THE PECULIARITIES OF SEEDS AND THE QUALITY OF THE GREEN MASS OF SOME NON-TRADITIONAL CROPS IN THE REPUBLIC OF MOLDOVA
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PARTICULARITĂŢILE SEMINȚELOR ȘI CALITATEA MASEI VERZI LA UNELE CULTURI NETRADIȚIONALE ÎN REPUBLICA MOLDOVA

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ABSTRACT
The article presents the results of the studies on the peculiarities of the seeds and the quality indices of the green mass, obtained from the non-traditional crops Amaranthus hypochondriacus, Raphanus sativus var. olifera, Sinapsis alba, Linum usitatissimum, Sesamum indicum and the hybrid Rumex tianschanicus × Rumex patientia. The results reflect the values of dimensional parameters, friability, seed structure and quality indices of the harvested green mass (nutritive value, biochemical potential to obtain biomethane). It has been demonstrated that the criterion of dimensional proportionality K_{dp}, used in the present research, shows the real structure of the seeds. The harvested green mass from non-traditional crops has the optimal content of protein and carbohydrates for animal feed and biomethane production.

REZUMAT
Sunt prezentate rezultatele studiilor privind particularitățile semințelor și indicilor de calitate a masei vegetale, obținute din culturi de plante netradiţionale în Republica Moldova: Amaranthus hypochondriacus, Raphanus sativus, Sinapis alba, Linum usitatissimum, Sesamum indicum, hibridul Rumex patientia. Rezultatele obținute reflectă valorile parametrilor dimensionali, de friabilitate, de structură a semințelor și indicii de calitate a masei verzi recoltate (valoarea nutritivă, potențialul biochimic de obținere a biometanului). S-a demonstrat că criteriul de proporționalitate dimensională K_{dp}, utilizat în prezenta lucrare, redă structura reală. Masa recoltată din culturi de plante netradiţionale investigate are conținutul optim de substanțe proteice și carbohidrați necesari pentru alimentația animalelor și producerea biometanului.

INTRODUCTION
According to the information presented by specialized international organizations (*U.S. Census Bureau, 2023; U.S. Energy Information Administration, 2023; United Nations, 2023),* in 1950, world population reached 2.5 billion people, over fifty years – in 1999 – 5.98 billion (population growth rate in the period 1950-1999: 69.6 million/year). In August 2023, Earth's population is estimated at 7.99 billion *(population growth rate in the period 2000-08.2023: 85.5 million/year).* According to the above-mentioned sources, the global population is expected to keep growing, reaching 8.9÷9.55 billion in 2050 (the average expected growth rate in 08.2023-2050: 48.5 million/year). Simultaneously with population growth, the total energy consumption has also increased. In 1950-1999, the world population increased 2.4 times, but energy consumption increased 4 times. At the same time, during the mentioned period, the production of cereals increased 3 times and the indicators of economic development increased 5 times (*International Energy Agency, 2023; United Nations, 2023; FAO, 2016*). The analysis of statistical data and the forecast of the development of human society prove that the world population is constantly rising, requiring urgent measures to maintain the quality of people's lives.

Managing these interdependent trends in the development of human society is possible only by strengthening food and energy security, as well as by improving the ecological situation. The studies carried out demonstrate, that the achievement of these complex objectives of vital importance in the development of human society can be achieved by protecting biodiversity, mobilizing plant genetic resources, making use of the fodder and energy potential of non-traditional plants and implementing them in the bioeconomic circuit (*FAO, 2016; Bojariu et al., 2021; Cerempei, 2016; Kshnikatkina et al., 2005; Rakhmetov, 2011, 2018; Roman et al., 2016; Țîței, 2015, 2020b, 2023; Țîței and Roșca, 2021; Teleuţă and Ţîţei, 2016; Von Cossel, 2019)*.

In the Republic of Moldova and in other countries, theoretical and practical results have been achieved on implementing the potential of non-traditional plants of several botanical families, including the following *Asteraceae* (*Cynara cardunculus, Silphium perfoliatum*), *Fabaceae* (*Galega orientalis*, *Onobrychis arenaria*), *Hydrophylaceae* (*Phacelia tanacetifolia*), *Malvaceae* (*Malva crispa*, *Sida hermaphrodita*), *Poaceae* (*Pennisetum glaucum, Sorghum almum*). These results indicate, in particular, the physico-chemical and technological properties of the seeds and the green mass of these plants (*Cerempei et al., 2022, 2023; Coşman et al., 2017; Cumplido-Marin et al., 2020; Kaliniewicz, et al., 2015; Peni et al., 2020; Rakhmetov, 2011, 2018; Schäfer et al., 2017; Teleuţă and Ţîţei, 2016; Von Cossel, 2019; Zarczynski et al., 2021*).

