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SOME PHYSICAL AND TECHNOLOGICAL PROPERTIES OF SEEDS OF NON-TRADITIONAL PLANT SPECIES IN THE REPUBLIC OF MOLDOVA

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Abstract

The goal of our research is to fulfil the potential of non-traditional plant species in the Republic of Moldova, of the families: Asteraceae (Silphium perfoliatum, Cynara cardunculus), Fabaceae (Galega orientalis, Astragalus galegiformis, Medicago sativa) and Poaceae (Sorghum almum, Festuca arundinacea). This study presents the results of the research on the seeds characteristics of these plant species: dimensional parameters, friability, morphological structure, specific apparent weight, the weight of 1000 seeds, dosing instability and degree of seeds crushing in the respective device of the seed drill. Our research has shown that the seeds of the studied plants (except tall fescue) have high indices of dimensional uniformity and friability: angle of repose $\alpha \leq 32.5°$ and flow angle on steel $\alpha_1 \leq 27.8°$, on wood $\alpha_1 = 30.6°$ and on enamel $\alpha_1 = 26.3°$. The obtained indices of the physical properties are necessary to justify the correct choice, calculation and adjustment of the technical means of handling the seeds, and the indices of the technological properties serve as a basis for the correct choice of the seed metering devices for seed drills and the sowing parameters.

***Key words**: dimensions, dosage instability, friability, non-traditional plant species, seed properties.*

INTRODUCTION

Climate change, which is a global phenomenon, imperatively requires the mobilization of plant genetic resources that were previously underused or not used at all in the bioeconomic cycle, but can be successfully used under the new conditions (Cline, 2007; FAO, 2017). Currently, a lot of research is conducted in various countries, aiming at appreciating and using the potential of non-traditional plant species (Mayr et al., 2013; Jasinskas, 2014; Gansberger et al., 2015; Schäfer et al., 2017; Prakash et al., 2019; Kwaśniewski et al., 2020). However, in the above mentioned publications there is little or no information about species that are of interest in the Republic of Moldova. Moreover, the pedo-climatic conditions in the Republic of Moldova influence the properties and characteristics of the plant biomass, including seeds. That is why it is of scientific and practical interest to study the properties of plant species that are non-traditional for the bioeconomic cycle of the Republic of Moldova, of the following families: *Asteraceae* (cup plant - *Silphium perfoliatum*; cardoon - *Cynara cardunculus)*, *Fabaceae* (fodder galega - *Galega orientalis*, milkvetch - *Astragalus galegiformis*) and *Poaceae* (Columbus grass - *Sorghum almum*). The biomass of these non-traditional plants has a high potential for use as feed and raw material for the agricultural and food sector, the pharmaceutical industry, bioenergy production and other branches of the economy. The results of previously conducted research show that the above-mentioned plant species have a productive potential of fresh biomass of 44-100 t/ha (from such biomass, biomethane can be produced with the quota of 270-350 l/kg organic matter), of seeds – 2.5-4.0 t/ha (from which 0.8-1.1 t biodiesel can be obtained) and of energy biomass (calorific value 18.3- 19.0 MJ/kg) - 10-24 t/ha (Țîței & Roșca, 2021).

It is known that the morphological structure and size of the seeds substantially influence their friability (Hailis et al., 1998; Matei & Feher, 2010; Ene & Mocanu, 2016;); therefore, a comprehensive study of this influence in the case of seeds from the families *Asteraceae*, *Fabacea*e and *Poaceae* is necessary.

The result of the large-scale use of plant species of the three above-mentioned families depends to a large extent on the properties of the seeds. Therefore, it is necessary to know the physical and technological properties (characteristics) of the seeds, which have a special importance not only for the harvested plant biomass, but also for the management of the technological operations of conditioning (cleaning, calibration, drying, treatment), storage, transport and sowing. However, there is insufficient information in the above-mentioned bibliographic sources on the properties of the seeds of non-traditional species. Thus, the goal of our research has been to determine the physical and technological properties of the seeds of non-traditional plant species of the families: *Asteraceae*, *Fabaceae* and *Poaceae*.

MATERIALS AND METHODS

The seeds of plant species from the families *Asteraceae* (*Silphium perfoliatum*; *Cynara cardunculus*; *Helianthus annuus*), *Fabaceae* (*Galega orientalis*, *Astragalus galegiformis, Medicago sativa*) and *Poaceae* (*Sorghum almum*, *Festuca arundinacea*) served as research subjects. The studied seeds of non-traditional plant species were collected from the experimental field of the "Alexandru Ciubotaru" National Botanical Garden (Institute), Chisinau (C 46°58′25.7″ N, B 28°52′57.8″ E).

