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Influence of Rotational Speed of Seed Plates on the Quality Seeding in Laboratory Operating Conditions

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Abstract: The simulation results of sunflower seeding in the laboratory with seed plates from 12 to 36 holes at working speeds from 4 to 10 km/h are presented. At a working speed of 6 km/h, the seed plate n = 12 with a rotational speed of 0.652 m/s achieved an average seeding spacing of 23.26 cm. At this rotational speed, the plate achieved a QFI of 89.15. The seed plate n = 36 with a rotational speed of 0.217 m/s achieved an average spacing of 21.76 cm with a QFI index of 98.45. At a working speed of 10 km/h, the seeding machine achieved an average spacing of 23.87 cm with a seed plate n = 12. The same seed plate achieved a rotational speed of 1.812 m/s. The seed plate n = 36 with a rotational speed of 0.602 m/s recorded an average spacing in the seeding simulation of 22.52 cm.

Keywords: intra row spacing; rotational speed; seeding; vacuum seeding machine

1 INTRODUCTION

Seeding sunflower seeds represents a significant activity in its total production. It is from this significance the proverb "As you sow, so shall you reap". The importance of sunflower seeding in the Eastern part of Croatia also has its great economic significance due to the installed processing capacities. Seeding is mainly done with vacuum pneumatic seeding machines with the most common use of seedplates with n = 18 holes Φ2.5 to 3.5 mm. In the seeding technology, the seed companies suggest seeding medium-early hybrids with a vegetation of 110 to 130 days from 50 to 60000 ha^{-1} plants, and later hybrids with a vegetation length of 130 to 150 days in a set of 45 to 55000 ha^{-1} plants at a harvest time. In standard technology with a row spacing of 70 cm or 142 rows with a length of 100 m per ha^{-1} seeding must be done at a row spacing of 21 to 24 cm. Authors [1] and [2] state that between 7 to 10% of plants are lost from seeding to harvest, which can be attributed to poor seeding machine adjustment and incorrect selection of technical seeding factors. Authors [3] state that proper seeding machine adjustment plays an important role in overall maize production. Authors [4] in their research state the appearance of "external" and "internal" factors that affect the quality of seeding. Laboratory factors include all those that affect the precision of seeding, and are conditioned by the construction of the seeding machine, and these are the rotational speed of the seeding plate, working elements of seeding machines such as seed singulator, drive transmission system from wheel to seeding device, method of filling the seeding device, and the method of transporting the seed into the furrow. Authors [5] define the appearance of "working rhythm". These authors explain that these unbalanced modes of seeders transmission elements are due to imperfections of the composition of elements and different wear during operation of the seeder. They referred to the processing systems that have a significant impact on the percentage of emerged plants. The demand for increasing operational capacity requires higher speeds when performing the agricultural activities and more efficient seeders-fertilizers and machinery, in general, to reduce operational costs and improve the quality of the seeding process [6]. The speed of the seeding machine at the time of seeding should be increased to the level that the quality of work is not impaired, [7, 8]. Author [2] states that the seeding speed is conditioned by several factors such as soil preparation, plot slope, etc. During the mechanized seeding, several factors interfere with the establishment of the plant stand and crop productivity, and the machine operation speed in the field is one of them. This parameter can influence the skidding of the wheels; field capacity; speed of the seed-metering mechanism; distance and depth of seeds; occurrence of doubles, and mechanical damage [9]. The precision index (Prec) was the coefficient of variation of the spacings after omitting the missed and multiple seed drops [10]. Authors [11] reported a practical upper limit of 29% for the value of Prec, since 29% would be obtained with any random scattering of seeds within the target range. An acceptable Prec for seed measurements taken in the field should fall below 29%, which would mean that the standard deviation of spacings within the target region would be ≤ 29% of the theoretical spacing [10]. For seeders for seeding broad-row crops, the acceptable value of the coefficient of variation (CV) is 20% [12]. On the other hand, [13] proposed 4.75% for the upper limit of missand multiple index values. Authors [14] report that at a speed of 6 km/h all three drills are working with a coefficient of variation less than 25% and with values from 19.25 to 22.72 which meets the criteria of quality of seeding. The percentage of pairwise from 1.66 to 2.64 is indicator of good seeting of seeders. The percentage of empty places from 4.24 to 4.93%. Proportion of seeds sown at a given distance is from 92.5 to 94.09%, which is a successfull indicator of seeding. Authors [15] investigated the physical properties of seeds as they affect variables such as vacuum level, rotational speed, and diameter of seedplate hole. At the end of the study, the authors concluded that the hole diameter, rotational