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A Comparative Study on the Characteristics of Seeds and Phytomass of New High-Potential Fodder and Energy Crops

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Abstract: The purpose of this research is to capitalise on the potential of non-traditional plant species in the Republic of Moldova from the families *Asteraceae* (cup plant *Silphium perfoliatum*; cardoon *Cynara cardunculus*), *Fabaceae* (fodder galega *Galega orientalis*, sand sainfoin *Onobrychis arenaria*), *Hydrophylaceae* (phacelia *Phacelia tanacetifolia*), *Malvaceae* (curly mallow *Malva crispa*; Virginia mallow *Sida hermaphrodita*) and *Poaceae* (perennial sorghum *Sorghum almum*, pearl millet *Pennisetum glaucum*). The study presents the research results on the seed properties (dimensional parameters, structure, friability, apparent specific mass, mass of 1000 seeds) and on the phytomass quality of the above-mentioned plants. The obtained results demonstrate that the criterion of dimensional proportionality K_{dp}, proposed in this paper, effectively reflects the structure of the seeds; the seeds of new crops (except phacelia) have high friability (angle of repose $\alpha \leq 33°$ and angle of static friction on steel $\alpha_1 \leq 27.8°$, on wood $\alpha_1 = 34.7°$, on enamelled surface $\alpha_1 = 30°$). The natural fodder from the researched species is characterised by a crude protein content of 9.0–23.4%, dry matter digestibility of 56.0–66.5%, digestible energy load of 11.16–12.95 MJ kg^{-1}, metabolizable energy of 9.16–10.63 MJ kg^{-1}, net energy for lactation of 5.18–6.76 MJ kg^{-1}, and relative feed value RFV = 74–129. The biochemical biomethane potential from studied vegetal substrates is 297–353 l kg^{-1} VS.

Keywords: biochemical methane potential; dimensions; friability; nutritive value; phytomass quality; seeds properties

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1. Introduction

The conservation and improvement of biodiversity has become a basic objective in science and the world economy [1], which requires the development of agriculture and forestry and the implementation of a set of measures to improve the efficiency of the management of technical systems and chemical agents, at the same time paying increased attention to the efforts of maintaining and developing biological systems. Therefore, in the last 20–30 years, a series of works dedicated to the in-depth studies of new plant species have been published, with the aim of mobilizing new plant genetic resources and capitalizing in the bioeconomic circuit of their polyvalent potential, being intended for feed, honey, energy, pharmaceuticals, food needs, and land improvements, including marginal and contaminated lands [2–17]. At the same time, FAO specialists [18] point out that at the present moment, it is imperative not only to improve biodiversity and increase agricultural production but no less important to reduce the losses of agricultural raw materials and food products, which currently constitute approx. 1/3 of the obtained production, or 1.3 billion t $year^{-1}$. The reduction in the above-mentioned losses will allow to improve the ecological situation and solve the socio-economic problems in the world economy.

Achieving the vital tasks specified by international organizations [1–3,18], adapting the agricultural sector to climate changes and mitigating them is possible by implementing new cultivars of non-traditional plant species in the agro-economic system and fulfilling their full potential based on in-depth studies of the elements of agrobiological and technical systems. In the technological chain of agricultural production, the process of sowing new crops is of particular importance, and the efficiency of this operation largely depends on the peculiarities and quality indices of the seeds. Therefore, studies on the physical and technological properties of the seeds of agricultural crops, particularly, the cultivars of new and non-traditional plant species, are of topical interest nowadays. The analysis of technical-scientific achievements demonstrates that there are papers [19–26] that present the results of multilateral studies on the properties of the seeds of new plant species and techniques for incorporating them into the soil. The authors made substantial contributions to the field of agronomy, identifying the technological procedures for cultivating new plant species and determining optimal sowing dates and conditions for seed treatment, seed production, and seed storage. The physical and technological properties (dimensional parameters, friability) of the seeds of some new plant species are described in these papers [23,25–27].

The analysis of available sources of information demonstrates that the physical and, respectively, technological properties of seeds depend on the variety of plant species and the soil climatic conditions of plant cultivation. It is necessary to mention that the notion of "non-traditional plant species, new crops" in this paper is valid for the soil climatic zone of South-Eastern Europe (Romania, Ukraine, Republic of Moldova, etc.). At the same time, new and non-traditional plant species are native to America (*Sida hermaphrodita*, *Silphium perfoliatum*, *Sorghum almum*, and *Phacelia tanacetifolia*), Africa (*Pennisetum glaucum)*, the Caucasus Mountains (*Galega orientalis*), and the Mediterranean Basin (*Cynara cardunculus).* Some new and non-traditional plant species, taking into account their importance, have been studied in the last 20–30 years under the conditions of Western and Central Europe [6,9–13,28,29]. In South-Eastern Europe, several studies on the properties of the component parts of new plants have been carried out [30–36]; however, these studies do not contain sufficient information for the inclusion of the mentioned plants in the bioeconomic circuit.

At the "Alexandru Ciubotaru" National Botanical Garden (Institute), Chisinau, for more than 70 years, research has been carried out on the mobilization and acclimatization of new plant species, contributing to the identification of valuable forms and the expansion of the gene pool of plant resources with multiple utilities for the national economy, and breeding activities were completed with the creation of new cultivars and, subsequently, to their homologation and patenting [37–40]. Among these cultivars, there are: 'Vital' of cup plant *Silphium perfoliatum*; 'Melifera' of lacy phacelia *Phacelia tanacetifolia;* 'Energo' of Virginia fanpetals *Sida hermaphrodita;* 'Argentina' of perennial sorghum *Sorghum almum*; 'Sofia' of fodder galega *Galega orientalis*, etc. Some agro-biological peculiarities of the newly created cultivars have been presented in our previous papers [41–43]. The important advantage of the mentioned plant species is that they can also be cultivated on degraded, polluted, or marginal lands where traditional crops have low yields or cannot be cultivated [42].

The experience obtained over several years proves that inclusion in the agro-economic system and making use of the full potential of the new non-traditional plant crops require a thorough and complex study of the features of seeds and the quality indices of the harvested phytomass. The knowledge of these peculiarities and quality indicators allows, on the one hand, the adequate adaptation of the techniques of sowing, harvesting, and handling in order to obtain a qualitative and profitable product, and, on the other hand, the mentioned knowledge is a strong argument for the economic agents to implement non-traditional species. Another reason why it is necessary to know the properties of the seeds is the fact that most of the non-traditional plant species and new homologated cultivars, except phacelia, are perennial; therefore, there are higher requirements for these seeds because the established plantations must be highly productive for about 10 years.

Based on the analysis carried out, the goal of our paper is to contribute to the fulfilment of the potential of some new crops, including fodder and energy biomass, by conducting a comparative study on the characteristics of the seeds and the quality indices of the plant mass obtained from the above-mentioned species in comparison with traditional crops.

Achieving the proposed goal is possible by measuring the dimensional (length, width, and thickness LWT), geometric (geometric mean diameter $D_{g,}$ sphericity S), and mass (mass of 1000 M_{1000} seeds, apparent density ϱ_v) parameters of the seeds. The need to study the above-mentioned parameters is determined by the fact that they, being dependent on the morphological structure and biochemical composition of the seeds, are used in the design and implementation of the technical operations of sowing, threshing, calibrating, storing, etc.

2. Materials and Methods

In order to achieve the above-mentioned goal, a methodology was developed that includes the following successive study stages: (a) measuring the physical properties of the seeds of traditional and new crops; (b) evaluation of the biochemical composition, fodder nutritional value, and its biochemical potential to obtain biomethane.