The size of the seeds is an important characteristic of a plant species and indicates, first of all, the potential for obtaining the plant biomass yield. The dimensional parameters of seeds (length, width, thickness ℓ x b x δ) were measured according to standard metods, with a calliper ȘȚ-I-125-0,05 an error of ± 0,05 mm. For each species, 25 seeds were measured from the average sample. The division of seeds samples of each species was performed by the quartering method in accordance with standard metods.

For small seeds, it is recommended to separate the seed fractions using sieves and to determine the fractional distribution, which is an important characteristic trait, determining technological qualities and areas of practical use of seeds (Ene & Mocanu, 2016). For this purpose, 5 samples weighing 150-250 g were taken from the seeds of each species, for which the fractional distribution was determined by sieving with vibrating sieves, using the sieve shaker AS 200 manufactured by the Retsch company (Germany) equipped with a sieve that had square meshes with sizes in the range of 0.25-3.15 mm. The process of separating the fractions of seed material took 15 minutes for each sample, the frequency of the vertical vibrations of the sieves corresponded to position 2 on the scale of the shaking device. Each sample was weighed with the electronic precision balance EW-3000-2M (Kern company, Germany), with an accuracy of 0.01 g.

To determine the weight of 1000 seeds (M_{1000}), a sample was taken and its weight (m) was measured; the result was estimated up to hundredths of gram. After that, the number (N) of the grains in the sample was counted and the value of M_{1000} was calculated according to the formula:

$$M_{1000} = (m/N) * 1000 \text{ [g]} \quad (1)$$

The typification of morphological structures, as well as the dimensional analysis of seeds, is necessary because it allows the correct design and use of technological processes, technical means of handling, planting, harvesting and processing of planting material (seeds, bulbs etc.). According to specialists (Matei & Feher, 2010; Hailis et al., 1998), the shape of the seeds influences their friability the most. The seeds with spherical or near-spherical shape have the highest flow rate. The more the shape of the seeds differs from the spherical shape, the lower the friability. The study of the morphological structure of the seeds was performed based on the classification that divides the seeds into 5 types:

1. Spheroidal: the dimensions of the seed are almost equal
($\ell \simeq b \simeq \delta$) (pea, soybean etc.);
2. Flattened: the width is approximately equal to the length, and the thickness is much smaller
($\ell \simeq b >> \delta$) (lentil);
3. Elliptical: the thickness is equal to the width, but the length is much bigger
($\ell >> b \simeq \delta$) (legume crops);
4. Elongated: all the dimensions differ from each other, the length being the biggest
($\ell > b \neq \delta$) (cereal crops);
5. Pyramidal (triangular).

The flow capacity (friability) of material bodies indicates their ability to move in an inclined plane at an angle to the horizontal plane (flow angle α_1) or to form a natural slope with a certain angle (angle of repose α) relative to the horizontal plane during free fall on a flat surface. The values of the angles α and α_1 are constant characteristics of the planting material of each species and do not change, regardless of the amount of this material. The determination of the angles α and α_1 of the planting material of each species is an important practice in the design of warehouses, transport and conditioning facilities (different types of transport means, elevators, cleaning and drying devices etc.) (Ene & Mocanu, 2016). The determination of the angle of repose α was performed by 2 methods: a) *general* - forming a pile of seeds of a conical shape, wh ich is obtained by pouring them through a funnel and letting them falling freely on a horizontal surface (Figure 1 a, b); b) *local* - applying the digital inclinometer on the inclined surface of the seed cone. To measure the angle α, samples with a volume of 200-250 ml were taken from the majority fractions obtained after sieving and several instruments and accessories were used (depth calliper SG 0-250, instrumental ruler 0-400 mm, funnel, digital inclinometer 360° (accuracy ± 0.20).

The measurement of the angle α with the help of the inclinometer was performed on 4 lines in 2 perpendicular planes, and the parameters of the cone (height h, diameter of the base D) were determined in 2 perpendicular planes. The value of the angle of repose was calculated according to the formula:

$$\text{tg}\ \alpha = 2\ h/D \quad (2)$$

The flow angle α_1 of the seed grains (Figure 1c) was measured using a table with the upper surface rotating vertically. On this surface, plates of steel 10, enamelled steel and wood were successively fixed. The angle α_1 was measured using a digital inclinometer. The measurement test was replicated 10 times when determining the values of the angle α and 5 times - for the angle α_1, which determined the standard deviation and the confidence interval.

