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Influence of the physical properties of sugar beet seeds over the work quality of the seeding mechanism**

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A b s t r a c t. Biological, physical and technological properties of the sugar beet seed, tillage quality and quality of the seed placement to the soil have a predominant effect on the value and evenness of the sugar beet field emergence. During planting, the distance between two successive seeds in the row depends upon the technical parameters of the planter: the type of planting unit mounted on the frame, the forward speed, and the design and the type of planting mechanism drive. The measurements were realized in the laboratory and in field conditions according to the ISO 7256/1 Standard. The field experiments were conducted on loamy-sandy loamy soil where 30% of the soil aggregates were less than 0.01 mm and the soil moisture level was 19.4%. The experiments were conducted using two types of sugar beet cultivars – Roxana (calibration 3.5-4.75 mm) and Flair (calibration 3.5-4.5 mm). The paper is focused on making a comparison between the planting quality of two types of sugar beet planters equipped with different planting mechanisms. The first machine was a planter with an internal mechanism of gathering openings and the second machine was based on the vacuum principle. A sugar beet planter equipped with an air under vacuum pressure system caused more damage to the seeds during higher forward working speeds (5.4%). In the case of the planting mechanical system, the highest degree of seed damage was caused by forward working speeds of 1.0-1.5 m s^{-1}.

K e y w o r d s: sugar beet, seed properties, planting, planters, working speed

INTRODUCTION

In the current conditions of the European Union, sugar beet is grown by using different tillage technologies (conventional tillage, soil conservation tillage, no-till technology). In our conditions, conventional tillage technology is mainly used with sowing seeds at a certain final distance between the seeds, without any subsequent manual intervention. During the cultivation of sugar beet, attempts were made to intensify its production, which means that the aim was to obtain the highest amount of biomass with no changes in the sugar content in the sugar beet roots (Haghverdi *et al*, 2017). The prospect of reaching such aim depends upon the soil and climatic conditions. However, strict implementation of technology also plays a role in reaching the set goals during the sugar beet planting process (Sigdel *et al.,* 2021; Findura *et al.,* 2022). This involves carefully maintaining the quality of soil preparation even before the beginning

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of germination, as the initial water intake by the seed takes place. In connection with the required temperature (*ca.* 7-8°C), it is important to establish a form of seeding bed that will provide the largest possible contact surface of the seed with the soil to allow for gas exchange, heat transfer, *etc.* (Rybiński *et al*., 2008). These patterns were studied by Brunotte (1985), Páltik (2005), Turan (2011), who stated that the optimal seed water transfer occurs when the size of the soil particle in the seed area falls within a range of 1/5 to 1/10 of the seed diameter. When considering a 3.5 to 4.75 mm coated sugar beet seed, the soil particle size should be between 0.35 and 0.95 mm.

The use of a suitable seed planter together with high-quality seeds makes it possible to achieve a high yield of planting (Turan *et al*., 2015; Rybiński *et al*., 2009 and 2011). The physicochemical properties of the seeds of cultivated plants determine their technological usability to a great extent (Gundel *et al.,* 2018; Ćwiklińska *et al.,* 2021; Alimohammadi *et al.,* 2022; Jaques *et al.,* 2022). The physical characteristics of seeds affect the efficiency of the technological process, the main task of which is to prepare seeds for sowing or for consumption. Energy and germination capacity depend on the size of seeds. Larger and heavier seeds produce a higher emergence and better yields (Andreoli and de Andrade, 2002; Rusinek and Molenda, 2007). The determined values of physical features can be used to determine the optimal operating parameters of the sets of machines and devices used, among others, in cultivation (Vogel, 2002). Damage to the seed caused by the seeding mechanism also impairs its physico-mechanical properties (Bulgakov, 2018; Rybiński *et al*., 2014; Mykhailov *et al.,* 2021). Seed sowing should be carried out by means of precision seeders, this conclusion may be justified with both technological and economic reasons (Varina *et al*., 2001; Jaques *et al.,* 2022).