The seeds and phytomass obtained from taxa of the following families served as subjects of research:

(a) *Asteraceae* (sunflower *Helianthus annuus* L. local variety "Ana"—control crop; cup plant *Silphium perfoliatum* L. local variety "Vital"; artichoke thistle *Cynara cardunculus* L. introduced taxa);
(b) *Fabaceae* (soybean *Glycine max* L. Merr. local variety 'Clavera'; and alfalfa *Medicago sativa* L. variety "Cezara"—control traditional crops; fodder galega *Galega orientalis* Lam. local variety "Sofia"; sand sainfoin *Onobrychis arenaria* (Kit.) DC local ecotype);
(c) *Hydrophylaceae* (phacelia *Phacelia tanacetifolia* Benth local variety 'Melifera');
(d) *Malvaceae* (curly mallow *Malva crispa* L. introduced taxa; Virginia mallow *Sida hermaphrodita* (L.) Rusby losal local variety 'Energo');
(e) *Poaceae* (oat *Avena sativa* L., variety "Sorin", common wheat *Triticum aestivium* L., local variety "Moldova 614"—control crops; the perennial sorghum *Sorghum almum* Parodi, local variety "Argentina"; pearl millet *Pennisetum glaucum* [L.] R.Br. introduced taxa).

The phytomass and the seeds were collected from studied plant species growing in the experimental plot of the National Botanical Garden (Institute) "Alexandru Ciubotaru", Chişinău, latitude 46°58′25.7″ N and longitude 28°52′57.8″ E.

2.1. Measurement of Physical Properties of Seeds

The dimensional parameters of the seeds (length, width, and thickness LWT) were measured, at the first stage, according to the recommendations [44–46] using a mechanical caliper 0–150 mm with the error limit $\Delta_{lim} = \pm 0.05$ mm (producer—Tolsen). For each species, 25 seeds taken from the average sample were measured; the samples were sampled using the four-quarter method. At the second stage, 15 seeds were taken from each measured sample, for which the LWT dimensions were checked using the MMI-2 instrumental microscope with the error limit $\Delta_{lim} = \pm 0.004$ mm (producer—Novosibirsk Instrument-Making Plant). The fixation of the seeds on their edges, in the process of measuring the thickness T, was performed with the help of two instrumental rulers (0–150 mm).

Based on the measured values of the LWT dimensional parameters, the geometric parameters of the seeds were calculated according to [44,45]:

- geometric mean diameter

$$D_g = (LWT)^{1/3}, [mm], \quad (1)$$

- sphericity

$$S = (D_g/L) \times 100, [\%], \quad (2)$$

In addition to the geometric parameters mentioned in expressions (1, 2), for characterizing the shape of the seeds, the criterion of dimensional proportionality, which reflects the ratio between the main dimensions of the seeds, was developed and used:

$$K_{dp} = (L/T)/(W/T)/(T/T) = (L/T)/(W/T)/1, \quad (3)$$

The apparent density ϱ_v was determined from five repetitions; for this purpose, seeds were poured into a vessel with a precise volume and then weighed with an error of ±1 g. The ϱ_v value was calculated according to the expression:

$$\varrho_v = m/V, [kg\ m^{-3}], \quad (4)$$

where m is the mass of the seeds [kg] and V is the capacity of the vessel [m^3].

The mass of the seeds was determined with the electronic scale EW-3000-2M (manufacturer—KERN & SOHN GmbH, Balingen, Germany), with the error limit $\Delta_{lim} = \pm 0.01$ g.

The study of dimensional, mass, and friability parameters, as well as the morphological structure of the seeds, is necessary because it allows for the correct design and utilization of the technological processes for handling the seed material. The study of the seed structure was carried out based on the K_{dp} criterion and the classification, which divide seeds into the 5 types described by us in the article [47] by dividing the seeds into 5 types ((1) Spheroidal—$L \simeq W \simeq T$; (2) flattened—$L \simeq W >> T$; (3) elliptical—$L > W \simeq T$; (4) elongated—$L >> W \not\simeq T$; and (5) pyramidal). Also in the aforementioned publication, we have reflected methods for determining the mass for 1000 seeds, M_{1000}, as well as the friability properties of the seed (the angle of repose α, the angle of static friction α_1).

To measure friability, the following instruments and equipment were used: 0–250 mm depth caliper with error limit $\Delta_{lim} = \pm 0.05$ mm (producer-Kalibr), instrumental ruler 0–400 mm, funnel, digital clinometer GIM 60, error limit $\Delta_{lim} = \pm 0.05$ mm (producer-Bosch Profesional, Renningen, Germany). The value of the angle of repose was calculated according to the formula:

$$tg\ \alpha = 2\ h/D \quad (5)$$

The angle of static friction α_1 was measured on low-carbon steel plates S235JR (EN 10025-2/2004) and enamelled steel with roughness R_a 0.63, and on wood—R_a 1.25.

The statistical processing of the results of measurements was carried out using the program Excel 2021 (Microsoft Corporation, Redmond, WA, USA).

2.2. Evaluation of Biochemical Composition and Fodder Value, and Biochemical Biomethane Potential of Fresh Mass from Studied Plant Species

The samples of fresh mass for the evaluation of the biochemical composition were taken during the flowering period, in perennial species in the 3rd year of life, crushed and subjected to dehydration, at 60 °C, in special equipment, and then the plant samples were finely ground in a laboratory ball mill. The content of crude protein (CP), crude fiber (CF), crude ash (CA), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), and total soluble sugars (TSS) was determined using the near-infrared spectrophotometry method with the use of PERTEN DA 7200 and standardised methods at the RDI for Grassland Brasov, Romania. The concentrations of cellulose (Cel), hemicellulose (HC), relative feed value (RFV), dry matter digestibility (DDM), fodder energy value (metabolizable energy (ME), digestible energy (DE), and net energy for lactation (NEl)) were estimated by applying the accepted equations. The carbon content of the organic matter was calculated according to Badger et al. [48]. Biochemical methane potential was evaluated according to Dandikas et al. [49].

3. Results and Discussion

3.1. Physical Properties of Traditional and New Crops Seeds

The results of the studies demonstrate that the dimensional characteristics of the seeds of crops from the *Asteraceae* family have the following values (Table 1): *Helianthus annuus*—

LWT = 9.2 × 5.6 × 4.2 mm; *Silphium perfoliatum*—LWT = 11.05 × 5.85 × 1.30 mm; *Cynara cardunculus*—LWT = 7.55 × 3.45 × 2.45 mm. The criterion of dimensional proportionality varies within the following limits: the minimum value K_{dp} = 2.19/1.33/1 for *Helianthus annuus* seeds (S = 65.2%) and the maximum—K_{dp} = 8.4/4.46/1 for cup plants (S = 39.8%). A mutual dependence is observed, a link between the values of the K_{dp} criterion and the sphericity S: the closer the seed structure is to the spherical shape, the higher the sphericity value becomes, approaching 100%, and the lower—the K_{dp} value, evolving towards the ideal 1/1/1 ratio (Table 1).

Table 1. Values of seeds dimensional and mass parameters.