The research on the technological properties of the seeds was carried out on a stand based on the cereal seed drill SZ 3.6 (Chervona Zirka company, Ukraine), which has been designed to sow on 24 rows, at a distance between rows of 0.15 m and at a depth in the limit h = 40-80 mm.

a) b) c)

Figure 1. Aspects of the process of measuring the angles α and α_1: a), b) cones of seeds (*Silphium perfoliatum*, *Helianthus annuus*), c) the inclined surface with seeds

The seed drill operates at a speed within the limit V = 7-12 km/h and the seeding rate is N = 15-200 kg/ha. The seed drill SZ 3.6 is equipped with individual seed metering devices with grooved cylinders, being intended for sowing a wide range of species (cereals, legumes, vegetables) (Figure 2). For research, the seed drill has been modified in such a way as to provide the possibility to study the dosing process on a single section. For this purpose, the respective dosing section was filled individually by installing a special device made for this research. Respectively, dosed seed samples were taken from the exit of the same section. The weight of each sample was determined with the electronic precision balance EW-3000-2M (Kern company, Germany), with an accuracy of 0.01 g.

a)

b)

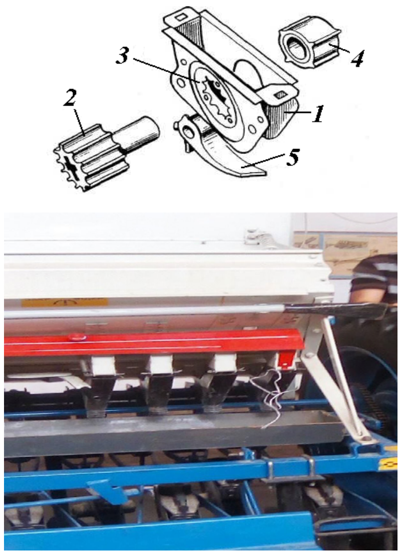

Figure 2. Seed metering device with grooved cylinder: a) general view; b) moments of the research process: 1 - frame; 2 - grooved cylinder; 3 - rotating sleeve with grooves; 4 - coupling sleeve; 5 - bottom support

The seed metering devices used for the research were adjusted to two values of the seeding rate (minimum N_{min}, maximum N_{max}), which were obtained as follows: a) minimum seeding rate N_{min}: the minimum values of the working length of the grooved cylinder L_{min} and of the rotations of the same cylinder n_{min} have been set, the transmission ratio in the action mechanism of the grooved cylinder having the maximum value i_{max} = 7.32; b) maximum seeding rate N_{max}: the maximum values of the length of the grooved cylinder L_{max} = 29 mm and of the rotations n_{max} with the minimum value of the transmission ratio i_{min} = 0.77 were set. To dose the small seeds (fodder galega, astragalus, Columbus grass) it was possible to perform a process with a minimum value of working length L_{min} = 5 mm, for larger seeds it was necessary to increase L_{min} up to 9 mm for cardoon seeds and up to 14 mm for cup plant seeds. The seed metering device was operated manually, from the support and drive wheel. The slow rotation of the drive wheel corresponded to the speed of movement of the seed drill within the limit 7-9 km/h (1.9-2.5 m/s). In the performed experiments, the number of rotations of the drive wheel had the following values: in most cases - n = 20 rot., and when the mass of dosed seeds was too small, to increase the measurement accuracy, the number of rotations was n = 30 rot. It should be noted that in the operating instructions of the seed drill SZ 3.6, it is recommended to perform 14 rotations to adjust the seeding rate.

Setting the drive wheel to do 20 rotations limits the movement of the seed drill to a distance of 78.19 m or a sown area of 281.47 m^2.

While processing the data obtained as a result of the experiments, the following indicators were calculated:

1. Average seed weight measured by one device in all the repetitions of the experiment:

$$m_{med} = \sum m_i / n \text{ [g]} \qquad (3)$$

where m_i is the weight of the seeds dosed repeatedly by a device i, [g]; n – the number of repetitions, [unit.], (in each experiment, by 5 repetitions were done);

2. The deviation of the weight of seeds dosed in a repetition i, from the mean value:

$$\Delta m_i = m_i - \overline{m}_{med} \text{ [g];} \qquad (4)$$

3. The instability of seed dosing during the technological process:

$$I_d = (\overline{\Delta m}_{ir} / m_{med}) \cdot 100 \text{ [\%];} \qquad (5)$$

where $\overline{\Delta m}_{ir}$ is the arithmetic mean deviation of the seed mass dosed in 5 repetitions from the mean value:

$$\overline{\Delta m}_{ir} = [\sum \Delta m_i]/n = [\sum (m_i - \overline{m}_{med})]/n \text{ [g];} \qquad (6)$$

The instability of seed dosing can also be estimated based on the formula for calculating the coefficient of variation v:

$$v = (\sigma / m_{med}) \cdot 100 \text{ [\%];} \qquad (7)$$

where σ is the standard deviation of the seed weight in different repetitions:

$$\sigma = \sqrt{[\sum (m_i - m_{med})^2 / (n-1)]} \text{ [g]} \qquad (8)$$

4. The degree of seed crushing (mechanical damage) was calculated from the ratio of the weight of the crushed seeds and the total weight of the sample before the separation of the crushed and undamaged seeds:

$$g = (m_s / m_{tot}) \cdot 100 \text{ [\%]} \qquad (9)$$

where m_s is the weight of the seeds crushed in a sample [g]; m_{tot} - the total weight of the sample [g].