speed and vacuum level are the three most important variables that affect the success of precision seeding. The authors state that the rotational speed of the seedplate is a variable that limits precise seeding and it should not exceed 0.13 m/s. Also, the physical properties of the seed play an important role in selecting the appropriate hole diameter and vacuum level (the greater the spherical diameter of the seed, the larger the hole diameter on the seedplate, and the lower the sphericity, the lower the vacuum level required). This means that higher seeding precision can be achieved over a wide range of vacuum levels, but with an appropriate seedplate hole diameter within a limited rotational speed range. Authors [16] state that the moisture content has a great influence on the aero-dynamic properties of seeds. The results showed that the final speed of maize seeds increased linearly from 10.65 to 12.15 m/s, while the humidity increased from 4 to 40%. The results also showed an initial decrease in the coefficient of resistance from 0.61 to 0.52 at 4 and 12% moisture content, and then increased from 0.53 to 0.63 at a moisture content of 16 to 40%. Authors [17] in their research state that the terminal speed for sunflower seeds showed a linear significant increase of 2.56 to 3.92 m/s with an increase in moisture content from 5.41% to 17.14%. Authors [18] stated the highest average terminal velocity was at moisture content of 30% for Badami and Doursefid sunflower cultivars as 7.08 and 6.97 m/s respectively, and the lowest was at the moisture content of 7% for both seed varieties, as 5.46 and 5.39 m/s respectively. With decrease in moisture content, drag coefficient tended to increase, so that its value for Badami and Doursefid changed from 0.59 to 0.95 and 0.52 to 0.75 respectively. Authors [19] state that the optimum vacuum pressure was determined as 4.0 kPa for maize I (288.7 ± 1.90 One thousand kernel mass, g) and maize II (372.50 ± 2.10 One thousand kernel mass, g); 3.0 kPa for cotton, soya bean and watermelon I; 2.5 kPa for watermelon II, melon and cucumber; 2.0 kPa for sugarbeet; and 1.5 kPa for onion seeds. This data was obtained using mathematical prediction models based on the mass of a thousand grains, sphericity, grain density on the maize cob. Authors [20] in their paperwork conclude that the performance of the seeding system is affected by the hole diameter of the seedplate. The optimal hole diameter would be about 3.8 mm and can vary depending on the size and shape of the seeds. The vacuum level is also important and interacts with the hole diameter. The optimal level would be 7.7 kPa, but it also depends on the physical properties of the maize seed. The authors state that the optimal rotational speed of the seedplate for maize seed is 0.07 m/s (0.7 m/s working speed), but at such speed, a small area would be seeded in a unit of time. Therefore, the authors suggest increasing the speed to 0.15 m/s (1.5 m/s working speed) although increasing the speed decreases the QFI index. Authors [21] examined the performance of a pneumatic vacuum seeding system. The test was performed in the laboratory and cotton seedplates with a hole diameter of 3.5 mm and a different number of holes (22, 30, 36, 40, 48, 60, 72) were used. The rotational speed of the seedplates ranged from 0.15-0.85 m/s. The accuracy of the achieved seed spacing was poor at angular velocities less than 0.25 m/s and greater than 0.65 m/s. The highest values of the QFI index were achieved at a rotational speed of 0.35 m/s in seedplates with 22, 40, 48 and 60 holes. Authors [22] state that a vacuum of 2.67 kPa at rotational speed of seedplate of 20 min^{-1} with hole diameter of 2.83 mm achieved a MISS Index of 0.59%. They also state that the same rotational speed of the seedplate at reduced vacuum to 2.35 kPa at a hole of 2.78 mm results in relatively low MULT Index values (4.3%). Field research confirmed the results of laboratory research, which were slightly higher values and concluded that laboratory testing is the basis for prototyping for future prototype production and popularization. Authors [23] developed regression models using the data obtained via sticky band tests and showed that 16 seeds s^{-1} was the upper limit of seed release frequency (SRF) for cotton and maize seeds. The upper limit of seedplate rotational speed was found to be 0.34 m/s. The use of 72 holes instead of 26 holes in the seedplate at 6.3 kPa created a vacuum band in the width of 10 mm around holes and this increased the multiple index and caused a reduction in seeding performance. For this reason, the use of seedplates with 60 or 52 holes is recommended for cotton seed. The forward speed of either 1.0 or 1.5 m/s was found to be acceptable for the seed spacing of 0.05 and 0.10 m, respectively. Aerodynamic calculations verified that widely used seedplates with 26 holes were the appropriate ones for seeding maize seeds. Authors [24] in their research were using 5 seedplates with different number of holes (20, 26, 36, 52, 72) and a diameter of 4.5 mm. The plates are used on a pneumatic seeding machine and the vacuum was 6.3 kPa. Based on the research, the authors concluded that the seeding machine achieved maximum performance using a seedplate with 36 holes at working speeds of 1.0 and 1.5 m/s at a seeding spacing of 10 cm. The working speed has a negative effect on the seeding operation when the working speed is 2.0 m/s.