Name of the Species	Dimensional Parameters, mm				Geometric Parameters		Mass Parameters	
	L	W	T	Criterion K_{dp}	D_g, mm	S, %	ρ_v, kg m^{-3}	M_{1000}, g
				Asteraceae				
Helianthus annuus	9.20 ± 1.1	5.60 ± 0.3	4.20 ± 0.4	2.19/1.33/1	6.0 ± 0.51	65.2	445.0 ± 1.86	68.5 ± 1.10
Silphium perfoliatum	11.05 ± 0.9	5.85 ± 0.4	1.30 ± 0.05	8.4/4.46/1	4.39 ± 0.26	39.8	230.1 ± 1.17	21.31 ± 0.06
Cynara corduncułus	7.55 ± 0.9	3.45 ± 0.3	2.45 ± 0.18	3.11/1.42/1	3.99 ± 037	52.8	637.5 ± 1.43	48.89 ± 0.22
				Fabaceae				
Glycine max	7.10 ± 0.25	5.40 ± 0.27	5.20 ± 0.25	1.36/1.04/1	5.83 ± 0.26	82.5	719.2 ± 2.44	147.2 ± 0.44
Medicago sativa	2.15 ± 0.10	1.20 ± 0.06	1.05 ± 0.06	2.03/1.12/1	1.48 ± 0.07	68.2	818.7 ± 2.59	1.78 ± 0.03
Galega orientalis	3.55 ± 0.4	1.90 ± 0.22	1.45 ± 0.07	2.47/1.31/1	2.13 ± 0.18	59.8	784.2 ± 3.77	6.27 ± 0.05
Onobrychis arenaria	5.60 ± 0.3	3.95 ± 0.21	2.35 ± 0.15	2.41/1.7/1	3.73 ± 0.21	66.4	370.8 ± 2.76	14.63 ± 0.12
				Hydrophylaceae				
Phacelia tanacetifolia	2.55 ± 0.21	1.50 ± 0.16	1.00 ± 0.13	2.51/1.45/1	1.57 ± 0.16	61.3	543.3 ± 2.93	1.53 ± 0.01
				Malvaceae				
Malva crispa	2.10 ± 0.08	2.10 ± 0.08	1.45 ± 0.13	1.41/1.41/1	1.85 ± 0.09	88.9	428.9 ± 2.13	2.68 ± 0.09
Sida hermaphrodita	2.20 ± 0.12	2.05 ± 0.08	1.45 ± 0.1	1.52/1.43/1	1.88 ± 0.1	85.1	704.6 ± 3.43	4.81 ± 0.12
				Poaceae				
Avena sativa	9.60 ± 1.2	2.80 ± 0.4	2.00 ± 0.1	4.8/1.4/1	3.77 ± 0.36	39.3	381.0 ± 4.18	32.75 ± 1.48
Triticum aestivium	6.40 ± 0.42	3.25 ± 0.3	3.00 ± 0.19	2.13/1.08/1	3.97 ± 0.29	62.0	772.2 ± 3.74	35.50 ± 1.63
Sorghum almum	5.60 ± 0.15	2.80 ± 0.13	2.40 ± 0.09	2.33/1.16/1	3.34 ± 0.12	59.6	656.0 ± 3.89	6.99 ± 0.14
Pennisetum glaucum	3.00 ± 0.12	2.25 ± 0.19	2.15 ± 0.16	1.39/1.05/1	2.43 ± 0.15	81.5	675.0 ± 1.89	5.47 ± 0.18

The identified values of the dimensional parameters for the seeds of crops from the *Asteraceae* family correlate to a large extent with the results mentioned in the literature. According to the data [50,51], seeds of different *Helianthus annuus* hybrids have the following dimensions: LWT = (9.31–12.1) × (4.5–5.9) × (2.95–4.87) mm. In the papers [23,52], the following values of the sizes of *Silphium perfoliatum* seeds are presented: in natural form, LWT = (9–15) × (4.5–9) × (≤1–1.5) mm; in mechanically treated and coated form, LWT = (8.4–9) × (4.7–5.2) × (1.3–2.6) mm.

The values of the criterion of dimensional proportionality K_{dp} for the seeds of *Cynara corduncułus*, *Helianthus annuus*, and *Silphium perfoliatum* plants demonstrate that they belong to type (4). Elongated, in which all three dimensions are distinguished from each other, with length having the highest value ($L > W \not\approx T$). However, unlike *Helianthus annuus* seeds, *Cynara corduncułus* seeds do not have a shell (capsule), having a smooth coat. The *Silphium perfoliatum* seeds have palea/husks on the outer surface (such as maple seeds), and that is why, after falling, these seeds tend to form piles in layers.

The seeds of crops in the *Fabaceae* family have the following values of dimensional characteristics (Table 1): *Glycine max*—LWT = 7.1 × 5.4 × 5.2 mm; *Medicago sativa*—LWT = 2.15 × 1.20 × 1.05 mm (D_g = 1.48 mm); *Galega orientalis*—LWT = 3.55 × 1.9 × 1.45 mm; *Onobrychis arenaria*—LWT = 5.6 × 3.95 × 2.35 mm. The results obtained in this work are included in the results of other research. For a series of *Glycine max* hybrids and cultivars, the authors [53,54] present the following dimensional parameters: LWT = (6.1–8.19) × (4.5–7.12) × (4.4–6.23) mm. In paper [55] the *Medicago sativa* seed dimensions are given: LWT = (2.36–2.72) × (1.39–1.47) × (1.07–1.35) mm.

The values of the criterion K_{dp} = 1.36/1.04/1.0 for *Glycine max* seeds (S = 82.5%) convincingly show that they belong to type (3). Elliptical (L > W $\simeq$ T), which is specific for leguminous crops. The pods of *Onobrychis arenaria*, which are characteristic of plants from the leguminous family, according to their morphological structure, register type (2). Flattened (L $\simeq$ W >> T) with the criterion value K_{dp} = 2.41/1.7/1 and the sphericity S = 66.4%. The skin of the pods in these seeds has macro-irregularities (macro-asperities). The structure of the *Medicago sativa* and the *Galega orientalis* seeds corresponds to the same type (3). Elliptical with the criterion values K_{dp} = 2.03/1.12/1 and K_{dp} = 2.47/1.31/1, respectively, the sphericity has values S = 68.2% and S = 59.8%, respectively. It should be noted that in the *Fabaceae* family, *Glycine max* and *Medicago sativa* seeds are best classified, according to their shape, as type (3). Elliptical, and in other studied seeds, the difference between the values of width and thickness is slightly greater.

In the *Hydrophylaceae* family, the properties of the seeds of a single representative, *Phacelia tanacetifolia*, were studied, which have some of the lowest values of the dimensional characteristics (D_g = 1.57 mm) (Table 1): LWT = 2.55 × 1.5 × 1.0 mm and the criterion K_{dp} = 2.51/1.45/1 specific for type (3). Elliptical (L > W $\simeq$ T) with sphericity S = 61.3%. The specificity of *Phacelia tanacetifolia* seeds lies in the fact that their coat is coarse.

In this research, the *Malvaceae* family had two representatives, the seeds of which are characterised by the following values of dimensional characteristics (Table 1): *Malva crispa*—LWT = 2.1 × 2.1 × 1.45 mm (S = 88.9%); *Sida hermaphrodita*—LWT = 2.2 × 2.05 × 1.45 mm (S = 85.1%). The structure of *Malva crispa* and *Sida hermaphrodita* seeds with the criterion values K_{dp} = 1.41/1.41/1 and K_{dp} = 1.52/1.43/1, respectively, belongs to type (2). Flattened (L $\simeq$ W >> T). The external aspect of *Sida hermaphrodita* seeds also tends a little towards type (5). Pyramidal (triangular), having both concave and convex surfaces on the same grain. The coat surface of *Malva crispa* seeds is coarse, while in *Sida hermaphrodita* seeds it is smooth, as in the seeds of the *Fabaceae* family (*Glycine max*, *Medicago sativa*, *Galega orientalis*, and *Onobrychis arenaria*), stimulating high values of friability.

