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Evaluation of the Seed Flow Uniformity of the Fluted Feed Roller Designed for Coarse-Grained Seeds

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ABSTRACT
In this study, the nine fluted rollers designed for coarse-grained seeds and with the flute diameters of 18, 20, and 22 mm and the flute depths of 5, 8, and 11 mm were evaluated for dry bean seed. Each fluted roller were operated at the ground speeds of 1.0, 1.5, and 2.0 m s^{-1} for at the seed rates of 80, 120, and 160 kg ha^{-1}. Performance for the flow accuracy of the seeds is taken into account in the evaluations and for this; the values of coefficient of variation were used. The optimum dimensions were determined by applying statistical analyses for the CV values obtained from each replication in the study conducted in three replications. According to the analysis results, it was determined that the prescribed flute diameters do not have a stable effect on the flow accuracy, the flow accuracy partially increased as flute depth was increased, and better as the seed rate and the speed of the feed shaft was increased. In this regard, the optimum dimensions for the best seed flow accuracy were obtained from the flute depth of 8 mm, seed rate of 160 kg ha^{-1}, and at the ground speed of 2.0 m s^{-1}.

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İri Daneli Tohumlar için Tasarlanan Oluklu Makaranın Tohum Akış Düzgünlüğünün Değerlendirilmesi

ÖZET
Bu çalışmada, iri taneli tohumlar için 18, 20 ve 22 mm oluk çaplarında ve 5, 8 ve 11 mm oluk derinliklerinde tasarlanan dokuz adet oluklu makara kuru fasulye tohumunun akış düzgünlüğü için değerlendirilmiştir. Her bir oluklu makara, 80, 120 ve 160 kg ha^{-1} ekim normları için 1.0, 1.5 ve 2.0 m s^{-1} ilerleme hızlarında çalıştırılmıştır. Tohum akış düzgünlüğünün belirlenmesinde varyasyon katsayısı değerleri kullanılmıştır. Üç tekerrürlü olarak yürütülen çalışmada, her tekerrürde elde edilen CV değerleri için istatistiksel analizler yapılarak, optimum boyutlar belirlenmiştir. Analiz sonuçlarına göre, öngörülen oluk çaplarının akış oranı düzgünlüğü üzerinde kararlı bir etkisinin olmadığı, oluk derinliği arttıkça akış oranı düzgünlüğünün kısmen arttığı, ekim normu ve ilerleme hızı arttıkça akışın daha iyi olduğu belirlenmiştir. Bu bağlamda, en iyi tohum akış düzgünlüğü için optimum boyutlar, 8 mm'lik oluk derinliği, 160 kg ha^{-1} ekim normu ve 2,0 m s^{-1} ilerleme hızından elde edilmiştir.

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INTRODUCTION

One reason for reduced yield is uneven seed germination (Nafziger, 1996). The uniform development of the plant depends on the even of the plant distribution in the field, that is, the precision and accuracy of the application rate of the seed metering mechanism. The uneven flow of seeds during sowing, which depends on the metering mechanism of the seeder, causes uneven seed distribution in the field and affects competition among plants in terms of existing moisture, light, and nutrients (Griepentrog, 1998; Karayel and Özmerzi, 2002).

Dry bean seeds can be planted with both cereal seeders and precision seeders. However, there are restrictive reasons in choosing a seeder, such as purchasing power of the enterprise, the farmer's lack of technical knowledge about precision seeders (Ess et al., 2005), precision seeders cannot technically perform the sowing operation in narrow row spacing (Parish et al., 1999), and sowing performance deteriorates in spacing less than 5 cm intra-row (Önal, 2011).

Fluted roller seeders can be used as an alternative to these seeders for the sowing of small and coarse seeds (Halley and Soffe, 1988). Griepentrog (1994) stated that the fluted roller seeders, which are cheaper for narrow row spacing, were relatively preferred precision seeders. Fluted roller metering devices have been in use for over 300 years and are the most widely metering devices used in today's mechanical cereal seeders (Brown, 2003; Maleki et al., 2006; Li et al., 2016; Yang et al., 2018). Despite widely preferred due to its design, simplicity, ease to manufacture, lightweight, easy flow rate adjustment, and suitable for high-speed sowing, when the appropriate roller structural and operating parameters are not selected for seeds with different physical properties, the metering device may give an uneven seed distribution pattern (Ryu and Kim, 1998; Brown, 2003; Ess et al., 2005; Jin et al., 2018).