2 MATERIALS AND METHODS

The research was conducted at the Department of Agricultural Engineering and Renewable Energy Resources, Faculty of Agrobiotechnical Sciences Osijek by placing a pneumatic seeding machine MaterMacc Twin Row-2 of the Italian company Foton LovoI International Heavy Industry Group on a test table (Fig. 1) to simulate sunflower seeding with the possibility of adjusting various technical seeding factors.

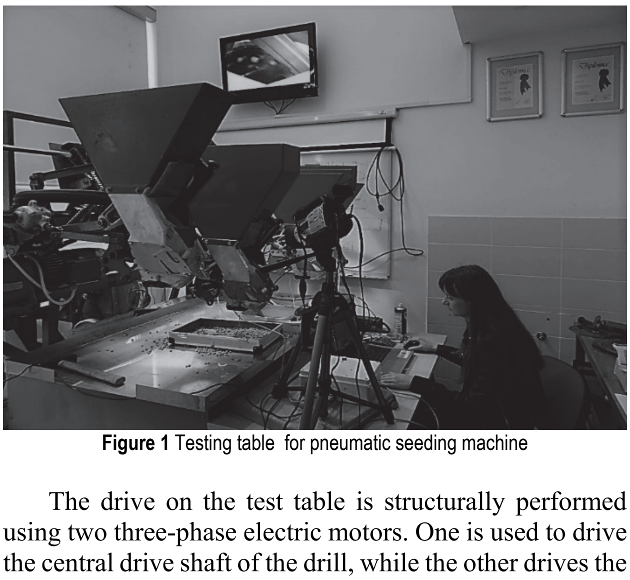

Figure 1 Testing table for pneumatic seeding machine

The drive on the test table is structurally performed using two three-phase electric motors. One is used to drive the central drive shaft of the drill, while the other drives the fan. The speed of both electric motors is controlled by a static frequency regulator (Adjustable Speed Drives, Variable Frequency Drives - VFD). By setting the fan shaft speed to 3200 rpm (400 min^{-1} PTO) on the MaterMacc Twin Row-2 Seeding machine with filled seedplates n = 12, n = 18, n = 24, n = 30 and n = 36 holes Φ3.5 mm achieved a vacuum of 2.80 kPa, and at 4320 rpm

(540 min^{-1} PTO) a vacuum of 4.60 kPa was recorded. The determination of the most favorable position of the seed singulator was performed according to the different distances of the seed singulator teeth in relation to the center of the seedplate hole (Tab. 1).

Seeding simulation was performed at a theoretical distance of 22.067 cm at a dynamic drive wheel diameter d = 52.52 cm at a measurement length of 100 m in four repetitions. Other test simulation factors are shown in Tab. 2.

Table 1 Distance of the tooth tip of the seed singulator remover from the center of the seedplate hole (Φ3.5 mm) in mm

Mark on the scale	Measuring point - number of teeth			
	1	4	8	13
2.00	−0.25	−0.75	−1.25	−1.75
3.00	0.5	−0.25	−0.50	−1.00
3.50	1.00	0.00	−0.25	−0.75
4.00	1.75	0.25	0.00	−0.25
4.50	2.00	1.25	0.25	0.00

Table 2 Technical factors during measurements at the tested seedplates

Hole numbers of seedplate (n)	Seedplate (hole Φ3.5 mm)					
	12	18	24	30	36	working speed / m/s
Distance between 2 holes / mm	52.84	35.25	26.44	21.15	17.62	
Drive wheel to seed plate ratio (i)	0.623	0.415	0.311	0.249	0.207	
Rotational speed / m/s	0.290	0.193	0.145	0.116	0.096	1.11
Seed releasing frequency / s	3.479	3.476	3.474	3.474	3.468	
Rotational speed / m/s	0.652	0.435	0.326	0.261	0.217	1.66
Seed releasing frequency / s	7.828	7.822	7.816	7.822	7.803	
Rotational speed / m/s	1.160	0.773	0.579	0.464	0.385	2.22
Seed releasing frequency / s	13.917	13.906	13.895	13.906	13.872	
Rotational speed / m/s	1.812	1.207	0.905	0.724	0.602	2.77
Seed releasing frequency / s	21.746	21.728	21.728	21.728	21.676	
Theoretical spacing / cm	22.067					

Dynamic drive wheel radius D_d = 52.52 cm; Seedplate diameter = 0.1979 m

The spacings were determined with the help of a sensor for detecting the time of seed passage, whereby the central unit calculates the seeding spacings with the simulated working speed. The position of the seeding machine was determined by an encoder 1200 with an error in measuring the distance travelled of ±1.37 mm, where a very high position accuracy was achieved, and it was mounted on the drive shaft of the seeding machine.