The analysis of the situation in the given field of research demonstrates that it is possible, under the soil-climatic conditions of the Republic of Moldova, to make full use of the potential of a number of non-traditional plants from the families *Amaranthaceae, Brassicaceae, Linaceae, Pedaliaceae, Polygonaceae*, which are studied to a lesser extent by the international scientific community *(Abbasi et al., 2018; Alekksha Kudos, Chandan, 2018; Amorim et al., 2019; Biel et al., 2017; Bhat et al., 2018; Das, 2016; Elleuch et al., 2007; Gautam et al., 2016; Herrmann et al., 2016; Kshnikatkina et al., 2005; Kukusheva and Stepanov, 2016; Mursec et al., 2009; Peiretti, 2018; Póti et al., 2014; Rahnama, Safaeie, 2017; Rakhmetov, 2011, 2018; Rakhmetov and Rakhmetova, 2006; 2011; Rakhmetov et al., 2004; Seppälä, 2013; Słomka and Wójcik Oliveira, 2021; Ustak et al., 2011; Uteush, 1990; Von Cossel, 2019)* and the one from the Republic of Moldova *(Chisnicean et al., 2011; Teleuţă and Ţîţei, 2016; Teleuță et al., 2008; Țîței, 2015, 2020, 2023; Țîței and Roșca, 2021; Teleuţă and Ţîţei, 2016).*

Therefore, the goal of our work has been to contribute to the exploitation of the fodder and energy biomass potential of the non-traditional plant species from the families *Amaranthaceae, Brassicaceae, Linaceae, Pedaliaceae, Polygonaceae* by conducting studies on the seed peculiarities and the quality indices of the phytomass produced from these species under the conditions of the Republic of Moldova.

MATERIALS AND METHODS

To achieve the goal, the following objectives were set:

1. To measure the physical-mechanical and technological features of seeds;
2. To determine the biochemical composition and the nutritional value of the feed, also the biomethane potential of phytomass substrates.

Based on the goal and objectives of the research, the following species from the collections "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, Chisinau were studied.

The seeds and the phytomass collected from taxa of the following families served as research objects:

A. *Amaranthaceae* (*Amaranthus sp.,* prince's-feather *Amaranthus hypochondriacus);*
B. *Brassicaceae (*fodder radish *Raphanus sativus* var. *oleifera,* white mustard *Sinapis alba);*
C. *Linaceae (*flax *Linum usitatissimum);*
D. *Pedaliaceae (*sesame *Sesamum indicum);*
E. *Polygonaceae (*hybrid sorrel *Rumex tianschanicus*× *Rumex patientia);*
F. *Fabaceae* (alfalfa *Medicago sativa* – control).

Methods of measuring the physico-mechanical properties of seeds

It is known that the correct selection of parameters for facilities, machines and equipment, as well as operating regimes of technological processes in the agri-food sector largely depends on the dimensional characteristics and morphological structure of the seeds (*Ene and Mocanu, 2016; Matei and Feher, 2010*).

As dimensional parameters, the length L, the width W and the thickness T of seeds were considered, being measured according to the recommendations ((*Mohsenin, 2020*) using a mechanical calliper ST-I-125-0.05 (GOST 166-89) with the error limit ± 0.05 mm. The accuracy of the results was ensured by measuring, for each plant species, at least 25 grains taken from the average sample, sampled at predetermined intervals by the four-quarter method.

The determined values of the dimensional parameters (length L, the width W and the thickness T) of seeds, served as a basis for calculating their geometric parameters:

- geometric mean diameter

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

- sphericity

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

Along with the geometrical parameters D_g, S, calculated according to the formulas (1, 2), it was elaborated and applied, for a more detailed appreciation of the shape of the seeds, the criterion of dimensional proportionality K_{dp}, which was determined based on the ratio of the main dimensions *L, W, T*:

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

The morphological structure of the seeds was established based on the objective parameters, taking into account the calculated values of the K_{dp} criterion and the requirements of the classification, which divides the seeds into 5 distinct types, resulting from the relationships of the *L, W, T* parameters of seeds, which are specific for each type:

1. *Spheroidal*, which have almost equal values of seed dimensions $L \doteq W \doteq T$, characteristic of peas, soybeans, etc.;
2. *Flattened*: seed width is approximately equal to the length, and the thickness index is much smaller $L \doteq W >> T$ (lentil);
3. *Elliptical*: the thickness and the width are equal, while the length is bigger $L > W \doteq T$ (legumes);
4. *Elongated*: all the dimensions differ from each other, with length having the greatest value: $L >> W \not\doteq T$ (cereals);
5. *Pyramidal*: with triangular sides (buckwheat).