The research dealt with the effect of the dimensional qualities of the seeds in relation to the forward working speed of the seed planter with reference to the final seed quality using the two most frequently used planting mechanisms. Planting quality was assessed using ISO 7256/1 for the evaluation of the exact planter.

MATERIAL AND METHODS

The quality of seeding is conditioned by the required vertical (deep) and horizontal (flat) distribution of the seeds in the soil with minimal damage inflicted by the planting device. The field experiments were carried out using soil with the percentage of soil particles of less than 0.01 mm equivalent to 20-30%, it was classified as a clayey-sandy soil. The measurements were carried out on the farm of PD Žemberovce. The farm is located in the Hontian/Levice region, with the territory geographically belonging to the Štiavnica Mountains. The Žemberovce area is located in a macroregion characterized by the warm and very dry weather conditions, with a predominantly mild winter. The annual sunshine is 1 722 h. The global radiation per year is 1 240 kWh per m^2. The altitude of the farm in Žemberovce is 226 m above sea level.

The two most commonly used mechanisms of sugar beet planting were compared. The first one is the mechanical system with internal filling (Fig. 1a). It allows for the achievement of more favourable speed ratios when the seed is dropped from the sowing hole of the disc. The quality of this mechanism is determined by appropriate seed calibration. The second sowing mechanism tested was the pneumatic vacuum (Fig. 1b). It is structurally more demanding, but is not particularly sensitive to the dimensional uniformity of the seeds.

Seed quality measurements were carried out under field conditions in accordance with standard ISO 7256/1 within the range of the forward working speeds allowed for by the tractor used. The uniformity of seed placement in the row is affected not only by the forward working speeds but also by other technical parameters such as the seed outlet height (mm) and the attachment of the seeding unit. All units and accuracies are shown in Table 1.

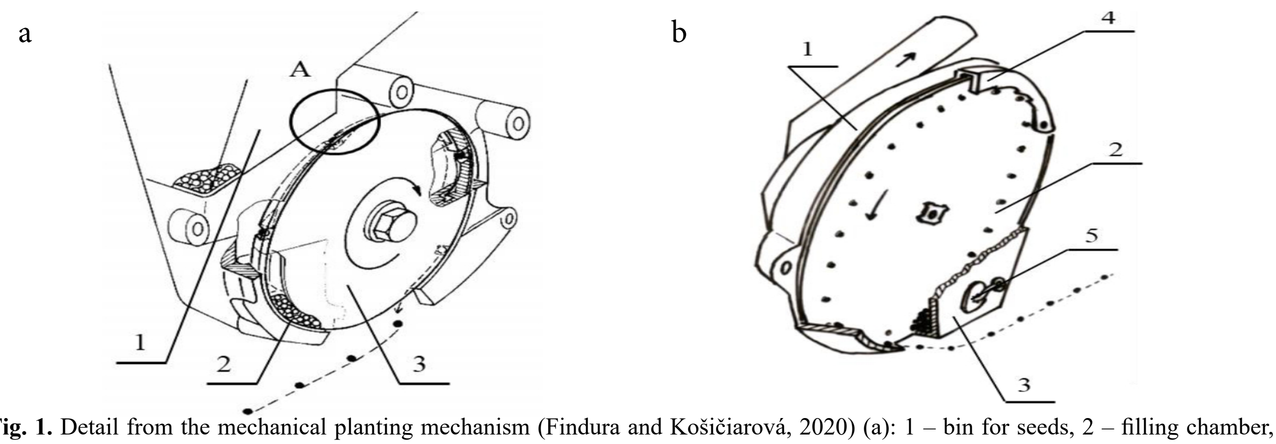

Fig. 1. Detail from the mechanical planting mechanism (Findura and Košičiarová, 2020) (a): 1 – bin for seeds, 2 – filling chamber, 3 – planting disc, A – disc picking hole. Detail of the pneumatic planting mechanism (b): 1 – vacuum chamber, 2 – planting disc, 3 – filling chamber with seeds, 4 – wiper, 5 – seed outlet.