RESULTS AND DISCUSSIONS

The results of the measurements of the seeds of species of the Asteraceae family show that cardoon *Cynara carduncululus* seeds before calibration were divided into 3 fractions according to their size: the majority fraction exceeded the size of 3.15 mm (mass quota - 62%), the second fraction had a size of 3.15-2.8 mm (30.39%) and the third fraction 2.8-2.0 mm (7.57%). These 3 fractions together made up 99.96% of the total amount of seeds researched, and 0.04% constituted residues, losses, which was much less than the standard value: <2%. For further studies, *Cynara carduncululus* seeds were calibrated, using the majority fraction >3.15 mm (97.5%) (Table1).

The separation of seeds into fractions using the sieve shaker AS 200 is done by vertical vibrations of the sieves, therefore, in this case, the limit size for the passage of seed grains through the square meshes of the sieves is the width of these seeds b. The results of the measurements show that the dimensional characteristics of cardoon *Cynara carduncululus* seeds (fraction> 3.15 mm) have the following values: ℓxbxδ = (7.5 ± 0.9) x (3.65 ± 0.40) x (2.40 ± 0.25) mm (tab.1), the size ratio being ℓ:b:δ = 3.1: 1.5: 1.0. The value of seed width (b = 3.65±0.40 mm) exceeded the mesh size of the sieve (3.15 mm). The sunflower seeds (with shells) (fraction >3.15 mm) had the following dimensions ℓxbxδ = (9.2±1.1) x (5.6±0.3) x (4.2±0.4) mm with the ratio ℓ:b:δ = 2.2: 1.3:1.0.

According to the data presented by Hailis et al., 1998; Manea, 2011; Trubilin et al., 2009, the width of the seeds of the main agricultural crops varies within the following limits: cereals (b = 1-5 mm, wheat, rye, barley, oats, millet), crops that need mechanical weed control (b = 2-12 mm, sunflower), vegetables (b = 1.3-4 mm, tomatoes, onions, radishes, cabbage, carrots). At the same time, the sunflower seeds have, according to the same authors, the following dimensional characteristics: ℓxbxδ = (7.5-15.0) x (2.5-8.6) x (1.7-6.0). The dimensions of the sunflower seeds studied by us fall within the limits identified by the above-mentioned authors.

After sieving, it has been found that the cup plant seeds fit into a single fraction that is larger than 3.15 mm (97.5%). A specific trait of these seeds is that they have a marginal wing, and after peeling the cup plant seeds in a special device (model MDA 1), no significant changes in their fractional distribution were observed.

The factors that influence the flow capacity of seeds are the shape, size and the texture of the surface of the seed grains, their moisture and physical purity, as well as the surface (material, roughness) on which they flow. The flow capacity is higher when the shape of the seeds is close to the spherical shape, their surface is smoother, the humidity - lower and the proportion of impurities - also lower. The studied seeds were previously conditioned according to humidity U and physical purity P. The surfaces on which they flowed were identical (steel 10, wood, enamel) for all seeds. Therefore, it is further necessary to study the influence of the shape and outer surface of the seeds on their friability.

The above-mentioned ratios of the dimensions of cardoon and sunflower seeds ℓ:b:δ, as well as the study of the morphological structure of these seeds (Figure 3) show that they belong to the type 4. Elongated, in which all three dimensions differ from each other, but length has the biggest value (ℓ> b≉δ).

Cynara carduncululus seeds, according to their morphological structure, are identical to sunflower seeds, but, unlike the latter, they do not have a shell.

Silphium perfoliatum seeds, in terms of shape, belong to the type 2. Flattened (ℓ≃b>δ), having a marginal wing (somehow like maple seeds), due to which, after falling, these seeds tend to form a layered pile (Figure 1a, Figure 3). The belonging to types 2 and 4 did not prevent the studied seeds from having high friability.

The studied seeds demonstrated the following values of the friability indicators (Table 1): a) sunflower, control, natural angle of repose α=32.9° ±1.1° (general method) and α=33.2°±2.0° (local method); flow angle on steel α_1=29.3°±0.5°, on wood α_1=31.3°±0.6°, on enamel surface α_1=25.3°±0.4°; b) cardoon, angle of repose α=30.3°±0.9° (general method) and α=31.1° ±0.9° (local method) for cleaned but uncalibrated seeds, and for calibrated seeds (fraction >3.15 mm) α=28.2°±1.3° (general method) and α=29.0°±1.3° (local method);

flow angle on steel α_1= 27.7°±0.8°, on wood α_1=30.6° ±1.1°, on enamel surface α_1= 26,3° ±0,8°; c) cup plant, angle of repose α= 29.4°±1.5° (general method) and α=31.1°±2.1 (local method); flow angle on steel α_1=27.8°±0.3°, on wood- α_1=29.1°±1.5°.

