشوئی موزع بر صفات مورد اندازه‌گیری، معنی‌دار بود. اثر متقابل بین تعداد لوله‌های سقوط و سرعت دورانی موزع، فقط بر میزان بذر ریخته شده در هکتار معنی‌دار بود. همچنین، اثر سه‌گانه هر سه متغیر بر میزان بذر ریخته شده در هکتار معنی‌دار بود. با مقایسه میانگین‌ها، مشخص گردید که با افزایش سرعت دورانی و موقعیت کشوئی موزع، ضریب تغییرات وزن بذر کاهش می‌یابد؛ در حالیکه با افزایش تعداد لوله‌های سقوط، ضریب تغییرات وزن بذر افزایش می‌یابد. اگر چه، با تغییر تیمارهای ذکر شده، الگوی معکوسی برای نرخ بذر ریخته شده، مشاهده گردید. کمینه میزان بذر ریخته شده (۶/۱ کیلوگرم در هکتار- در محدوده پیشنهادی میزان بذر ریخته برای کشت کلزا)، در سرعت دورانی ۴۶/۵ دور در دقیقه و طول مؤثر موزع ($\frac{1}{6}$ از طول کل موزع استوانه شیاردار) توسط مقسمی با ۳۲ لوله سقوط بدست آمد.