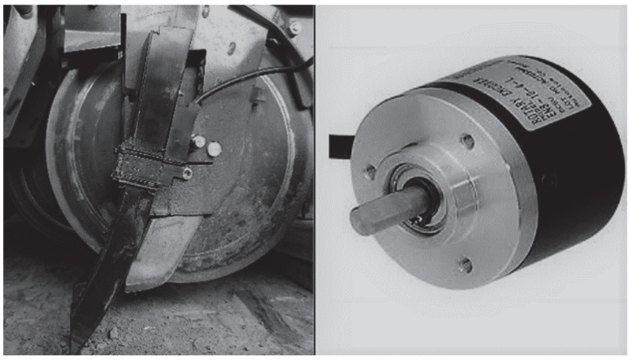

Figure 2 Seed pass sensor and encoder 1200 for seeder position monitoring

Air flows through a hole in the radial direction and air stream lines form a semi-sphere envelope and air velocity increases as the radius of the envelope goes down. The air velocity, Vr_1, at r_1 distance from the center of holes is calculated by Eq. (1).

$$V_{r1} = \frac{r_2^2}{r_1^2} \cdot \frac{\alpha\sqrt{\frac{2gp}{\gamma}}}{2} \tag{1}$$

where r_2, is the hole radius on the seedplate, α, is the flow coefficient (assumed to be 0.7), γ is the specific weight of air (11.2 N/m^3 at 20 °C and 96 kPa), p is the vacuum pressure in N/m^2, and g is acceleration due to gravity [12].

The air velocity in the center of the hole, Vr_2, can be calculated by Eq. (2).

$$V_{r2} = \alpha\sqrt{\frac{2gp}{\gamma}} \tag{2}$$

The terminal velocity of seeds in the air stream has to be known prior to the design of vacuum type precision seeders and these values were found to be 2.56 do 3.92 s^{-1} for sunflower depending on moisture level [16].

The rotational speed of the seedplate V_p and the forward speed of the seeder V_f can be calculated from Eqs. (3) and (4).

$$V_p = \frac{\pi d n_p}{60} \tag{3}$$

$$V_f = \frac{n_p}{60} k Z_t \tag{4}$$

where d is the pitch diameter of holes (seedplate diameter) in m, n_p is the rpm of the seedplate in min^{-1}, k is the number of holes in the seedplate, and Z_t is the theoretical seed spacing in m.

Seed releasing frequency, SRF, is the number of seeds released from the metering unit in 1 s^{-1}. At specific theoretical seed spacing, the SRF and the forward speed relationship is shown as in Eq. (5).

$$Z_t = \frac{V_f}{SRF} \tag{5}$$

Most of the research was conducted according to the ISO standard, namely: ISO 7256-1: 1984 for single seed drills - standard seeding (Seeding equipment - Test methods - Part 1: Single seed drills), and ISO 7256-2: 1984 for seeders with seeding in double rows - seeding in strips or twin row seeding (Seeding equipment - Test methods - Part 2: Seed drills for seeding in lines).

The comparison of the precision of work in the simulation of individual factors of the tested seeding machines is based on the evaluation of the seeding uniformity using the indices QFI, MULT and MISS. The ISO standard classifies the determination of spacing into three different groups of seed spacing according to the theoretical spacing (Z_t).

I. The multiple index MULT (I_{mt}) indicates the percentage of multiple seed drops (N_{mt}) (0 to ≤ 0.5 Z_t), Z_t is the theoretical seed spacing,

$$I_{mt} = \frac{N_{mt}}{N} 100 \qquad (6)$$

II. Quality of feed index (QFI) indicates the percentages of single seed drops in the range of > 0.5 Z_t to ≤ 1.5 Z_t.

III. Missing index, The miss index (I_{ms}) is the ratio of number of spacing (N_{ms}) greater than 1.5 times of set spacing and total number of measured spacings (N):

$$I_{ms} = \frac{N_{ms}}{N} 100 \qquad (7)$$

Seed spacing uniformity of the main seed distribution (QFI), called precision (Prec. index), is expressed by the coefficient of variation (CV_m, %) as shown in Eq. (8).

$$CV_m = \frac{\sigma}{Z_m} 100 \qquad (8)$$

where σ is the standard deviation of the main seed distribution (QFI) and Z_m is the mean seed spacing of the main seed distribution curve.