The seeds of crops from the *Poaceae* family have the following dimensional characteristics: *Avena sativa*—LWT = 9.6 × 2.8 × 2.0 mm; *Triticum aestivium*—LWT = 6.4 × 3.25 × 3.0 mm; *Sorghum almum*—LWT = 5.6 × 2.8 × 2.4 mm; *Pennisetum glaucum*—LWT = 3.0 × 2.25 × 2.15 mm. The authors [56] present the following dimensional parameters for *Sorghum bicolor* seeds with different moisture levels, 10.9%–24.2% (d.b.): LWT = (5.02–5.69) × (4.25–4.63) × (3.22–3.53) mm. The papers [53,57,58] show the dimensional values of *Pennisetum glaucum* seeds of various varieties and moisture: LWT = (3.0–4.46) × (2.30–3.39) × (1.54–2.51) mm.

The criterion of dimensional proportionality and sphericity in the studied seeds has the following values: *Avena sativa*—K_{dp} = 4.8/1.4/1 and S = 39.3%; *Triticum aestivium*—K_{dp} = 2.13/1.08/1 and S = 62.0%; *Sorghum almum*—K_{dp} = 2.33/1.16/1 and S = 59.6%; *Pennisetum glaucum*—K_{dp} = 1.39/1.05/1 and S = 81.5%. The analysis of the values of the K_{dp} criterion and of the sphericity demonstrates that the morphology of the *Avena sativa* seeds belongs to type (4). Elongated with characteristic dimensional ratios for cereals: L >> W $\not\simeq$ T. The structure of the seeds of *Triticum aestivium*, *Pennisetum glaucum*, and *Sorghum almum* falls into type (3). Elliptical (L > W $\simeq$ T), having the shape of a circumference in the transverse section of the seeds.

The analysis of the mass parameters of the studied seeds (Table 1) demonstrates that their values for traditional and new crops correlate with the structure and geometric parameters. The seeds of crops from the *Asteraceae* family have the geometric mean diameter D_g, with values at the upper level in relation to seeds from other families, and, respectively, the values of the mass of 1000 seeds belong to the same level: *Helianthus annuus* seeds—D_g = 6.0 mm (S = 65.2%), M_{1000} = 68.5 g; *Cynara cordunculus* seeds—D_g = 3.99 mm (S = 52.8%), M_{1000} = 48.89 g; *Silphium perfoliatum* seeds—D_g = 4.39 mm (S = 39.8%), M_{1000} = 21.31 g.

The obtained results coincide with those presented in the literature: the values of the geometric and mass parameters for *Helianthus annuus* seeds are equal—D_g = (5.12–6.5) mm, S = (31.3–60.8)%, M_{1000} = (41.8–89.0) g, apparent density ϱ_v = 330.1–449.86 kg m^{-3} [50,51];

for *Silphium perfoliatum* seeds in their natural form, the values of the mass of 1000 seeds vary approximately within the limit of 14–21.5 g [23,52]. In the case of seeds from the *Asteraceae* family, there is a tendency to decrease the M_{1000} mass from 68.5 g (sunflower) to 21.31 g (cup plant), one of the causes of this tendency being the decrease in the values of the diameter D_g from 6.0 mm to 3.99 mm and of the sphericity S = 65.2%→39.8%.

The above-mentioned hypothesis is also confirmed in the case of *Glycine max* seeds (*Fabaceae* family), which have the highest mass value M_{1000} (147.2 g) with the geometric parameters: diameter D_g = 5.83 mm and sphericity S = 82.5%. These seeds are also distinguished by their dense structure, lacking a shell/pod.

The following crops have the smallest dimensions and, respectively, the smallest mass values per thousand seeds: *Medicago sativa*—D_g = 1.48 mm (S = 68.2%), M_{1000} = 1.78 g; *Phacelia tanacetifolia*—D_g = 1.57 mm (S = 61.3%), M_{1000} = 1.53 g; *Malva crispa*—D_g = 1.85 mm (S = 88.9%), M_{1000} = 2.68 g; *Sida hermaphrodita*—D_g = 1.88 mm (S = 85.1%), M_{1000} = 4.81 g; *Galega orientalis*—D_g = 2.13 mm (S = 59.8%), M_{1000} = 6.27 g; *Pennisetum glaucum*—D_g = 2.43 mm (S = 81.5%), M_{1000} = 5.47 g. The seeds of other studied crops demonstrated intermediate values of the geometric and mass parameters: *Sorghum almum*—D_g = 3.34 mm (S = 59.6%), M_{1000} = 6.99 g; *Onobrychis arenaria*—D_g = 3.73 mm (S = 66.4%), M_{1000} = 14.63 g; *Avena sativa*—D_g = 3.77 mm (S = 39.3%), M_{1000} = 32.75 g; *Triticum aestivium*—D_g = 3.97 mm (S = 62.0%), M_{1000} = 35.50 g (Table 1). Therefore, the results of the measurements demonstrate that, in the case of seeds with small and medium dimensions, the existence of a correlation between the values of the geometric parameters and the mass parameters is also confirmed. At the same time, for the studied seeds, their morphological structure also has an influence on the M_{1000} mass values. For example, the seeds of *Malva crispa* (D_g = 1.85 mm, S = 88.9%) and *Sida hermaphrodita* (D_g = 1.88 mm, S = 85.1%) have almost equal values of the geometric parameters, but the values of the mass of 1000 seeds essentially differ: M_{1000} = 2.68 g and M_{1000} = 4.81 g, respectively. This is because *Sida hermaphrodita* seeds have a denser structure with a smooth outer surface.

The morphology of the seeds most influences the values of apparent density ϱ_v (kg m^{-3}), which is the highest in seeds with a dense structure and a smooth outer surface: *Medicago sativa*—ϱ_v = 818.7 kg m^{-3}, *Galega orientalis*—ϱ_v = 784.2 kg m^{-3}, *Glycine max*—ϱ_v = 719.2 kg m^{-3} (all seeds from the *Fabaceae* family); *Triticum aestivium*—ϱ_v = 772.2 kg m^{-3}. The seeds that contain in their structure the palea/husks of the fruit/pod have the lowest value of the apparent density (kg m^{-3}): *Silphium perfoliatum*—ϱ_v = 230.1 kg m^{-3}, *Helianthus annuus*—ϱ_v = 445.0 kg m^{-3}, *Onobrychis arenaria*—ϱ_v = 370.8 kg m^{-3}, *Avena sativa*—ϱ_v = 381.0 kg m^{-3}. *Malva crispa* and *Phacelia tanacetifolia* seeds also have low apparent density values (ϱ_v = 428.9 and 543.3 kg m^{-3}, respectively) because of their loose structure and coarse outer surface. Other plant species (*Cynara cardunculus*, *Sorghum almum*, and *Pennisetum glaucum*) have seeds with an apparent density in the range of ϱ_v = 637.5–675.0 kg m^{-3}.

For some plant species researched in this paper, there are data on the geometric and mass parameters of the seeds in the literature: *Medicago sativa* (moisture—7.98–22.1% d.b.)—D_g = (1.47–1.59) mm, M_{1000} = (1.797–2.295) g [55]; *Pennisetum glaucum*—D_g = (2.45–2.63) mm, S = (67.0–83.3)%, M_{1000} = (7.3–11.95) g, apparent density ϱ_v = (646.4–827.5) kg m^{-3} [57,58]; *Sorghum* sp.—D_g = (4.09–4.53) mm, S = (81.8–79.6)%, apparent density ϱ_v = (775.05–699.69) kg m^{-3} [56]; *Glycine max*—D_g = (4.9–7.14) mm, S = (80–91)%, M_{1000} = (83.96 ± 1.38) g, apparent density ϱ_v = (719.0–766.12) kg m^{-3} [53,54].