Table 1. Specific technical parameters of tested planters

Planting mechanism	Seed outlet height	Diameter of the planting disc	Number of the filling openings (diameter of the openings)	Attachment of the seeding unit	Regulation of planting bed in depth	Type of the planting bed
	(mm)					
Mechanical with the internal filling of the openings	61	240	5 (5.5)	parallelogram	supporting wheel	chisel
Pneumatic vacuum type	115	220	31 (2.1)	parallelogram	supporting wheel	chisel

Table 2. Attributes of used seeds

Seed (calibrated)	Emergency	Dimensions of the seeds			Shape coefficients				Weight of the 1000 seeds (g)
		Lenght $\bar{d}$	Width $\bar{s}$	Thickness $\bar{h}$	$k_1 = \frac{\frac{l+s}{2}}{h}$	$k_2 = \frac{s}{h}$	$k_3 = \frac{l}{h}$	$k_4 = \frac{l}{s}$	
(mm)	(%)	(mm)							
Flair (3.5-4.5)	98	3.88[a]	3.64[a]	3.14[a]	1.81	1.16	1.23	1.07	22.53[a]
SD	n/a	0.05	0.05	0.05	n/a	n/a	n/a	n/a	0.21
Roxana (3.5-4.75)	98	4.21[b]	3.83[b]	3.61[b]	1.11	1.06	1.17	1.10	26.40[b]
SD	n/a	0.05	0.05	0.05	n/a	n/a	n/a	n/a	0.25

$\bar{d}$, $\bar{s}$, $\bar{h}$ – average leght, width, thickness of the seeds, k_1, k_2, k_3, k_4 – shape coefficients of seeds, SD – standard deviation. The same letters indicate no significant differences between the results obtained. Different letters (a, b) indicate the occurrence of significant differences between the obtained results.

In assessing the physico-mechanical properties of the coated sugar beet seeds and their impact on seed damage, an attempt was made to:
– determine the dimensional characteristics of the seeds,
– monitor the strength properties of the seeds,
– trace the friction properties of the seeds,
– monitor seed damage inflicted by the planting equipment.

When examining the seed dimensionality, the seed size and the shape properties of the seeds were investigated. The length (l), the width (w) and the thickness (t) of the seeds were measured with an accuracy of 0.1 mm and 1 000 seeds were measured. The length and width were determined using image analysis (Gancarz *et al.,* 2007). The thickness of the seeds was determined using a modified micrometre with the required precision (Table 2).

When measuring the seed damage caused by the planting mechanism, an attempt was made to assess the strength of the seeds during static loading by using an INSTRON Universal Testing Device and measuring instruments with 50 repetitions applied for each variation (Śmigała *et al.,* 2021).

Through successive loading, the force increased evenly until mechanical damage of the seeds occurred. Such damage was manifested by a sharp drop in the resistance of the seed to the force applied. Force value limits were read from the deformation curve at the point at which biological macroform deformation occurred (Fig. 2).

When assessing the effect of the friction properties of the seeds on the planting quality, according to the methodology developed by Bartoš and Waradzin (1981) for individual seed species, the coefficient of shear friction μ and the stable apparent angle α were determined. The shear friction coefficient on a tilted plane fitted with a plastic mat identical to the planting stock material were determined. Changing the angle of the inclined plane, resp. the elevation of the inclined plane was realized by means of a continuous transmission. The specimen was fastened so that its movement on the inclined plane only involved contact with the inclined plane and seed pad.