Seeding simulation was performed with sunflower seeds and its shape values are shown in Tab. 3.

Table 3 Dimensions and test weight of seeds used in this study

Seed dimensions / mm	$\bar{x}$	σ	C.V. / %
Length	9.134	0.471	5.16
Width	4.552	0.421	9.25
Thickness	3.478	0.533	15.32
Surface area / mm^2	Sphericity / %	Geometric mean diameter	Roundness / %
86.260	57.368	5.240	49.835

Bulk density 48.5 kg/m^3; Thousand–seed weight 591.6 g; Moisture grain 7.2%

3. RESULTS AND DISCUSSION

3.1 Results of Measurement of Vacuum Values at Holes of Seedplates

The vacuum, which is created by the rotation of the fan, must adhere to the seeds at the openings of the seed plate, opposing the force of gravity and the forces created by the rotation of the plate as a consequence of the rotational speed [25]. We can say that the vacuum opposes the weight and friction of the seeds, and the centrifugal force.

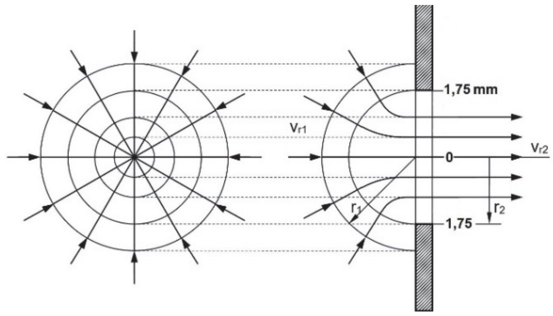

Figure 3 Suction of air through a hole seedplate [25] and [26]

Table 4 Air velocities at different distances from the center of a hole

Vacuum pressure / kPa	Terminal velocity / m/s	Distances from the center of a hole (r_1) / mm			
		0	1.75	6.75	11.75
		Air velocity (V_{r1}) m/s			
2.80	3.51	49.024	24.512	1.648	0.544
4.60		62.838	31.419	2.112	0.697

Grain moisture 7.2%; Hole diameter (d_0) = 3.5 mm

The calculation showed at a vacuum of 4.6 kPa, that the air speed at a distance of 5 mm from the edges of the seedplate hole was 2.112 m/s, and at a distance of 10 mm the value of 0.697 m/s was recorded. Based on this, the correctness of the selection of the maximum number of openings on the seedplate n = 36 with a seeding opening distance of 17.62 mm was confirmed. It is theoretically possible considering the air speed of 0.697 m/s that individual seeds can be adhered to the seedplate in the space between the two holes.

3.2 Results of Measuring the Most Favorable Position of the Seed Singulator

The selection of the favorable position of the seed singulator on the seedplate was performed by simulating the seeding operation at 6 km/h using a seedplate n = 12. The research was performed at an operating vacuum of 2.80 kPa (3200 min^{-1} fan shaft speed) and a vacuum of 4.60 kPa (4320 min^{-1} fan shaft speed). The most favorable results of the obtained spacings (Tab. 5) were achieved at a vacuum value of 4.60 kPa at the seed singulator position on mark 4.50. At this position, the first tooth of seed singulator was 2.00 mm from the center of the hole, while the thirteenth, i.e. the last tooth, was in the center of the seed hole Φ3.50 mm. The selected position of a seed singulator was applied in subsequent research in this paper.

Table 5 Achieved seeding spacings at different positions of the seed singulator

Seed singulator positions	$\bar{x}$	σ	R / cm	QFI indeks	Prec. indeks (CV)
4.25	24.05	8.234	+1.983	85.00	11.69
4.50	22.11	4.863	+0.043	94.25	8.69
4.75	23.02	7.511	+0.953	88.00	10.46
4.25	24.05	8.234	+1.983	85.00	11.69

Dynamic drive wheel radius D_d = 52.52 cm; n = 12; Φ3.5 mm; drive wheel and plate ratio i = 0.623; Rotational speed 0.652 (ms^{-1}) at seed drill speed v = 6 km/h; R - The difference between the average achieved and theoretical spacing Seed releasing frequency s^{-1} = 7.828; Theoretical spacing 22.067 cm; Vacum = 4.60 kPa.