Current developments in seeders have been allowing higher sowing speeds. However, it is not easy to achieve a successful distribution uniformity pattern at these speeds for seeds of different physical properties. Therefore, improving the flow rate uniformity in fluted roller seeders is still an important research focus. Important studies have been carried out on the structural features of fluted roller metering devices. Nukeshev et al. (2016) proposed a new design of roller pin, where the pins are in the form of a truncated pyramid to prevent passive zone on the roller during sowing; they reported this configuration allowed the metering devices to operate properly in slow roller rotational speed. And, Sugirbay et al. (2020) showed that the discharge uniformity of the pin and the discharge amount increase by optimizing the design parameters of the new pin-roller for variable-rate and variable-speed applications. Yıldırım and Kuş (2014) designed fluted rollers with different flute diameters (18, 20, and 22 mm) and flute helical angles (0, 10, and 20^o) to examine the flow rate uniformity of metering device for coarse seeds. They reported that the best flow rate values were obtained from the flute diameter of 18 mm and the helical angle of 20^o.

One of the most important parameters affecting sowing performance in metering devices of the fluted roller is the physical properties of seeds such as shape, size, and mass. Fluted feed rollers, especially in the case of using the suitable flute diameters for the seed sizes, have a universal structure that can sow various seeds from small seeds to coarse seeds. In this context, in this study, the flow accuracy of the dry bean was investigated for different seed rates and ground speeds using fluted feed rollers designed in different flute diameters and depths.

MATERIALS and METHODS

This research was carried out at workshop of department the farm machinery and technologies engineering of the agricultural faculty, Ataturk University, Turkey. Dry bean (*Phaseolus vulgaris L.*) seeds cleaned of foreign materials such as stones, crust, garbage, and so on were used in tests. Thousand-grain weight, angle of repose, sphericity, bulk density, and moisture content values of dry bean seeds were 309 g, 20 °, 64%, 770 kg m^{-3} and 10%, respectively. In addition, seed sizes (length, width, and thickness) ranged from 9.5-14.1 mm, 6.7-9.0 mm, and 3.2-6.1 mm, respectively. The test setup consisted of a fluted roller seed metering mechanism coupled to a DC motor via a chain drive (Fig. 1). A speed control unit was used to synchronize the DC speed corresponding to the ground speed of operation. The active area of the rollers was adjusted by a screw mechanism.

Nine fluted rollers made of Delrin was used in the tests. The fluted rollers with bottom delivery used in the study were manufactured in the flute diameters of 18, 20, and 22 mm according to dry bean sizes and the flute depths of 5, 8, and 11 mm. The rollers were used in the feed unit at the bottom of the hopper of the seeder. The width of the slot between the roller and the bottom plate of the feed unit was 13.5 mm.

In the study, which was carried out according to the completely randomized factorial design, the flow uniformity of the dry bean seeds from the fluted roller metering device was examined. The experiments were arranged in three replications including three flute diameters, three flute depths, three roller rotation speeds (i.e. three ground speeds) for three seed rates of dry bean. Dry bean is sown in inter-row distances of 40-60 cm and the rates of 60-180 kg ha^{-1} based on the various big of seed. The seed rates of 80, 120, and 160 kg ha^{-1} for dry beans were used in the study. The inter-row distance of dry beans was selected 45 cm according to the values used in practice. The individual flow rates of the fluted rollers were calculated to obtain the seed rates of 80, 120, and 160 kg ha^{-1} at the roller rotation speeds of 8, 13, and 18 min^{-1} corresponding to the ground speeds of 1.0, 1.5, and 2.0 m s^{-1} in a seeder for the inter-row distance of 45 cm (Table 1).

A precision balance was employed at the bottom end of the seed delivery mechanism to detect the flow rates of seeds. The seed flowed from the fluted roller metering device for each replication was weighed at intervals of 0.1 second cumulatively with an accuracy of 0.01 g and the data were transmitted simultaneously to a PC with a continuous stream by RS 232 C interface circuit of the balance (Yıldırım and Kuş 2016). The coefficient of variation (CV) values defined as the standard deviation divided by the mean value were used to evaluate the seed flow uniformity of the fluted roller metering device. For this, by taking the differences between successive cumulative weighing values of each repetition, absolute weighing values were obtained and the CV values were computed from these values. However, Duncan multiple range tests were conducted to show whether there was a difference between parameter levels. The CV values were evaluated according to the criteria reported by Turgut et al. (1995). According to this the CV values of 0-5%, 5-10%, and 10-20% were "very good", "good", and "acceptable", respectively. For this, the 200 (20 s), 133 (13.3 s), and 100 (10 s) data were evaluated for the ground speed of 1.0, 1.5, and 2.0 m s^{-1} for the row of 20 m, respectively. The study, in which 27 trials were carried out for each roller, was completed with a total of 243 experiments.