The outer surface of the sunflower *Helianthus annuus* seeds is rough (Figure 3a), which increases the coefficient of friction between the seeds, on the one hand, and between the seeds and the material of the inclined surface, on the other hand. Therefore, the given seeds had higher angle of repose α with 4.2°-4.7° as compared with cardoon seeds, which have smooth surface (Figure 3b). A higher flow angle α_1 is also characteristic of sunflower seeds (Table 1). The cup plant *Silphium perfoliatum* seeds, which have smooth surface, have friability values between those of cardoon and sunflower seeds.

Table 1. Values of physical and technological properties of seeds

Plant species; Material of the surface on which seeds flow	Angle (°) of:			Size, ℓ·b·δ, mm/ majority fraction, mm (% mas.)	Specific apparent weight ρ_v, g/l	Weight of 1000 seeds (M_{1000}), g
	flow α_1	repose α, method				
		general	local			
Family ***Asteraceae***						
Cynara cardunculus		28.2±1.3	29.0±1.3	(7.5±0.9)x(3.65±0.40)x x(2.40±0.25) /> 3.15 mm (97.5%)	637.52	48.89
Steel 10	27.7±0.8					
Wood	30.6±1.1					
Enamel	26.3±0.8					
Helianthus annuus		32.9 ±1.1	33.2±2.0	(9.2±1.1)x(5.6±0.3)x x(4.2±0.4) /> 3.15 mm (98.7%)	445.18	62.84
Steel 10	29.3±0.5					
Wood	31.3±0.6					
Enamel	26.8±0.4					
Silphium perfoliatum		29.4±1.5	31.1±2.1	/> 3.15 mm (97.5%)	380.82	20.26
Steel 10	27.8±0.3					
Wood	29.1± 1.5					
Family ***Fabaceae***						
Astragalus galegiformis		26.0±1.1	26.9±1.3	/2.0-1.4 mm (83.3%)	802.92	9.33
Steel 10	22.8±0.4					
Wood	26.3± 0.5					
Galega orientalis		32.5±0.1	33.4±0.2	/2,0-1,4 mm (97.3%)	784.24	6.00
Steel 10	27.7±0.3					
Wood	29.8±0.8					
Medicago sativa		30.2±0.4	31.5±0.4	/2.0-1. 4mm (98.3%)	765.19	1.91
Steel 10	27.3±0,4					
Wood	33.6±0.9					
Enamel	26.7± 0.2					
Family ***Poaceae***						
Festuca arundinacea		36.0±0.9	38.7±2.2	(6.4±0.5) x(1.35±0.3)x x(0.8±0.1)	287.13	2.62
Steel 10	30.1±0.2					
Wood	43.2±0.5					
Enamel	26.7±0.3					
Sorghum almum		26.5±0.9	27.2±0.8	/2.0 –1.4 mm (92.0%)	656.00	8.00
Steel 10	19.9±0.3					
Wood	24.2±0.2					

There is a difference between the values of the angle α measured according to the general and the local method, this difference is 0.30 for *Helianthus annuus* and 0.80 for cardoon (Table 1). The lower values of the angle α determined by the general method are probably caused by the lack of a well-defined tip at the seed cone (Figure 1a, b), which decreases the height of the cone and, implicitly, the value of the angle of repose. The local method performed with the digital device provides a high accuracy of the measurement, but the lateral sides of the seed cones are not even, especially in the cup plant seeds (Figure 1a), therefore the deviations of the values of angles α are greater in the case of the local method. Therefore, taking into account that most studies are based on the general method of measuring the angle α, as well as taking into account the above-mentioned facts, we will use in most cases the results obtained by the general method and, if necessary, those obtained by the local method.

a) b) c)

Figure 3. The morphology of the seeds of the plants from the Asteraceae family: a) *Helianthus annuus*; b) *Cynara cardunculus*; c) *Silphium perfoliatum*

In order to verify the phenomena mentioned in previous scientific articles (Hailis et al., 1998; Matei & Feher, 2010; Dragoș, 2011), we have studied the friability of cardoon cleaned and uncalibrated seeds (mixture of fractions), as well as calibrated one (fraction > 3.15 mm).

The results obtained (Table 1) confirm the influence of seed purity on their friability: in both methods used (general, local) the angle of repose α is by 2.1° lower than in the case of calibrated seeds. In previous articles (Hailis et al., 1998; Matei & Feher, 2010), values of the angle of repose α of the seeds of different sunflower varieties and hybrids in the limit α=31°- 45° were presented. Analysing these data, we came to the conclusion that the value of the angle of repose of sunflower seeds determined by us in our research (α=31.8°-34.0°) corresponds to the results obtained previously.