3.3 Results of the Influence of Rotational Speed of Seedplate on Intrarow Spacing in Sunflower Seeding

The research was conducted with the assumption that the seedplate n = 36 for the predicted theoretical distance of 22.067 cm will have three times less rotational speed (m/s) than the plate n = 12, allowing sunflower seeds to take a more favorable position on the seedhole. Also the research was carried out under controlled technical conditions of the seedplate as indicated in Tab. 2 (rotational speed (m/s), drive wheel to seed plate ratio (i), Seed releasing frequency^{-1}) at all four working speeds. The obtained research results are shown in Tab. 6. Determining the quality of seeding machine work at different rotational speeds of seed plates in the simulation of seeding at a theoretical distance of 22.067 cm was performed using seeding quality indices by ISO standard 7256/1 and 7256/2 or miss index (MISS), multiple index (MULT) and quality of feed index (QFI). The obtained results of seeding quality indices are shown in Tab. 7.

Table 6 Achieved spacings in the simulation of seeding sunflower seeds at a theoretical spacing of 22.067 cm using plates with different hole numbers at four working speeds km/h

Seedplate (n)	$\bar{x}$	σ	Median	Mode	Variance	Range	Working speed / km/h / rotational speed / m/s
12	21.90	3.606	22.11	22.11	13.001	42.24	4 / 0.290
18	21.99	3.191	22.23	22.28	10.181	43.56	4 / 0.193
24	21.88	3.363	22.28	22.28	11.311	40.43	4 / 0.145
30	21.62	2.457	21.78	21.78	6.035	27.06	4 / 0.116
36	21.79	2.577	21.78	21.78	6.643	29.70	4 / 0.096
12	23.26	6.806	22.11	21.78	46.321	55.44	6 / 0.652
18	22.01	4.219	21.78	21.74	17.796	44.06	6 / 0.435
24	22.55	4.707	21.78	21.78	22.155	42.41	6 / 0.326
30	21.97	4.391	22.28	2145	19.285	42.08	6 / 0.261
36	21.76	2.788	21.78	21.78	7.773	40.26	6 / 0.217
12	23.14	6.980	22.11	21.78	48.722	45.21	8 / 1.160
18	22.79	5.664	22.44	22.44	32.078	42.90	8 / 0.773
24	22.51	5.632	22.23	21.78	31.719	45.54	8 / 0.579
30	22.10	5.101	22.28	22.28	26.017	42.08	8 / 0.464
36	22.38	4.442	21.78	21.78	19.735	43.56	8 / 0.385
12	23.87	8.526	22.11	21.78	72.694	65.01	10 / 1.812
18	22.98	7.121	22.28	21.45	50.706	44.55	10 / 1.207
24	23.59	6.954	22.44	22.44	48.358	44.88	10 / 0.905
30	23.01	6.526	22.23	21.24	42.585	44.95	10 / 0.724
36	2252	5.029	21.78	21.78	25.290	42.57	10 / 0.602

Dynamic drive wheel radius D_d = 52.52 cm; Hole diameter (d_0) = 3.5 mm; Theoretical spacing 22.067 cm

Table 7 Achieved values of seeding quality indices (MULT, QFI, MISS) at different working speeds and different rotational speeds of tested seedplates

Working speed / km/h	Seedplate (n)	MULT	σ	QFI	σ	MISS	σ
4	12	1.95	0.447	96.85	0.978	1.20	0.925
	18	1.25	0.177	97.60	1.782	1.15	1.755
	24	1.50	0.177	97.75	0.829	0.75	0.771
	30	1.20	0.542	98.80	0.542	2.50	0.661
	36	1.20	0.371	98.80	0.371	0.00	0.00
6	12	2.65	0.602	89.15	1.981	8.20	2.072
	18	1.90	0.418	96.20	2.273	1.90	2.637
	24	1.20	0.597	95.40	3.516	3.40	3.660
	30	2.50	0.661	95.55	1.708	1.95	1.565
	36	1.35	0.454	98.45	0.274	0.20	0.326
8	12	3.60	1.376	87.65	7.081	8.75	5.977
	18	1.85	0.652	92.55	3.094	5.60	2.854
	24	2.25	1.311	93.10	2.020	4.65	2.643
	30	2.70	1.037	93.95	3.497	3.35	2.742
	36	1.35	0.894	95.75	2.562	2.90	2.596
10	12	3.95	0.411	84.50	1.658	11.55	1.882
	18	3.85	0.576	88.00	1.510	8.15	1.587
	24	2.05	0.411	88.75	2.767	9.20	2.689
	30	2.35	1.126	90.50	3.102	7.15	2.848
	36	1.60	0.628	94.45	2.612	3.95	2.496

Dynamic drive wheel radius D_d = 52.52 cm; Hole diameter (d_0) = 3.5 mm; Theoretical spacing 22.067 cm