Table 1. The individual flow rates and effective flute length values of fluted rollers
Çizelge 1. Oluklu makaraların akış oranları ve etkin makara uzunlukları

Ground speed, m s^{-1} (min^{-1})	Seed rate (kg ha^{-1})					
	80		120		160	
	Flow rate (g s^{-1})	ERL (mm)	Flow rate (g s^{-1})	ERL (mm)	Flow rate (g s^{-1})	ERL (mm)
1.0 (8)[a]	3.6	24	5.4	34	7.2	42
1.5 (13)	5.4	21	8.1	31	10.8	39
2.0 (18)	7.2	18	10.8	28	14.4	36

[a]: Values in brackets is feed shaft speeds, ERL: effective flute length

RESULTS and DISCUSSION

The results of variance analysis and multiple range test applied to the CV values obtained from each repeat are shown in Table 2. According to Table 2, the effect of the ground speed (or feed shaft revolution), flute diameter, and flute depth on the flow accuracy of dry bean seeds was found to be highly significant ($P<0.001$). As seen in multiple range tests, increased ground speed and seeding rate decreased CV values, thus increasing seed flow accuracy. Although the results of the variance analysis were significant and there was a general difference between the levels in the results of the multiple comparison test, the CV values of the flute diameter did not show a significant decrease or increase. This shows that the projected roller flute diameters do not provide a uniform flow uniformity for dry bean seeds. It is also possible to understand the instability in seed flow accuracy occurring due to the flute diameter, from the change in CV values, showed in Figures 2, 3, and 4.

The results of the multiple range test show that all levels of ground speed differ significantly from each other in each seeding rate. As the seed rate increased, the CV values decreased for all ground speeds. For this reason, it can be said that the higher seed rate and the ground speed increased the flow accuracy in bean sowing with fluted roller metering devices. With the increase of seed rate from 80 kg ha^{-1} to 160 kg ha^{-1}, the decrease rate in the CV values occurring at 1.0, 1.5, and 2.0 m s^{-1} ground speeds, were 28%, 32%, and 35%, respectively. CV values, which are higher at the same ground speeds and lower seeding rates, increased the flute fill rate with the increase of the seeding rate and accordingly decreased the CV values. In addition, the rate of decrease in the CV values that occurred at 80, 120, and 160 kg ha^{-1} seed rates with the increase of the ground speed were 47%, 50%, and 52%, respectively.

Since sufficient time cannot be provided while working at low roller rotation speeds with lower seeding norms, the flutes are not filled with seeds and as a result, pulsed flow occurs. Seed flow mass increased, as effective roller length was increased to achieve seed rates of 80, 120, and 160 kg ha^{-1} at the same ground speed. It is thought that it was provided a more stable flow as the flutes will fill better by seeds as the seed flow mass increases. However, it is thought that the decrease in the CV values with the increase in the ground speed is not due to the better filling of the flutes, but by the faster rotating roller providing a more stable flow.

When the results in flute depth were examined, there was a more stable situation compared to the flute diameter. While the CV values obtained depending on the flute depth were lower at lower seeding rates, these values also increased with the increase of the seeding rate. In fact, with the greatest seeding rate and ground speed, CV values decreased with increasing flute depth and seed flow became more stable. Increasing the seeding rate improved seed flow uniformity by decreasing CV values at all levels of both flute diameter and flute depth. While CV values in all flute depths were statistically different from each other in the lowest seeding rate, there was no statistical difference between 5 and 8 mm flute depths in the remaining seeding rates. The lowest CV values in flute depth are generally obtained from 8 mm. With the increase of seeding rate from 80 kg ha^{-1} to 160 kg ha^{-1}, the decrease rate in the CV values occurring at 5, 8, and 11 mm flute depths, were 27%, 34%, and 33%, respectively. It is obvious that the greatest decrease in

CV values occurred with the increase of the ground speed in each seeding rate. In this context, the parameter that most affects the flow accuracy of the dry bean seed was the ground speed (i.e. the rotational speed of the roller).