The study of seeds from the Fabaceae family demonstrated that alfalfa *Medicago sativa* (control) have a majority fraction of 2.0-1.4 mm (98.3%), and the *Astragalus galegiformis* seeds are represented by 2 fractions: 2.0-1.4 mm (83.3%) and 2.8- 2.0 mm - 16.6%. The share of both fractions together is equal to 99.9%.

In 2019-2020, we researched the influence of weather conditions on the seed size of fodder galega *Galega orientalis*. In the seeds harvested in 2019, two fractions were identified: the majority 2.0-1.4 mm (97.3% mas.) and the secondary fraction 1.4-1.0 mm (2.4%), together, these two fractions made up 99.7% of the mass of seeds. In 2020, the distribution of *Galega orientalis* seeds changed a little: the majority fraction 2.0-1.4 mm (91.9%) and the secondary fraction 1.4-1.0 mm (7.9%). The changes in the distribution of *Galega orientalis* seeds are 2020: long-term hydrological and atmospheric drought.

We would like to mention that the seeds of the species of the *Fabaceae* family have identical dimensional characteristics: their majority fraction falls within the limits of 2.0-1.4 mm, with a share of over 83%.

The seeds of alfalfa, fodder galega and astragalus have many similarities in their shape (Figure 4) and fit in the 3rd category – eliptical, having a thickness approximately equal to the width, and the length being the biggest value ($l >> b \simeq \delta$) similar to the seeds of several leguminous crops. The shape of the seeds, as it was proved by the specialists (Hailis et al., 1998; Matei & Feher, 2010; Ene & Mocanu, 2016), it is the factor that most influences their flow capacity.

The seeds of spherical or almost-spherical shape have the highest flow capacity. The more the shape of the seeds differs from the spherical one, the lower the friability. The above-mentioned authors established that the best flow capacity is characteristic of the seeds of legume crops with rounded, smooth surfaces (peas, beans etc.) (type 1 and 3) and the lowest – of the flattened seeds with a rough surface of vegetable crops (carrots, dill, parsley etc.) (type 2). The seeds of cereal crops (type 4) have intermediate friability.

Our study shows (Table 1) that in the *Fabaceae* family, the astragalus seeds have the highest friability (the angle of repose α=26.0°±1.1° and the flow angle on steel α_1= 22.8°±0.4°, on wood – α_1= 26.3°±0.5°).
The next level of friability, a little lower, was found at alfalfa seeds (angle of repose α=30.2°± 0.4° and the flow angle on steel α_1=27.3°±0.4°, on wood α_1=33.6°±0.9°, on enamelled surface - α_1=26.7°± 0.2°) and fodder galega (α=32.5°±0.1° and α_1 on steel - 27.7°±0.3°, on wood–α_1=29.8°±0.8°). In the 3 studied species of the *Fabaceae* family (astragalus, alfalfa, fodder galega) the seed coat is smooth, hairless (Figure 4), as in the seeds of other legume crops, being one of the reasons why the values of friability are high.

a) b) c)

Figure 4. The morphology of the seeds of the plants from the Asteraceae family: a) *Helianthus annuus*; b) *Cynara cardunculus*; c) *Silphium perfoliatum*

In the *Poaceae* family, the seeds of *Sorghum almum* have the majority fraction with sizes in the range of 2.0-1.4 mm (92.0%) (Table 1), and the second most important fraction falls within the range of 2.8-2.0 mm (7.8%). Together, these two fractions make up 99.8%, the remaining 0.2% includes debris and losses. As a result of the measurements, we identified the dimensional characteristics of the seeds of tall fescue *Festuca arundinacea* which have the following values:
$\ell \times b \times \delta$=(6.4±0.5) x (1.35±0.3) x (0.8±0.1) mm (Table 1), the ratio of the dimensions being $\ell:b:\delta$ = 8.0: 1.7: 1.0. The highest friability in the *Poaceae* family is characteristic of Columbus grass seeds (the angle of repose = 26.5°±0.9° and the angle of flow on steel α_1=19.9°±0.3°, on wood α_1=24.2°±0.2° (Table 1), and the tall fescue seeds are characterized by the following values of angles α=36.0°±0.9° (general method) and α=38.7°±2.2° (local method), the flow angle on steel α_1=30.1°±0.2°, on wood α_1=43.2°±0.5°, on enamelled surface α_1=26.7°±0.3°. It should be noted that the difference in the values of the angle of repose α measured by the general and local method for most species does not exceed 1°, but in the case of cup plant this difference is 1.7° and in the case of tall fescue Δ = 2.7°. For both plant species, the big difference between the values of the angles α determined by the general and the local method is related to the morphological structure of the seeds. Cup plant *Silphium perfoliatum* has type 2. flattened seeds, with smooth surface (Figure 4), which favours the friability, but the surface of the formed seed cone is not even. The structure of the tall fescue *Festuca arundinacea* seeds (Figure 5) belongs to type 4. elongated ($\ell > b \neq \delta$) (identical to the cereals), being covered with paleae (glumes), which increase the coefficient of friction among the seeds and with the contact surfaces. That is why the surface of the cone formed by the tall fescue seeds is not uniform. Unlike the seeds mentioned above, the shape of columbus grass *Sorghum almum* seeds (Figure 5) belongs to type 3. eliptical ($\ell >> b \simeq \delta$) with smooth seed coat, and the cross section of the perennial sorghum seeds is almost round. Despite the fact that most *Sorghum almum* seeds have a peduncle (fruit stalk) at the tip, it does not have a negative effect on the friability of the seeds.
The analysis of the results of the research on the seeds from the 3 families (*Asteraceae*, *Fabaceae*, *Poaceae*) shows that in most of the performed experiments (Table 1) the values of the flow angle α_1 were lower than the values of the angle of repose α. The largest difference between α