An evaluation of the quality of sugar beet planting was carried out from the point of view of the distance between the seeds in the row wherein this characteristic was evaluated in accordance with the level of compliance to a standard by monitoring plant distribution in a line according to the multi-grade normal distribution. When assessing seed quality, and planting the seeds (plants) in a line, it is necessary to know the required distance of the *PVR* plants (in the field), respectively, PVS seeds (in laboratory conditions), the measured distance between the plants b_{ri} in the field and the effective distance between the plants *EVR*. The value of *EVR* is determined through calculation as a certain mean value of the measured distances. When evaluating seed quality in field conditions, the measured b_{ri} distances were divided by (Páltik *et al.,* 2002; Findura and Páltik, 2006):

– doubles when for the distance b_{ri} it is valid:

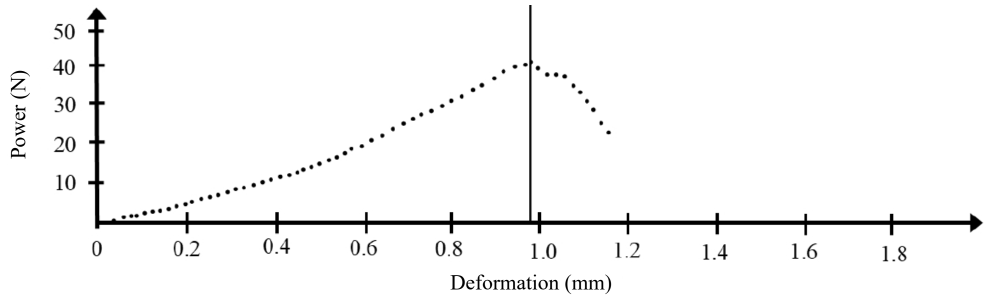

Fig. 2. Form of the recording of the pressure tests on the device.

$$0 \leq b_{ri} < 0.5\ (EVR) - \text{number } n_0\ , \tag{1}$$

– displacement at required distances:

$$0.5\ (EVR) \leq b_{ri} < 1.5\ (EVR) - \text{number } n_1\ , \tag{2}$$

– one-time omissions:

$$1.5\ (EVR) \leq b_{ri} < 2.5\ (EVR) - \text{number } n_2\ , \tag{3}$$

– double omissions:

$$2.5\ (EVR) \leq b_{ri} < 3.5\ (EVR) - \text{number } n_3\ , \tag{4}$$

– (k-1) multiple omissions:

$$(k\text{-}1)(EVR) \leq b_{ri} < (k{+}0.5)(EVR) - \text{number } n_k\ , \tag{5}$$

where: b_{ri} – measured plant distances in the field, EVR – calculated effective distance of the seeds (plants) from each other.

Determining the effective distance of plants (seeds) from each other is crucial in assessing the quality of the planting, as it affects the presence of doubles, omissions, *etc.*, as well as the variability in the distribution of seeds and plants by standard deviation, but also in the values of field emergence. One evaluating indicator of its variability is the value of the standard value.

The accuracy of plant placement may be expressed in terms of the standard deviation (s_r):

$$s_r = \sqrt{\frac{\sum_{k=0}^{i} \left[b_{ri} - k\,(EVR)\right]^2}{i-1}}\ , \tag{6}$$

where: EVR – effective distance of the plants, b_{ri} – measured plant distances in the field, i – number of all of the measured plant distances.

The results obtained were evaluated by means of Statistica software (version 12.0, StatSoft Inc., Tulsa, OK, USA). A multi-factor analysis of variance and Tukey test were also carried out. Statistical calculations were made on the basis of a specific algorithm written in Excel (Tretowski and Wójcik, 1991).

RESULTS AND DISCUSSION

At present, genetically monocot sugar beet seed with an approximately spherical to oval shape is delivered to the market. The individual sizes of the seeds affect the quality of planting, depending on the choice of the appropriate planting device (Ružbarský, 2003).

The properties of the shape were expressed by using k_1-k_4, shape coefficients, the more the mutual values of the coefficients are balanced, the more rounded in shape the seed will be. Table 2 shows the average values of the length, thickness, width and shape coefficients of the seeds used in both planters.