The CV values obtained in all combinations of fluted metering roller's ground speed, flute diameter, and flute depth for 80, 120, and 160 kg ha^{-1} seeding rates are respectively; it is shown in Figures 2, 3, and 4. The data point given for each flute depth in the figures is the average of three repeats. In all seed rates, for each flute diameter and depth, the highest mean CV values were obtained at 1.0 m s^{-1} ground speed and the lowest values at 2.0 m s^{-1} ground speed. The mean values of CV given in Figures 2, 3, and 4 vary between 4-20%. All CV values obtained from the current study, it was below the "acceptable" (CV <20%) limit value reported by Turgut et al. (1995).

Table 2. The results of variance analysis and Duncan's Multiple Range Test (DMRT)
Çizelge 2. Varyans analizi ve Duncan Çoklu Karşılaştırma Testi sonuçları

Variance sources	Seeding rate (kg ha^{-1})								
	80			120			160		
	df	SS	P	df	SS	P	df	SS	P
Ground speed (GS)	2	822.82	0.000	2	636.72	0.000	2	530.77	0.000
Flute diameter (FD)	2	14.69	0.000	2	20.16	0.000	2	20.58	0.000
Flute depth (FDH)	2	47.94	0.000	2	17.40	0.000	2	34.28	0.000
GS x FD	4	10.58	0.001	4	9.03	0.000	4	9.91	0.000
GS x FDH	4	5.26	0.037	4	2.71	0.133	4	4.93	0.000
FD x FDH	4	6.64	0.013	4	0.384	0.901	4	13.20	0.000
GS x FD x FDH	8	12.48	0.004	8	11.25	0.001	8	13.57	0.000
Error	54	25.79		54	19.82		54	5.44	
Total	80			80			80		
DMRT									
Seed rate+	Ground speed (m s^{-1})			Flute diameter (mm)			Flute Depth (mm)		
	1.0	1.5	2.0	18	20	22	5	8	11
80 kg ha^{-1}	16.35**a**	11.19**b**	8.69**c**	12.33**a**	12.43**a**	11.48**b**	12.00**b**	11.18**c**	13.06**a**
120 kg ha^{-1}	13.64**a**	9.35**b**	6.85**c**	9.34**c**	10.56**a**	9.92**b**	10.18**a**	9.30**b**	10.35**a**
160 kg ha^{-1}	11.77**a**	7.56**b**	5.64**c**	8.72**a**	7.61**b**	8.64**a**	8.79**a**	7.40**b**	8.78**a**

+: Means followed by the same letter in each group are not significantly different at the 0.95 level.