and α_1 was identified on the enamelled surface in the case of sunflower (Δ=6.1°) and tall fescue seeds (Δ=9.3°), in other cases this difference was less than 3°-4°. On the wooden surface, the difference α-α_1 had negative values for the seeds of cardoon (Δ=-2.4°), alfalfa (Δ=-3.4°) and tall fescue (Δ=-7.2°). For other studied species the difference α-α_1 had positive values. The obtained results (Table 1) show that, in most of the studied cases, the coefficient of friction among seeds (internal) has higher values than the coefficient of friction between seeds and the sliding surface (external), that is $\alpha > \alpha_1$. The shape and condition of the surface on which the seeds flow influences their friability: on smooth surfaces with low roughness, the friability of the seeds is higher than on those with high roughness.


a) b)

Figure 5. The morphology of seeds of plants of the Poaceae family: a) *Festuca arundinacea*; b) *Sorghum almum*

Therefore, on the enamelled and steel 10 surfaces, seeds have a better flow capacity than on those made of wood (Table 1). The biggest difference between the values of the angle of flow α_1 on wooden surfaces, on the one hand, and on those of steel 10 and enamel, on the other hand, is in alfalfa seeds (Δ=6.9°) and especially, in tall fescue seeds (Δ=16.5°), but in other seeds Δ≤4°.

The results obtained show that the high uniformity of the seed sizes in the studied species, which has been mentioned, has a beneficial influence on the accuracy of measuring the angles of repose and flow: the highest deviation of the angle α was in sunflower, cup plant and tall fescue (±2.0°-2.2°) when using the local method.

In our research the specific apparent weight ρ_v, g/l, was determined by three repetitions; for this purpose, the seeds were poured into a container with a volume of 3 l and then weighed, with an error of ± 1 g. The ρ_v was calculated according to the formula

$$\rho_v = m/V \qquad (10)$$

where: m is the weight of seeds [g]; V - the capacity of the container [l].

To determine the mass of 1000 seeds M_{1000}, samples were taken and their weight m was measured to hundredths of grams. After that, the quantity of seeds N was counted in each sample and the weight M_{1000} was calculated according to the formula:

$$M_{1000} = (m/N)*1000 \text{ [g]} \qquad (11)$$

The values calculated for the studied seeds (Table 1) of the specific apparent weight ρ_v are of practical interest and are necessary for designing the storage spaces, the organization of the transport, the customization of the equipment and the appreciation of some technological norms.

The weight of 1000 seeds M_{1000} is an important physical indicator of quality when establishing the sowing norm.

The research conducted with the seed drill SZ 3,6 has demonstrated that the seeds of relatively small size (fraction #2.0-1.4 mm) of fodder galega and astragalus had dosing instability values I_d lower than 1.93% seed crushing values of $g_s \leq 0.53\%$ (tab.2).

According to the agro-technical standards (Posâpanov et al., 2007; Mamonov A., 2017), the values of sowing rate instability of different crops need to correspond to the following criteria: cereals - $I_d \leq 2.8\%$; legumes - $I_d \leq 4\%$; grasses - $I_d \leq 9\%$. According to the agro-technical requirements the material prepared for sowing, the quantity of crushed seeds should not exceed 1%, which once again demonstrates the importance of keeping the seed material intact.

The obtained results allow to conclude that dosing fodder galega, astragalus and Columbus grass seeds with the seed metering device with grooved cylinder meets the agrotechnical requirements. The claim that good results can be obtained by dosing the above-mentioned seeds with the grooved cylinder can be supported by the fact that fodder galega, astragalus and Columbus grass seeds (Figures 4, 5) have many similarities in their shape and fall into the category 3. Elliptical, having the following indices of friability: the angle of repose $\alpha \leq 32.5°$ and the flow angle $\alpha_1 \leq 29.8°$ (Table 1).