The identified values of the apparent density ϱ_v and of the mass of 1000 seeds M_{1000}, specific to the studied seeds (Table 1), are of practical interest and are necessary for the dimensioning of storage spaces, the organization of transport, the calculation of machinery, and the appreciation of some technological norms. The M_{1000} mass values present an important physical index necessary for establishing the sowing rate and, simultaneously, an index of seed quality.

It is known that the factors that influence the flow property of the seeds are: the morphological structure, the size and condition of the surface of the seed coat, the moisture and their physical purity, on the one hand, and on the other hand, the condition of the surface (material, coarseness) of the machine on which the flow occurs. The seeds with a structure close to the spherical one, a smooth coat surface, low moisture, and a small amount of impurities showed high flow capacities. The seeds studied beforehand were conditioned according to moisture *U* and physical purity *P*. The surfaces on which the flow occurred were identical (steel *S235JR*, wood, and enamel) for all seeds. In the given conditions, the morphological structure and the state of their coat surface can influence the friability of the seeds.

In the *Asteraceae* family, the seeds demonstrated friability with the following values (Table 2):

(a) *Helianthus annuus* seeds, the angle of repose α = 32.9° (general method) and α = 33.2° (local method); angle of static friction on steel α_1 = 29.3°, on wood—α_1 = 31.3°, on enamelled surface α_1 = 25.2°;

(b) *Cynara cardunculus* seeds, the angle of repose α = 28.2° (general method) and α = 29.0° (local method); angle of static friction on steel α_1 = 27.7°, on wood α_1 = 30.6°, on enamelled surface α_1 = 26.3°;

(c) *Silphium perfoliatum* seeds, the angle of repose α = 29.4° (general method) and α = 31.1° (local method); angle of static friction on steel α_1 = 27.8°, on wood—α_1 = 29.1°, on enamelled surface α_1 = 26.3°. The higher values of the α angle in *Helianthus annuus* seeds are due to the micro-coarseness of the capsule surface, which increases the coefficient of friction between the seeds on the one hand and between the seeds and the inclined surface material on the other hand. Therefore, *Helianthus annuus* seeds showed values of the angle of repose α higher by 4.2–4.7° compared to *Cynara cordunculus* seeds, which have a smooth coat. The angle of static friction α_1 is also higher in *Helianthus annuus* seeds (Table 2). *Silphium perfoliatum* seeds with a smooth coat have a friability between *Cynara cardunculus* and *Helianthus annuus* seeds.

Table 2. Values of seeds friability parameters.

Name of the Species	The Angle of Repose α, Grade, Measurement Method			The Angle of Static Friction α_1,		
	General	Local	Average	Steel	Wood	Enamelled
			Asteraceae			
Helianthus annuus	32.9 ± 1.1	33.2 ± 1.8	33.1	29.3 ± 0.5	31.3 ± 0.6	25.2 ± 0.4
Silphium perfoliatum	29.4 ± 1.5	31.1 ± 2.1	30.3	27.8 ± 0.3	29.1 ± 1.5	26.3 ± 0.8
Cynara cordunculus	28.2 ± 1.3	29.0 ± 1.3	28.6	27.7 ± 0.8	30.6 ± 1.1	26.3 ± 0.8
			Fabaceae			
Glycine max	27 ± 0.6	25.5 ± 0.7	26.2	15.2 ± 1.1	16.3 ± 0.9	14.7 ± 0.3
Medicago sativa	30.2 ± 0.3	31.5 ± 0.4	30.9	27.3 ± 0.4	33.6 ± 0.9	26.7 ± 0.2
Galega orientalis	32.5 ± 0.9	33.4 ± 0.8	33.0	27.7 ± 0.3	29.8 ± 0.8	27.3 ± 0.4
Onobrychis arenaria	28.4 ± 0.7	31.8 ± 1.3	30.1	23 ± 0.1	29 ± 0.7	22 ± 0.1
			Hydrophylaceae			
Phacelia tanacetifolia	37.5 ± 1.2	38.3 ± 1.5	37.9	37.5 ± 0.8	39.1 ± 1.1	36.9 ± 0.7
			Malvaceae			
Malva crispa	29.2 ± 0.4	31.9 ± 0.9	30.6	27.7 ± 0.4	34.7 ± 0.4	30.0 ± 0.5
Sida hermaphrodita	30.7 ± 0.9	31.1 ± 0.9	30.9	26.6 ± 0.4	29.4 ± 0.8	25.7 ± 0.4
			Poaceae			
Avena sativa	29.2 ± 0.3	30.8 ± 0.6	30.0	25.2 ± 0.2	28.8 ± 1.2	23.7 ± 0.3
Triticum aestivium	25 ± 0.2	27.7 ± 1.2	26.4	21.8 ± 0.4	22.7 ± 0.7	22.2 ± 0.4
Sorghum almum	26.5 ± 0.9	27.2 ± 0.8	26.9	19.9 ± 0.3	24.2 ± 0.2	19.1 ± 0.3
Pennisetum glaucum	26.9 ± 0.4	26.8 ± 0.7	26.9	18.7 ± 0.3	24.2 ± 0.7	21.0 ± 0.5

In most of the studied seeds, a small difference is observed between the values of the angle α measured according to the general and the local method; this difference is 0.3° for *Helianthus annuus*, 1.7° for *Silphium perfoliatum*, and 0.8° for *Cynara cordunculus* (Table 2). The lower values of the angle α determined with the general method are probably caused by the lack of a well-defined peak at the seed cone, which reduces the height of the cone and, implicitly, the value of the angle of repose. The local method carried out with the digital device ensures a high measurement accuracy, but the lateral surfaces of the cones formed by the seeds are not uniform, especially in *Silphium perfoliatum* seeds; therefore, the deviations of the values of the α angles are greater in the case of the local method. Taking into account the fact that the difference between the values of the angle α, determined by the general and the local method is relatively small, for the analysis of the friability of the seeds, the average value of the angle α will be used, and, if necessary, the values α obtained by both methods will be used.

In the *Fabaceae* family, *Glycine max* seeds have the highest friability (the angle of repose α = 26.2° and the angle of static friction on steel α_1 = 15.2°, on wood—α_1 = 16.3°, on enamelled surface—α_1 = 14.7°) (Table 2), which have the dimensional parameters and structure suitable for the flow conditions. The next highest level of friability, decreasing, was demonstrated by the seeds of *Onobrychis arenaria* (the angle of repose α = 30.1° and the angle of static friction on steel α_1 = 23°, on wood—α_1 = 29°, on enamelled surface—α_1 = 22°), *Medicago sativa* (the angle of repose α = 30.9° and the angle of static friction on steel α_1 = 27.3°, on wood α_1 = 33.6°, on enamelled surface—α_1 = 26.7°) and *Galega orientalis* seeds (α = 33.0° and α_1 on steel—27.7°, on wood—α_1 = 29.8°, on enamelled surface—α_1 = 27.3°).

Phacelia tanacetifolia, *Hydrophylaceae* family, demonstrated the highest value of angle α (37.9°) and angle of static friction α_1 (37.5° on steel, 39.1° on wood and 36.9° on enamel), the cause of this phenomenon being the rough, coarse coat.

The friability of *Malva crispa* seeds (α = 30.6°) and *Sida hermaphrodita* (α = 30.9°), *Malvaceae* family, is analogous to that of seeds from the families *Asteraceae*, *Fabaceae* (Table 2). In our opinion, this result is due, first of all, to the morphological structure of the seeds (in *Malva crispa*—sphericity S = 88.9% and in *Sida hermaphrodita*—S = 85.1%), the coat of these seeds is not covered in husk, as that of barley, oat, etc. grains. The relatively higher value of the flow angle on wood for *Malva crispa* seeds (α_1 = 34.7^0) may be caused by coarseness on the outer surface of these seeds.