A voluntary agreement between the seed producers was used to calibrate the seeds to 3.5-4.75 mm (Božiková, 2012). The exact ISO standard designed to determine the dimensional properties of seeds does not exist, but it is possible to use a recommended representation in each of the dimensional classes listed in Table 3 as an allowable boundary.

When assessing the strength properties of the seeds, the strength of the package while bearing its static load in the direction of the seed thickness, *i.e.* the smallest size of a seed was taken as the evaluation criterion. Similar tests were carried out by Śmigała *et al.* (2021) with seeds using the same device. They found differences in the mechanical properties of the seeds depending on the shape, size and moisture content.

It should be noted that the moisture content of the seeds, which may be changed as a consequence of storage, climatic and other conditions during the day, is affected by the hygroscopic effect of the seed. The study attempts to simulate various humidity conditions and their influence over possible damage to the seed packaging due to mechanical action (Fig. 3).

The process of transferring seeds from the hopper to the planting mechanisms, and thus the seed manipulation process, is mainly affected by the frictional properties of the seed (Gureyev, 2002; Turan *et al.,* 2014). These properties are characterized by the coefficients of shear friction (μ) and the apparent angle (α).

On the basis of the results obtained, it may be concluded that small differences were found in friction between individual manufacturers. The lowest friction coefficient value was found in case of the Flair seed, which could favourably

Table 3. Percentage share/abundance of sugar beet seed in particular size type by calibration 3.5-4.75 mm

Width of the seed (mm)		Permissible limit		Roxana seed type		Flair seed type	
		(%)					
3.5-4.75		88		96.5		94.5	
< 3.5		6		3.5		5.5	
3.25-3.49	<3.25	4.5	1.5	3.5	0	4	1.5
> 4.75		6		0		0	
4.75 - 4.99	> 4.99	4.5	1.5	0	0	0	0

* Seed width is the second biggest parameter according to which the seed is calibrated.

affect the tuck process in the planting mechanism which in turn has a direct impact on seed damage during seed planting. As far as the apparent angle values are concerned, they moved within the range of 21.33-25.16° (Table 4).

When assessing seed damage with reference to the seedlings, what is commonly known as slight damage L (visible damage to the seed surface), medium damage S (less than 33% of the broken volume) and severe T damage (more than 33% of the broken volume) in percentage terms, based on the seed quantity was considered (Table 5).

The results published by other authors (Zhai *et al*., 2020; Yazgi, 2007; Turan *et al.,* 2014; Kowalczuk *et al*., 2017) show that seed damage is mainly affected by the dimensional and strength properties of the seed and the chosen type of planting mechanism. In view of the above, it was decided to compare the two most widely used types of planting mechanisms used on sugar beet planters, namely the mechanical planting mechanism with internal filling and the pneumatic vacuum type.

Based on the results obtained, it may be stated with some confidence that the planter representing pneumatic vacuum planting systems inflicted greater seed damage at higher forward working speeds in the case of both calibrations. By contrast, the mechanical planting mechanism with the internal filling of the planting holes caused greater damage at forward working speeds of 1-1.5 m s^{-1}, which

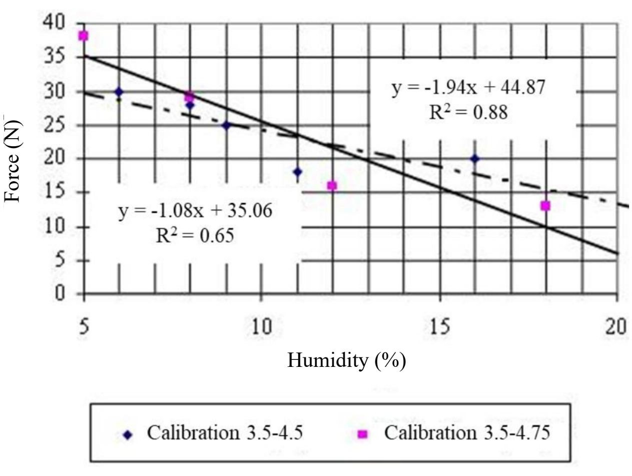

Fig. 3. Intensity of the destructive strength affecting the sugar beet seeds with a calibration of 3.5-4.5 and 3.5-4.75 mm.

may be justified by its design. The aforementioned planter requires a higher rotation frequency of the planting disc to achieve single-seed picking.