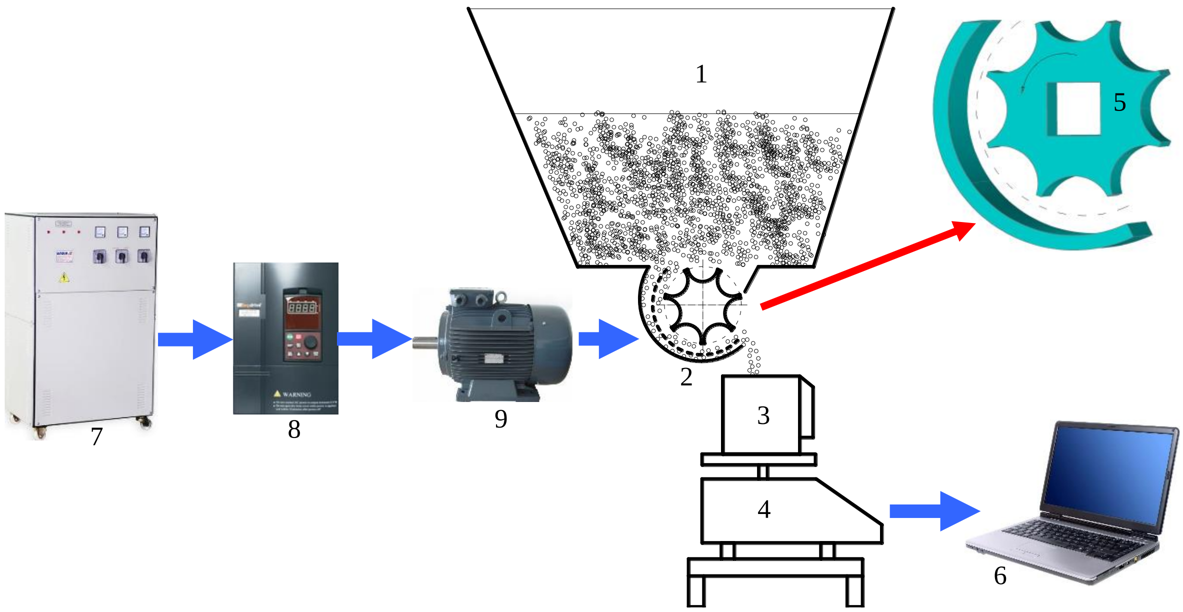

Figure 1. The instruments and equipment used in experimental test rig: hopper (1), seed metering device (2), container (3), electronic scale (4), and fluted roller (5), personal computer (6), regulator (7), speed control unit (8), and AC motor. (9)

Şekil 1. Deneme düzeneği: tohum deposu (1), ekici düzen (2), toplama kabı (3), hassas terazi (4), oluklu makara (5), bilgisayar (6), regülatör (7), hız kontrol ünitesi (8) ve elektrik motoru (9)