In the process of research on cardoon and cup plant seeds (*Asteraceae* family), which have the fraction #>3.15 mm, it was established that their characteristics differed when dosed with the grooved cylinder. The highest value of dosing instability in cardoon seeds was 1.91% and the degree of seed crushing was 0.36%, respectively. For cup plant seeds, the above-mentioned indices had the following values: $I_d \leq 6.55\%$ and $g \leq 3.49\%$. The good capacity of dosing cardoon seeds is due to their morphological structure of type 4. Elongated with smooth seed coat (Figure 3b), which causes the high values of friability: the angle of repose $\alpha = 28.2°$. Cardoon seeds had the same level of friability, dosage instability and resistance to crushing as the small seeds (fodder galega, astragalus, Columbus grass).

Cup plant seeds, according to the morphological structure, are of type 2. flattened (Figure 3c) and, although they have a sufficiently high level of friability, with the angle of repose α = 29.4°, because of the flattened structure with marginal wing, they had greater instability than the seeds of the previous species. The seeding rates of cup plant seeds influence the technological parameters: at the minimum seeding rate - I_d=6.55% and g=0.95%, and at the maximum – I_d=1.72% and g=3.49% (Table 2).

The maximum value of dosing instability of cup plant seeds (6.55%), although it is the highest in our experiments, still does not exceed the allowable value ($I_d \leq 9\%$) expected in the agrotechnical requirements. However, as for the maximum value of the degree of crushing of cup plant seeds, the situation is different (3.49%), because it exceeds the allowed value ($g \leq 1\%$). Therefore, the dosing of the cup plant seeds with the grooved cylinder is possible by using the low values of rotations of the cylinder or by increasing the seeding rate N, taking into account the real values of the degree of crushing of the seeds. Schäfer et al. (2015) adapted a precision seed drill ED 302 (Amazone company, Germany) for sowing cup plant seeds, their dosing being performed in the vacuum chamber on disks with horizontal axes of rotation. The research conducted in open field, with the adapted seed drill, has positive results, the optimal depth of incorporation of the seeds being 5 mm and the distance between rows of 50 cm, and the diameter of the holes on the disks varied within the limit of 1.2-2.2 mm.

Table 2. The results of measurements of dosing instability and degree of crushing of the seeds of the studied species

No.	Plant species	Dosing instability I_d (%) at		Variation coefficient v (%) at		Degree of crushing g (%) at	
		N_{min}	N_{max}	N_{min}	N_{max}	N_{min}	N_{max}
Asteraceae family							
1	*Cynara cardunculus*	1.91	0.17	4.8	0.43	0.07	0.36
2	*Silphium perfoliatum*	6.55	1.72	16.26	4.29	0.95	3.49
Fabaceae family							
3	*Galega orientalis*	0.92	1.93	2.29	4.84	0.53	0.36
4	*Astragalus galegiformis*	1.22	1.43	3.05	3.56	0.39	0.44
Poaceae family							
5	*Sorghum almum*	1.16	0.11	2.91	0.27	0.15	0.18

Note: $\mathbf{N_{min}}$, $\mathbf{N_{max}}$ – the minimal dose and the maximal dose of seeds, respectively

Our calculations showed that the values of the ratio between the coefficient of variation v and the dosage instability I_d vary slightly around $v/I_d \backsimeq 2.5$ for the seeds of all the studied plant species (Table 2). This finding suggests that only one of the indicators is sufficient to calculate the seed dosing instability: the dosing instability I_d or the coefficient of variation v. It is important to take into account the actual values of I_d (or v) and of the degree of seed crushing g when establishing the seeding rate under the real conditions.

CONCLUSIONS

Our research has made it possible to demonstrate that the seeds of the studied species of the families *Asteraceae, Fabaceae* and *Poaceae* (except *Festuca arundinacea*) have high values of dimensional uniformity and friability; the angle of repose $\alpha \leq 32.5°$ and the flow angle on steel $\alpha_1 \leq 27.8°$, on wood $\alpha_1 = 30.6°$, on enamelled surface $\alpha_1 = 26.3°$. One of the basic factors that influenced the friability of the seeds is their morphological structure. In tall fescue, the friability is low because of the morphology ($\alpha = 36.0°$ and $\alpha_1 \leq 43.2°$). The studied seeds had friability values (angle of repose α and flow angle α_1) at the same level as the majority of commonly cultivated field crops, which is very important because it allows the use of available buildings and technical means in the agricultural sector.

The comparison of the geometric parameters of the studied seeds and those of the agricultural plants widely used in the local agriculture makes it possible to predict some properties of the studied seeds and to rationally elaborate the technological itineraries, as well as to correctly select the technical means for the implementation of these itineraries.

Currently, as the results of our research suggest, seed metering devices with grooved cylinders, of individual or common type, can be used to sow the researched plants (cardoon, fodder galega, astragalus, Columbus grass). In order to sow cup plant seeds, the given devices need to be adjusted to the minimal values of rotation intensity.

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