In the *Poaceae* family, the values of the angle of repose of the seeds vary within narrow limits—from α = 26.4° for *Triticum aestivium* to α = 30.0° for *Avena sativa*. The *Avena sativa* seeds had the highest values of the angle of static friction (on steel—α_1 = 25.2°, on wood—α_1 = 28.8°, on enamelled surface—23.7°). For the seeds of *Triticum aestivium*, *Sorghum almum*, and *Pennisetum glaucum*, the values of the angle of static friction vary within narrow limits (on steel—α_1 = 18.7–21.8°, on wood—α_1 = 22.7–24.2°, on enamelled surface—α_1 = 19.1–22.2°). Despite the fact that the tip of most *Sorghum almum* seeds has a peduncle (the stalk of the fruit), the latter does not negatively influence the friability of the seeds. *Avena sativa* seeds in the given family have the lowest friability, the reason being the presence of the coating on these seeds and their structure that fully corresponds to type 4. Elongated ($L >> W \not\approx T$) with sphericity S = 39.3%.

The analysis of the results obtained with the seeds from the 5 families (*Asteraceae*, *Fabaceae*, *Hydrophylaceae*, *Malvaceae*, and *Poaceae*) demonstrates that in most of the experiments performed (Table 2), the values of the angle of static friction α_1 were lower than the values of the angle of repose α. The biggest difference between α and α_1 was identified on the enamelled surface in the case of *Helianthus annuus*, *Sorghum almum*, *Onobrychis arenaria* (Δ = 7.8–8.1°) and *Glycine max* (Δ = 11.5°), in other cases this difference is less than 6°. On the wood surface, the difference α-α_1 has negative values for the seeds of *Cynara cardunculus* (Δ = −2°), *Medicago sativa* (Δ = −2.7°), *Phacelia tanacetifolia* (Δ = −1,2°), *Malva crispa* (Δ = −4.1°). For other studied plant species, the difference α-α_1 has positive values. The results obtained (Table 2) demonstrate that in most of the studied cases, the coefficient of internal friction between the seeds has higher values in relation to the coefficient of external friction (between the seeds and the sliding surface), i.e., $\alpha > \alpha_1$.

The shape and condition of the surface on which the seeds flow influence their friability: on smooth surfaces with low coarseness, the friability of seeds is higher than on those with high coarseness. That is why, on the enamelled and steel surfaces, a better flow capacity of the seeds is recorded than in the case of those made of wood material (Table 2). The difference between the values of the angle of static friction α_1 on wood surfaces, on the one hand, and on steel S235JR, enamelled ones, on the other hand, varies up to a maximum of 6–7°. The influence of the seed structure on the above-mentioned difference is observed: increasing the values of seed sphericity S has the effect of decreasing the difference between the values of angle α_1 on wood surfaces and those on steel S235JR, enamelled surfaces.

In the literature, there is information on the friability of the seeds of the crops studied in this paper. The authors [32,33] established the following values of friability parameters for *Glycine max* seeds: the angle of repose α = 24.2–31.8°, angle of static friction α_1 = 9.3–16.0° on steel with galvanic coating and α_1 = 16.9–24.3° on wood. For *Medicago sativa* seeds, the angle of repose varies within the limit α = 27.05–33.21° [55], while *Sorghum* seeds showed the following values of friability parameters: α = 26.75–29.31°; α_1 = 31–35.8° on soft steel and α_1 = 35–37.6° on plywood [56]. The authors [27,57,58] determined for *Pennisetum glaucum* seeds the angle of repose α = 23.00–29.38°, angle of static friction on steel α_1 = 13.4–25° and α_1 = 12.5–21.7° on wood. The comparative analysis of the values of dimensional parameters, mass, and friability, determined by us and by specialists from other countries for the seeds of the studied crops, demonstrates that, although the plants were grown in different soil-climatic conditions with the variation of varieties and seed moisture, there is a sufficiently good correlation between the above-mentioned results, which proves the veracity of our results.

So, the results obtained in this paper demonstrate that both the seeds of traditional crops: sunflower *Helianthus annuus*, soybean *Glycine max*, alfalfa *Medicago sativa*, oat *Avena sativa*, common wheat *Triticum aestivium* and the seeds of new crops: cup plant *Silphium perfoliatum*, artichoke *Cynara cardunculus*, fodder galega *Galega orientalis*, sand sainfoin *Onobrychis arenaria*, phacelia *Phacelia tanacetifolia*, curly mallow *Malva crispa*; Virginia mallow *Sida hermaphrodita*, perennial sorghum *Sorghum almum*, pearl millet *Pennisetum glaucum*) have dimensional and mass parameters, structure, and friability that demonstrate the possibility of using the existing technical means in modern agriculture to carry out technological processes with the seeds of the above-mentioned crops.

3.2. Biochemical Composition and Fodder Value of Fresh Mass, and Biochemical Biomethane Potential of Fresh Mass Substrates from Studied Plant Species

We would like to mention that, at the time of harvesting the green mass, the studied species differed in height and leaf content in the forage. Thus, the plants of fam. *Asteraceae: Silphium perfoliatum* reached 248 cm with 57.7% leaves and heads in the fodder, *Cynara cardunculus*—195 cm with 59.7% leaves and heads in the fodder, and the control—*Helianthus annuus*—168 cm with 51.4% leaves and heads in the fodder; of fam. *Fabaceae*: *Galega orientalis*—148 cm with 59.1% leaves in the fodder, *Onobrychis arenaria*—88 cm with 54.3% leaves in the fodder, *Glycine max*—128 cm with 57.8% leaves and pods in the fodder, *Medicago sativa* 94 cm with 44.3% leaves in the fodder; of fam. *Hydrophylaceae*: *Phacelia tanacetifolia* plants achieved 92 cm with 56.4% leaves in the fodder; of fam. *Malvaceae*: *Malva crispa* reached 217 cm with 54.1% leaves in the fodder, *Sida hermaphrodita*—285 cm with 39.4% leaves in the fodder; of fam. *Poaceae*: *Avena sativa* reached 89 cm with 34.1% leaves in the fodder, *Triticum aestivium*—93 cm with 34.9% leaves in the fodder, *Sorghum almum*—248 cm with 33.4% leaves in the fodder, *Pennisetum glaucum*—135 cm with 74.6% leaves and panicle in the fodder.

The results regarding the biochemical composition and nutritional value of the freshly harvested mass of the researched species are presented in Table 3. It was established that natural fodder in terms of dry matter is characterised by 9.0–23.4% crude protein, 6.0–10.5%

ash, 26.6–39.9% crude fiber, 47.2–69.7% NDF, 28.8–42.2% ADF, 3.3–6.2% ADL, 25.2–38.2% Cel, 16.3–27.5% HC, and 4.6–18.4% TSS, with a dry matter digestibility value of 56.0–66.5%, digestible energy load 11.16–12.95 MJ kg^{-1}, metabolizable energy 9.16–10.63 MJ kg^{-1}, net energy for lactation 5.18—6.76 MJ kg^{-1}, the relative feed value RFV = 74–129. It could also be mentioned that a very high nutritional value can be seen in the fodder of the *Fabaceae* family, especially in fodder from *Galega orientalis* plants. *Cynara cardunculus* and *Silphium perfoliatum* fodder is characterised by a high crude protein content (15.4–16.4%) compared to *Helianthus annuus* fodder. *Phacelia tanacetifolia* fodder has a nutrient content at the level of alfalfa fodder. Fodder from Malvaceae family plants has a higher concentration of protein and a reduced concentration of structural carbohydrates compared to the researched plants of the Poaceae family. Analysing the results of evaluating the biochemical composition and nutritional value of the researched plants from the Poaceae family, it could be mentioned that *Pennisetum glaucum* fodder has the best protein supply, and according to the content of soluble and structural carbohydrates, digestibility of dry substances, and energy load, it is not essentially different from *Avena sativa* plant fodder. The natural fodder of *Sorghum almum* and *Triticum aestivium* is characterised by an optimal concentration of crude protein but a very high concentration of structural carbohydrates, which had a negative impact on the decrease in digestibility, energy load and relative feed value (RFV = 74–78).