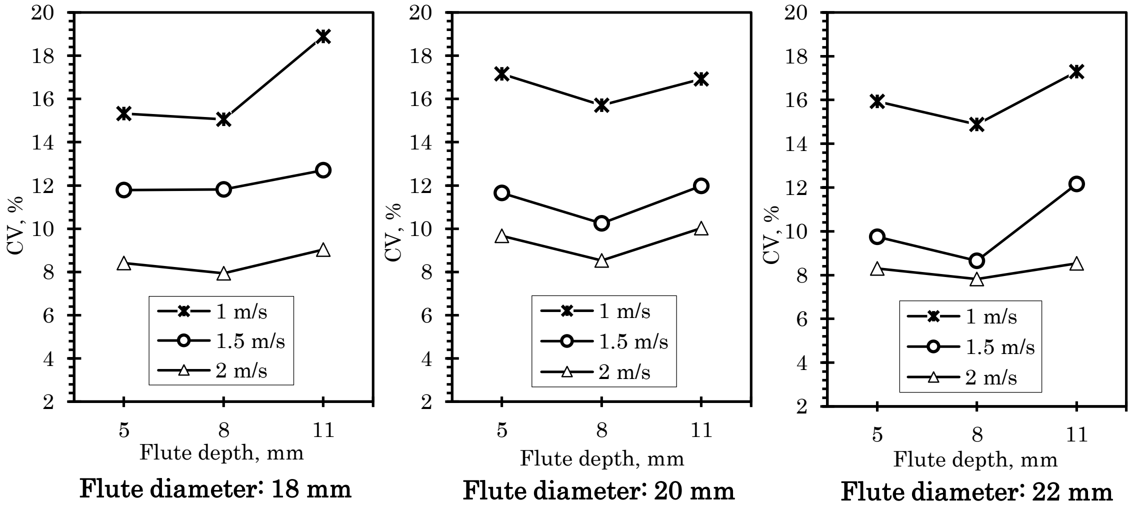

Figure 2. The line graphs of CV values for seeding rate of 80 kg ha^{-1}

Şekil 2. 80 kg ha^{-1} ekim normu için CV değerlerinin değişimi

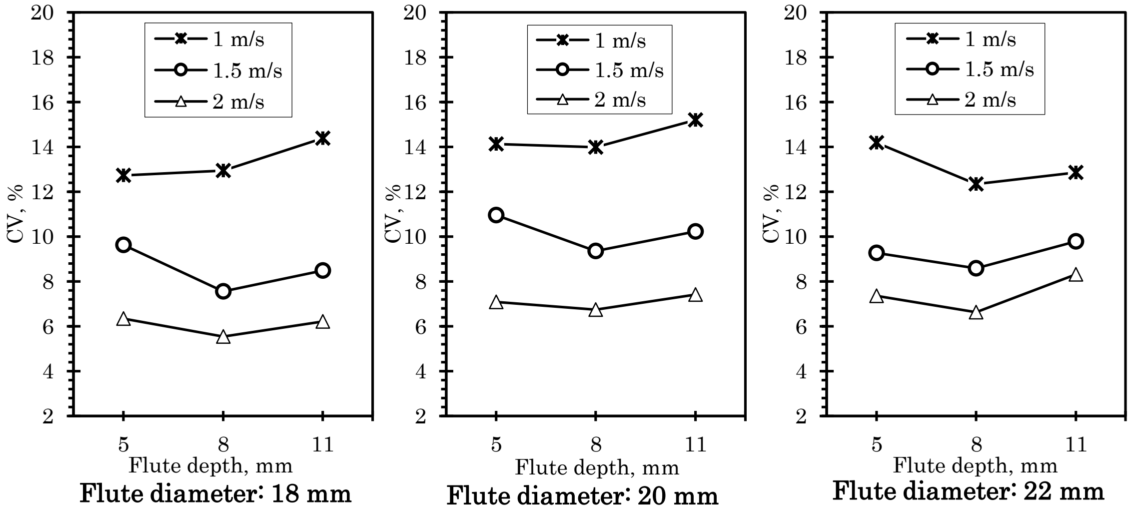

Figure 3. The line graphs of CV values for seeding rate of 120 kg ha^{-1}

Şekil 3. 120 kg ha^{-1} ekim normu için CV değerlerinin değişimi

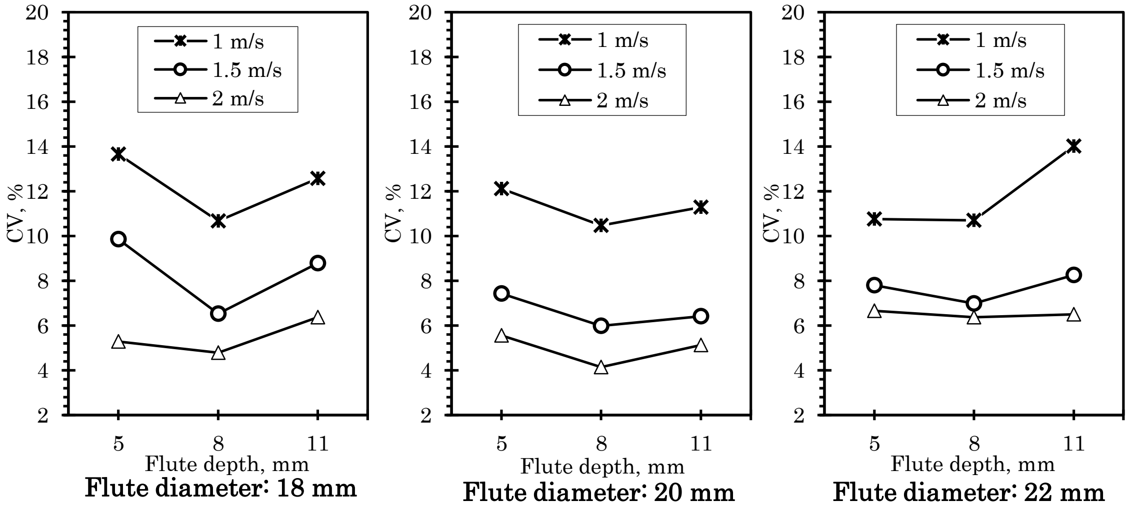

Figure 4. The line graphs of CV values for seeding rate of 160 kg ha^{-1}

Şekil 4. 160 kg ha^{-1} ekim normu için CV değerlerinin değişimi

CONCLUSIONS

In this study, the possibilities of sowing dry bean seed with a fluted roller metering device were investigated and optimum feed roller structural properties and operating parameters were determined for this seed. In this context, the results of current study are as showed:

1) The parameter that had the greatest effect on seed flow accuracy was the ground speed. With the increase in the ground speed, CV values decreased approximately by half.
2) It defected that, in the sowing of dry bean seeds with a fluted roller metering device, the increase in the seeding rate and ground speed improves the seed flow accuracy, the prescribed flute diameters do not have a stable effect on the flow accuracy, and the flow accuracy in the smallest and largest flute depths impaired.
3) It was determined that the CV values obtained for all parameters were within the acceptable limits specified in the literature.

As a result, it is recommended to use an 8 mm flute depth, and 2.0 m s^{-1} ground speed, where the best flow accuracy is achieved in all seeding rates, when sowing dry beans with a fluted roller metering device.

Author's Contributions

The contribution of the authors is equal.

Statement of Conflict of Interest

Authors have declared no conflict of interest.

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