Tab. 7 shows that in the seeding simulation at working speed 4 km/h (1.11 m/s) with the application of seed plates n = 12 and n = 36, no significant differences in the values of the QFI index were recorded. This was also to be expected as the simulation was performed at the lower limit of the acceptable operating speed for pneumatic seeding machines. At these low rotational speeds of 0.290 and 0.096 m/s sunflower seeds fully occupy a favorable position before and at the time of encountering the seed singulator. Increasing the working speed during the seeding simulation to 6 km/h (1.66 m/s) shows a slightly larger difference in the QFI index values. With a seedplate n = 12 at a rotational speed of 0.652 m/s, a QFI value of 89.15 was recorded, and seedplate n = 36 with a rotational speed of 0.217 m/s, achieved a QFI of 98.45. Using a seedplate n = 36, it was sown average 9.3% more seeds or 5984 plants ha^{-1} on acceptable spacing. At the upper limit of the simulation of 10 km/h (2.77 m/s) for a seedplate n = 12 with a rotational speed of 1.812 m/s, a QFI of only 84.50 and an average MISS index of 11.55 were recorded.

In the simulation with a plate $n = 36$ at a rotational speed of 0.602 m/s, a QFI value of 94.45 and a MISS index of 3.95 were recorded. Using a seedplate $n = 36$, we provided 9.95% of acceptable spacings and sowed 7.6% more seeds, ie 4890 ha^{-1} plants. At operating speed of 4 and 6 km/h, most of the achieved values of miss and mult index were less than 5% as stated by the author [13]. The obtained values of seeding quality indices for other tested seedplates are within the values of seedplates $n = 12$ and $n = 36$. The trend line of the obtained QFI index values is described by a linear function for the tested seedplates at $v = 8$ and $v = 10$ km/h (Fig. 4).

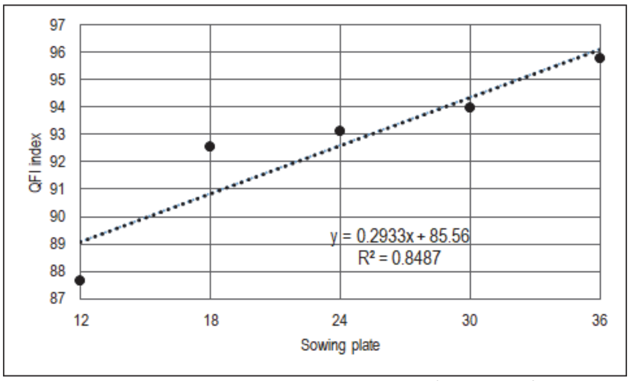

Figure 4 The trend line is described by the linear function $v = 8$ km^{-1}

In the simulation of the working speed $v = 10$ km/h, the obtained QFI index values can be represented by the linear function:

$Y = 0.3733x + 80.28$ ($R^2 = 0.9471$).

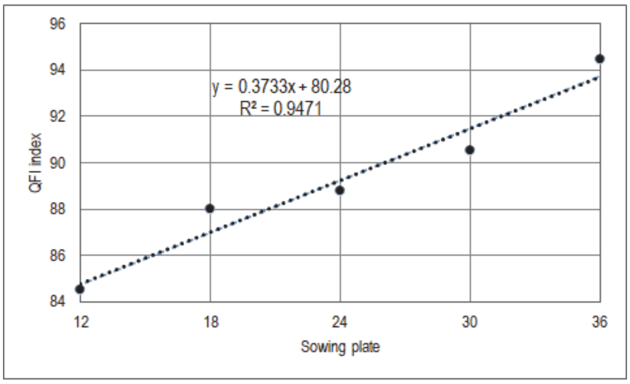

Figure 5 The trend line is described by the linear function $v = 10$ km^{-1}

Values precision index (Prec.) (CVm) at QFI spacing values is shown in Tab. 8. It can be seen from Tab. 8 that the seedplate $n = 12$ achieved the value of Prec. index (CVm) in the group of acceptable distances (QFI) at working speed of 4 km/h of 15.14% while the same seedplate at working speed of 10 km/h achieved a value of 32.66%. At simulation with seedplate $n = 24$ at a working speed of 4 km/h, the Prec. index (CVm) of 14.38%, and at working speed of 10 km/h a value of 28.17% was recorded. The best value of Prec. index (CVm) was achieved with a seedplate $n = 12$ at a working speed of 4 km/h and was 10.72%. By increasing the speed of the seeding machine to 10 km h^{-1}, the value of Prec. index (CVm) was 20.43%. From Tab. 8 it can be seen that the seedplate $n = 36$ at a working speed of 4 km/h had a lower Prec. index (CVm) in relation to the plate $n = 12$ by 4.42% and at the working speed of 10 km/h the difference was 12.23%. The obtained results are confirmed by the authors in their research [11, 10].