Table 3. Biochemical composition and nutritional value of natural fodder obtained from the researched species.

Variant	CP %	Ash %	CF %	ADF %	ADL %	NDF %	TSS %	Cel %	HC %	DDM %	RFV	DE MJ kg^{-1}	ME MJ kg^{-1}	NEl MJ kg^{-1}
Helianthus annuus	9.0	6.7	35.8	36.5	6.3	55.8	6.3	30.2	19.3	60.3	97	11.92	9.79	5.81
Silphium perfoliatum	16.4	9.0	31.7	35.4	4.8	55.6	5.6	30.6	20.2	61.3	103	12.11	9.94	5.96
Cynara cordunculus	15.4	7.6	30.0	32.6	5.4	55.5	8.0	27.2	22.9	63.5	106	12.50	10.26	6.28
Medicago sativa	17.2	9.1	33.1	34.7	5.8	51.0	8.3	28.9	16.3	61.9	113	12.50	10.26	6.04
Galega orientalis	23.4	10.5	26.6	28.8	3.6	47.7	10.0	25.2	18.9	66.0	128	12.95	10.63	6.76
Glycine max	17.8	9.4	28.6	31.0	4.9	48.4	14.2	26.1	17.4	64.8	124	12.73	10.45	6.46
Onobrychis arenaria	15.6	9.3	27.5	30.0	4.5	47.2	18.4	25.5	17.2	65.5	129	12.86	10.56	6.58
Phacelia tanacetifolia	17.0	10.4	32.4	35.9	5.6	53.8	2.6	30.3	16.9	60.9	105	12.05	9.89	5.90
Malva crispa	11.9	7.1	35.0	36.0	5.7	53.1	11.2	30.3	17.1	60.9	107	12.03	9.88	5.89
Sida hermaphrodita	14.4	6.0	37.9	37.7	6.2	54.6	4.6	31.5	16.9	59.5	101	11.79	9.68	5.70
Avena sativa	9.5	6.5	35.6	37.4	4.6	62.7	16.7	32.8	25.8	59.8	89	11.84	9.72	5.73
Triticum aestivium	10.1	7.9	39.9	42.2	4.0	69.7	7.9	38.2	27.5	56.0	74	11.16	9.16	5.18
Sorghum almum	10.6	9.6	39.2	42.1	4.5	67.0	11.0	37.6	24.9	56.1	78	11.18	9.18	5.19
Pennisetum glaucum	11.6	7.5	36.1	37.0	3.3	60.6	16.6	33.7	23.6	60.0	92	11.88	9.75	5.78

Different results are presented in the literature regarding the biochemical composition and feed value. Thus, the natural fodder from *Helianthus annuus* has a content of 8.7–20.40% CP, 2.0–8.1% EE, 24.10–25.0% CF, 36.9–52.5% NDF, 27.6–48.9% ADF, 9.7% lignin, 8.14–19.5% ash, 56.38% NFE, 64.4% DOM, 17.7 MJ kg^{-1} GE, 11.0 MJ kg^{-1} DE and 8.9 MJ kg^{-1} ME [59–63]; the fodder from *Cynara cardunculus* respectively, 13.2–18.4% CP, 1.40–2.81% EE, 23.9–38.4% NDF; 16.2–28.9% ADF,2.6–13.3% ADL [6,64,65]; *Silphium perfoliatum* fodder 6.6–20.40% CP, 52.5–69.7% NDF, 29.4–41.1% ADF, 4.09–8.30% lignin, 4.60–11.35% ash, 52.2–69.7% DOM, 11.32 MJ kg^{-1} DE, 9.2 MJ kg^{-1} DE and 5.31 MJ kg^{-1} ME [28–30,35,66,67], natural fodder from *Medicago sativa* 14.50–20.26% CP, 2.49–2.90% EE, 26.70–33.31% CF, 37.20–39.41% NFE, 39.90–65.50% NDF, 30.90–55.70% ADF, 7.6% lignin, 7.02–11.50% ash, 68.50% OM, 18.1 MJ kg^{-1} GE, 11.9 MJ kg^{-1} DE and 9.4 MJ kg^{-1} ME [66,68–71], natural fodder from *Galega orientalis* 16.18–22.84% CP, 2.95–3.90% EE, 24.58–36.85% CF, 47.50–57.90% NDF, 28.90–43.90% ADF, 3.70–6.30% lignin, 10.2% sugar, 7.51–12.48% ash, 64–82% DMD, RFV = 97–133, 10.2 MJ kg^{-1} ME [7–9,36,72,73], natural fodder from *Glycine max* plans 11.40–21.90% CP, 1.70–6.80% EE, 21.40–30.00% CF, 43.90–47.50% NFE, 28.00–66.27% NDF, 22.00–49.64% ADF, 3.80–9.10% lignin, 14.00–37.20% Cel, 2.64–18.00% HC, 3.00–14.00% ash, 58.20–84.21% IVDMD [8,74–81]; natural fodder from *Onobrychis arenaria* 14.51–20.60% CP, 1.00–4.16% EE, 21.24–32.40% CF, 46.70% NDF, 31.40% ADF, 4.80% lignin 34.00–46.00% NFE, 5.34–10.00% sugar, 26.90% Cel, 15.0% HC, 3.00–8.90% ash, 67.7% DMD, 12.52 MJ kg^{-1} DE, 9.81–10.78 MJ kg^{-1} ME, 6.56 MJ kg^{-1} NEl, RFV = 92 [62,82–86]; natural fodder from *Phacelia tanacetifolia* 9.65–21.26% CP, 1.61–3.20%

EE, 23.50–27.09% CF, 41.42–48.50% NDF, 36.20–37.79% ADF, 1.64–7.6% lignin 32.80–47.20% NFE [87–93], natural fodder from *Malva crispa* 15.60–26.10% CP, 2.15–3.22% EE, 15.00–32.00% CF, 34.74–46.05% NFE, 7.50–8.22% soluble sugars, 9.95–12.05% ash, 8.54–11.60 MJ kg^{-1} ME [7,8,94–97], natural fodder from *Sida hermaphrodita* 15.94–19.90% CP, 3.99% EE, 33.86% CF, 40.3–52.9% NDF, 30.8–37.1% ADF, 3.80–6.00% ADL, 6.00–7.30% TSS, 38.78%NFE, 31.00% Cel, 15.8% HC, 6.00–8.43% ash, 9.21–9.78 MJ kg^{-1} ME [94,97–100], natural fodder from *Avena sativa* 6.56–11.90% CP, 1.60–3.40% EE, 28.20–30.34% CF, 54.20–62.46% NDF, 31.00–39.02% ADF, 4.50% ADL, 7.10 %TSS, 49.98% NFE, 6.73–10.1% ash, 59.04–67.0% DOM, 18.0 MJ kg^{-1} GE, 11.5 MJ kg^{-1} DE and 9.3 MJ kg^{-1} ME [101–105]; natural fodder from *Triticum aestivium* 6.79–11.00% CP, 2.70% EE, 28.00% CF, 56.40–70.60% NDF, 31.90–41.42% ADF, 4.60% ADL, 10.6% TSS, 4.31–8.20% ash, 59.84–69.20% DOM, 17.90 MJ kg^{-1} GE, 11.9 MJ kg^{-1} DE and 9.6 MJ kg^{-1} ME [103–105], natural fodder from *Sorghum almum* 7.70–19.90% CP, 2.65–4.72% EE, 50.58–70.00% NDF, 26.69–50.53% ADF, 2.92–7.51% ADL, 10.6% TSS, 6.70–8.20% ash, 26.40–43.25% Cel, 20.89–37.40% HC [106–108], fodder from *Pennisetum glaucum* plants 8.08–16.20% CP, 4.80% EE, 29.20–49.30% CF, 32.80–50.50%NFE, 54.50–77.49% NDF, 30.80–45.45% ADF, 69.10% DDM [109–111].