The highest value of light damage to the seed of 5.4% resulted from the use of the pneumatic planting mechanism with Flair seed. The increased trend in Roxana seed damage may be justified by the higher percentage of seed close to the 3.5 mm threshold, with damage values for this seed ranging from 0-4.2% at a seed moisture content of 7.9%.

Different factors combine to produce the variability of plants in field conditions which will cause inaccuracies in seed placement to a greater or lesser extent (Alipour *et al*., 2022).

The seed accuracy criterion as expressed by the standard deviation value, indicates a lower value for the "more accurate" seeder. At present, planting sugar beet at the final distance of the plants without manual intervention, which means that there sometimes can be double stitches (DRR) which are undesirable because the plants later compete with each other. From the results in Table 6 we may observe that the mechanical planting systems tended to produce rather better results (DRR) at higher speeds and with the pneumatic vacuum system the trend is exactly the opposite.

Apart from the impact of the planting mechanism, other working parts of the planting unit have an effect on the seed distribution variability. From the planting point of the seeds, it is important to carry out the rolling or seeding of the seeds after they fall into the planting furrow, which depends upon the seed speed ratios when they leave the planting disc. The influence of the forward working speed on the accuracy of horizontal seed placing is shown in Table 6.

The distribution of the seeds in the furrows after sinking was determined, among other things, through measuring the difference between the horizontal component of the circumferential planting speed and the forward working seed speed of the planting machine. On the basis of the results obtained from an assessment of the accuracy of planting, it may be concluded that the mechanical planting system achieved the best results at forward working speeds of 1.65-1.93 m s^{-1} where the value of the standard deviation was 28.83 mm.

In the case of the pneumatic vacuum system, the best results were achieved at a forward working speed of 0.88 m s^{-1} and a 30.84 mm deviation. As the work rate

Table 4. Measured values of shear friction coefficient and seed apparent angle for individual. Types of the sugar beet seed

Type of the seed	Calibration (mm)	Shear friction coefficient (μ)	Seed apparent angle (α,°)
Flair	3.5-4.5	0.48[a]	25.16[a]
Roxana	3.5-4.75	0.58[b]	21.33[b]

Slight damage L (visible damage to the seed surface), medium damage S (less than 33% of broken volume) and severe T damage (more than 33% of the broken volume) in percentage from the seed quantity. The same letters indicate no significant differences between the results obtained. Different letters (a, b, c, d) indicate the occurrence of significant differences between the obtained results.

Table 5. Damage of the seeds by planting mechanisms in relation from the forward working speed

Planting mechanism	Working speed ($m s^{-1}$)	Seed damage					
		Flair seed type			Roxana seed type		
		L	S	T	L	S	T
Pneumatic vacuum type	1.0	1.2[a]	0.0[a]	0.2[a]	3.1[b]	0.3[a]	0.0[a]
	1.5	3.5[b]	0.4[b]	0.5[b]	3.9[b]	0.3[a]	0.5[a]
	2.0	5.4[c]	0.4[c]	0.3[a]	4.2[d]	0.5[a]	0.0[a]
Mechanical with internal filling	1.0	1.4[c]	0.0[a]	0.0[a]	1.4[c]	0.6[b]	2.0[d]
	1.5	0.7[b]	0.0[a]	0.0[a]	1.8[c]	0.0[a]	0.8[b]
	2.0	0.6[b]	0.0[a]	0.0[a]	0.8[b]	0.2[a]	0.0[a]

Explanations as in Table 4.