Table 8 Values prec. index (CVm) for tested seedplates at different working speeds and different rotational speeds

	Seedplate				
	hole 12	hole 18	hole 24	hole 30	hole 36
Working speed / m/s			1.11		
Rotational speed / m/s	0.290	0.193	0.145	0.116	0.096
Prec. indeks (CV_m)	15.14	13.84	14.38	11.17	10.72
Working speed / m/s			1.66		
Rotational speed / m/s	0.652	0.435	0.326	0.261	0.217
Prec. indeks (CV_m)	27.04	18.33	20.20	19.04	11.49
Working speed / m/s			2.22		
Rotational speed / m/s	1.160	0.773	0.579	0.464	0.385
Prec. indeks (CV_m)	27.07	23.16	22.02	20.57	18.73
Working speed / m/s			2.77		
Rotational speed / m/s	1.812	1.207	0.905	0.724	0.602
Prec. indeks (CV_m)	32.66	28.37	28.17	27.12	20.43

Dynamic drive wheel radius D_d = 52.52 cm; Seedplate diameter = 0.1979 m

In Tab. 9, with the seed plate $n = 12$, there are statistically significant differences in the achieved average spacings when increasing the working speed above the 4 km/h, therefore a higher working speed than V_1 is not recommended for this seed plate. Since the seed plate $n = 24$ rotates twice as slowly as the plate $n = 12$, a statistically significant difference was obtained only at the highest working speed of 10 km/h. With the seed plate $n = 36$, regardless of the increase in the seed drill speed from V_1 to V_4, there were no statistically significant differences in the average values of the seeding spacings, so this seed plate can be sown at higher speeds without loss of precision.

Table 9 Influence of seeding machine working speed and seedplate rotational speed on average seeding spacing LSD $_{(0.05)}$

Holes	Speeds / kmh			
	V_1 = 4 km/h	V_2 = 6 km/h	V_3 = 8 km/h	V_4 = 10 km/h
$n = 12$	21.7382^a	22.9268^b	22.8170^b	23.3966^b
$n = 24$	21.7460^a	22.3616^a	22.1952^a	23.3150^b
$n = 36$	21.7354^a	21.7060^a	22.1720^a	22.1908^a
$LSD_{(0.05)}\ v \cdot n = 0.72$				

4 CONCLUSION

The following conclusions can be made by conducting simulations of sunflower seeding in the laboratory at a theoretical distance of 22.067 cm using five seedplates with 12, 18, 24, 30 and 36 holes *Φ*3.5 mm at four working speeds of the seeding machine.

- a statistically significant difference in the influence of the rotational speed of the seedplates on the intrarow spacing was found,
- simulation of sunflower seeding at the working speed of 4 km/h and the rotational speed of 0.290 m/s of the seedplate n = 12 as well as at the rotational speed 0.096 m/s of seedplate n = 36, no significant differences were observed in the obtained values QFI index as well as significant average deviations from the theoretical seeding distance (n = 12, −0.167 cm and n = 36, −0.277 cm),
- by increasing the speed of the seeding machine to 6 km/h, the seedplate n = 12 with a rotational speed of 0.652 m/s achieved an average seeding distance of 23.26 cm, with a decrease in the set of 3299 ha^{-1} plants. At this rotational speed, the plate achieved 89.15 favorable seeding spacings (QFI 89.15) and 8.20% of unsown distances (MISS index). By analyzing the Prec. index (CVm) achieved a value of 27.04,
- with a seedplate n = 36 (rotational speed of 0.217 m/s) at a working speed of 6 km/h, an average distance of 21.76 cm was obtained, with 908 plants ha^{-1} sown more than the expected theoretical set. The QFI index amount is a very high 98.45 while the Prec. index (*CVm*) amount favorable 11.48,
- by increasing the working speed to 10 km/h, the seeding machine with seedplate n = 12 achieved an average spacing of 23.87 cm, ie a seeding decrease of 4860 plants ha^{-1} was recorded. The seedplate with a rotational speed of 1.812 m/s achieved a QFI index value of only 84.50 while the value of Prec. index (*CVm)* was 32.66,
- the seedplate n = 32 with a rotational speed of 0.602 m/s recorded an average distance in the seeding simulation of 22.52,
- cm or +0.453 cm more than the theoretical one, achieving a QFI index value of 94.45 while the value of Prec. index (*CVm*) was an acceptable 20.43,
- the results obtained for seedplates n = 18, n = 24 and n = 30 are within the limit values obtained by seedplates n = 12 and n = 36,
- reducing the rotational speed of the seedplate as much as possible will contribute toward increasing the favorable seeding spacings (QFI index) as well as approaching the theoretical set of plants ha^{-1} and reducing the value of Prec. index (*CVm*).

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