The capitalisation of energy biomass through anaerobic digestion is carried out in biogas plants with a wide variety of microorganisms, resulting in methane gas as a fuel for the production of heat and electricity and carbon dioxide. The digested residue is rich in macro- and micronutrients and is widely used in production farms as a fertiliser in organic farming. The results regarding the quality of the researched plant substrates and the biochemical potential for obtaining biomethane are presented in Table 4. The carbon/nitrogen ratio (C/N) is a basic factor that influences the correct course of digestion and biomethane yield. Methanogenic bacteria need an appropriate ratio of carbon to nitrogen for their metabolic processes, ratios greater than 30:1 proved to be unsuitable for optimal digestion, and ratios less than 10:1 proved to be inhibitory, due to low pH, poor buffering because of the high concentration of ammonia in the substrate. The nitrogen concentration in dry matter of the tested substrates varied from 14.40 g kg^{-1} to 37.40 g kg^{-1}, and the estimated carbon content was from 497 g kg^{-1} to 519 g kg^{-1}, C/N ratio being 13–36. The biochemical methane potential of the tested substrates ranges from 297 l kg^{-1} vs. (*Helianthus annuus*) to 353 l kg^{-1} vs. (*Pennisetum glaucum*). Data on biomethane production potential are presented in other publications. The *Helianthus annuus* substrates have a biomethane potential of 190–454 l kg^{-1} vs. [63,112–114]; *Silphium perfoliatum* substrate 280–300 l kg^{-1} vs. [10,28,29,33,41–43,115,116]; *Cynara cardunculus* substrates—209–293 l kg^{-1} vs. [117,118]; *Medicago sativa* substrates 248–410 l kg^{-1} vs. [71,92,97,119], *Galega orientalis* substrates 244–384 l kg^{-1} vs. [73,120], *Glycine max* substrate—266 l kg^{-1} vs. [121], *Phacelia tanacetifolia* substrates 217–300 l kg^{-1} vs. [42,92,122], *Malva crispa* substrate 237 l kg^{-1} vs. [97], *Sida hermaphrodita* substrates—131–394 l kg^{-1} vs. [28,41–43,97,100,115], *Triticum aestivium* substrate—369–390 l kg^{-1} vs. [119,123], *Pennisetum glaucum* substrates 257–278 l kg^{-1} vs. [63,119].

Table 4. Biochemical potential of obtaining biomethane from the plant substrates of the researched species.

Variant	OM %	CP %	ADF %	ADL %	NDF %	Cel %	HC %	C %	N %	C/N	Methane l kg^{-1} vs
Helianthus annuus	95.3	9.0	36.5	6.3	55.8	30.2	19.3	51.8	1.44	36	297
Silphium perfoliatum	91.0	16.4	35.4	4.8	55.6	30.6	20.2	50.6	2.62	19	337
Cynara cordunculus	92.4	15.4	32.6	5.4	55.5	27.2	22.9	51.3	2.46	21	327
Medicago sativa	90.9	17.2	34.7	5.8	51.0	28.9	16.3	50.5	2.75	18	321
Galega orientalis	89.5	23.4	28.8	3.6	47.7	25.2	18.9	49.7	3.74	13	371
Glycine max	90.6	17.8	31.0	4.9	48.4	26.1	17.4	50.3	2.85	18	337
Onobrychis arenaria	90.7	15.6	30.0	4.5	47.2	25.5	17.2	50.4	2.50	20	339
Phacelia tanacetifolia	89.6	17.0	35.9	5.6	53.8	30.3	16.9	49.9	2.72	18	324

Table 4. *Cont.*

Variant	OM %	CP %	ADF %	ADL %	NDF %	Cel %	HC %	C %	N %	C/N	Methane $l\ kg^{-1}$ vs
Malva crispa	92.9	11.9	36.0	5.7	53.1	30.3	17.1	51.6	1.90	27	312
Sida hermaphrodita	94.0	14.4	37.7	6.2	54.6	31.5	16.9	52.2	2.30	23	309
Avena sativa	93.5	9.5	37.4	4.6	62.7	32.8	25.8	51.9	1.52	34	329
Triticum aestivium	92.1	10.1	42.2	4.0	69.7	38.2	27.5	51.2	1.62	32	341
Sorghum almum	90.4	10.6	42.1	4.5	67.0	37.6	24.9	50.2	1.70	30	332
Pennisetum glaucum	92.5	11.6	37.0	3.3	60.6	33.7	23.6	51.4	1.86	28	353

4. Conclusions

This research has demonstrated that the criterion of dimensional proportionality K_{dp}, proposed by the authors and used in this paper, effectively reflects the structure of the studied seeds from the *Asteraceae*, *Fabaceae*, *Hydrophylaceae*, *Malvaceae*, *Poaceae* families, the following types being identified: Flattened ($L \backsimeq W >> T$, *Onobrychis arenaria, Malva crispa* and *Sida hermaphrodita* seeds), elliptical ($L > W \backsimeq T$, *Glycine max*, *Medicago sativa*, *Galega orientalis*, *Phacelia tanacetifolia*, *Triticum aestivium*, *Sorghum almum*, *Pennisetum glaucum* seeds), and elongated ($L > W \not\backsimeq T$, a *Cynara cardunculus*, *Helianthus annuus*, *Silphium perfoliatum*, *Avena sativa* seeds). At the same time, a correlation is observed between the values of the K_{dp} criterion and those of sphericity S: the closer the seed structure is to the spherical shape, the higher the sphericity value becomes, approaching 100%, and the lower the K_{dp} value, evolving towards the ideal 1/1/1 ratio. The analysis of the mass parameters of the studied seeds (mass of 1000 grains M_{1000}, apparent density ϱ_v) demonstrates that their values for traditional and new crops correlate with the structure and geometric parameters (LWT, geometric mean diameter, D_g). The comparison of the geometric and mass parameters of the seeds of new and traditional crops widely used in modern agriculture makes it possible to forecast some properties of the seeds of new crops and to rationally develop the technological process routes for the production of these crops, as well as to correctly select the technical means for the realisation of these routes.

The seeds of the new plant species studied possess, in relation to the seeds of most traditional field crops, high friability capacities: the angle of repose $\alpha \leq 33°$ and the angle of static friction on steel $\alpha_1 \leq 27.8°$, on wood $\alpha_1 = 34.7°$, on enamelled surface $\alpha_1 = 30°$), one of the basic factors that influenced the friability of the seeds being their structure. In *Phacelia tanacetifolia* seeds, because of coarse coat morphology, the friability of the seeds is lower ($\alpha = 37.9°$ and $\alpha_1 \leq 39.1°$). The analysis of the values of the angles of repose α and of the angle of static friction α_1, recorded for the studied seeds, confirms the possibility of using the existing buildings and technical means in the agri-food sector for the transportation, processing, and storage of these seeds, which is very important for the capitalization of their biological potential with minimal expenses.

The researched new and non-traditional plant species are of economic interest as fodder plants to be administered in the rations of farm animals, but also as energy biomass substrates for biomethane production stations as an alternative energy source.

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