Table 6. Selected planting quality parameters measured in field conditions of observed seeding mechanisms at various forward working speeds

Planting mechanism	Seed type (calibration) (mm)	Working speed ($m s^{-1}$)	PVR	*EVR*	sd	Plants placement				
						PRR	DRR	JV	DV	TV
			(mm)			(%)				
Mechanical *w*ith internal filling	Roxana (3.5-4.75)	0.65	197	191.6[a]	33.24	68.60	3.10	21.00	4.20	3.10
		1.04	197	192.3[a]	31.62	67.50	2.40	20.80	6.30	3.00
		1.65	197	192.9[b]	28.93	63.80	2.20	20.70	7.50	5.80
		1.93	197	190.2[c]	28.83	65.20	2.40	19.20	6.50	6.80
		2.35	197	193.5[d]	28.42	56.40	3.10	20.80	10.80	8.80
Pneumatic vacuum type	Roxana (3.5-4.75)	0.88	190	189.3[a]	30.84	81.40	1.00	13.40	2.90	0.90
		1.26	190	190.5[b]	35.31	77.40	0.90	17.50	3.10	1.20
		1.73	190	190.7[b]	39.36	83.00	2.10	12.40	2.40	0.10
		2.06	190	188.8[c]	42.21	78.30	2.90	15.40	3.10	0.40
		2.68	190	188.5[c]	48.82	78.80	3.60	15.90	1.20	0.50

PVR – required plant distance, *EVR* – effective plant distance, sd – standard deviation, PRR, DRR – required, double plant spacing; JV, DV, TV – single, double, triple skips. The same letters indicate no significant differences between the results obtained. Different letters (a, b, c, d) indicate the occurrence of significant differences between the obtained results.

increased, the seed variability in the row also increases, which is undesirable in terms of the practical use of the planter and in terms of the achievement of a high level of field performance.

CONCLUSIONS

The paper focused on evaluating the effect of the physical-mechanical properties of sugar beet seeds in terms of damage and on the quality of planting with the two most widely used planting mechanisms for sugar beet (a mechanical system with internal filling of the planting disc holes and a pneumatic vacuum system). Two seed calibrations were applied: The Flair seed type 3.5-4.5 mm and the Roxan seed type 3.5-4.75 mm. During the measurements, both laboratory and field experiments were performed on soils with the percentage of soil particles below 0.01 mm being 20-30%, that is to say, a clay-sandy soil. Based on the results obtained, the following statements may be made:

1. The measured values of seed calibration correspond to the recommended share in the individual size classes and the seed is also suitable for the mechanical principles of the seed planting machines.

2. When assessing the strength properties of the seeds, as an evaluation criterion, the strength of the seed coating in terms of its static load in the direction of seed thickness, *i.e.* the smallest size of the seed was taken as a criterion for assessment. It may be concluded that the tendency for the strength of the seeds to decrease with the increasing moisture content of the coating material has been recorded. A maximum force of 38.4 N was obtained at the lowest measured moisture content of 5%.

3. The smoothness of the seed tucking process has an influence over the frictional properties of the seeds. For the seed examined, the seed apparent angle ranged between 21.33 and 25.16°, which may have a secondary influence over the value of the omissions when assessing the quality of seed planting,

4. On the basis of the results obtained, it may be concluded that the planter representing the pneumatic vacuum planting system caused a greater amount of seed damage at higher forward working speeds at both calibrations. By contrast, the mechanical planting mechanism with the internal filling of the holes on the planting disc, caused more seed damage at forward working speeds of 1.0-1.5 m s^{-1}, which may be explained by its design.

5. In the area of the seed distribution variability of the seeds or plants in a row, the planter with a mechanical gathering of the seeds achieved better results as expressed by the standard deviations at higher forward working speeds (1.65-2.35 m s^{-1}), this was mainly due to the more ideal speed ratio that was applied to the seed when leaving the planting disc.

Data Availability Statement: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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