The friability (flow capacity) of seeds was evaluated based on a detailed study, which included measuring the values of the angle of repose α and of the flow angle α_1 on surfaces of different materials (steel, wood, enamel). In order to make sure that the results of measuring seed friability were accurate, the values of angle α were determined by 2 methods:

1. *The general method*, which is currently widely used by researchers (*Ene and Mocanu, 2016; Alekksha Kudos and Chandan, 2018; Cerempei et al., 2023*). In this case, this method was implemented by pouring the seeds through a funnel and letting them fall freely on a horizontal surface, thus forming a conical pile of seeds.
2. *The local method* was proposed and used in the present work, by applying the digital inclinometer on the tilted surface of the cone of seeds formed by free flow.

To form a conical seed pile, samples were taken from the majority fractions obtained after sieving. The volume of samples varied between 200 and 250 ml. The following instruments were used for the measurements: general method - depth calliper SG 0-250, instrumental ruler 0-400 mm; b) local method - digital inclinometer 360° with accuracy ± 0.2°. The measurement of the angle α was performed by the local method, by applying successively the inclinometer on 4 cone generators, in 2 perpendicular planes. To apply the general method, the parameters of the cone were measured in 2 perpendicular planes – the height *h* and the diameter of the base *D*. The value of the angle of repose was calculated according to the following formula:

$$\operatorname{tg} \alpha = 2h \cdot D^{-1} \tag{4}$$

The second criterion of seed friability, the flow angle α_1, was determined using a table with a vertically rotating upper surface. On the rotating surface of the table, plates made of steel 10 with low carbon content, GOST 16 523-97, C10, EN 10083-2:2006, enamelled steel and wood, were fixed successively. The flow angle α_1 was determined by applying the digital inclinometer when the seeds started moving on the inclined surface. To verify the accuracy of the results of measuring the friability parameters, the measurements were repeated as follows: when determining the values of the angle α, experiments were repeated 10 times, and for the angle α_1 – 5 times. The obtained results allowed the calculation of statistical parameters: the confidence interval and the standard deviation.

The detailed description of the methods and materials used in measuring the physical-mechanical and technological properties of the seeds (dimensional parameters, friability etc.) is given in the paper (*Cerempei et al., 2022*). The results of measurements were processed by applying the facilities of the MATHLAB and Microsoft Office Excel programs.

Methods of evaluation of the biochemical composition, nutritional value of feed and biomethane production potential

The green mass from non-traditional plant species was harvested in the budding - flowering stage, the control variant *Medicago sativa* in second growing seasons from for the first cut. For biochemical analyses, the harvested whole plants were cut into small pieces and dried in an oven with forced ventilation at a temperature of 60°C, at the end of the fixation, the biological material was finely ground in a laboratory ball mill.

The dry matter (*DM*) or total solid (*TS*) content was detected by drying samples up to constant weight at 105°C, crude protein (*CP*) – by Kjeldahl method; crude fat (*EE*) – by Soxhlet method, crude cellulose (*CF*) – by Van Soest method; ash – in muffle furnace at 550°C, nitrogen-free extract (*NFE*) was mathematically appreciated. The calcium (Ca) concentration of the samples was determined by using atomic absorption spectrometry method, phosphorus (P) concentration – by spectrophotometric method.

The gross energy (*GE*), metabolizable energy (*ME*), net energy for lactation (NEl) were calculated according to standard procedures:

$$GE= 23.9 \times CP+39.8 \times EE+ 20.1 \times CF+17.5 \times NFE \quad (5)$$

$$ME = 14.07 + 0.0206 \times EE - 0.0147 \times CF - 0.0114 \times CP \quad (6)$$

$$NEl= 9.10+0.0098 \times EE - 0.0109 \times CF - 0.073 \times CP \quad (7)$$

where: *CP* is the crude protein, [g/kg];
CF is the crude fibre, [g/kg];
EE is the crude fat, [g/kg];
NFE is the nitrogen-free extract, [g/kg].

The carbon (C) content of the substrates was calculated using an empirical equation indicated by *Badger et al. (1979)*:

$$C=OM/1.8 \quad (8)$$

where *OM* is the organic matter [g/kg].

The biogas (*BP*) and the biomethane potential (*MP*), litre per kg of organic dry matter, were calculated using the gas forming potential of nutrients according to Baserga (1998), corrected by the nutrient digestibility:

$$BP = 1250 \times DEE +700 \times DP+ 790 \times DCH \quad (9)$$

$$MP = 850 \times DEE +490 \times DP+ 395 \times DCH \quad (10)$$

where *DEE* is the digestible fats, [g/kg];
DP is the digestible protein, [g/kg];
DCH is digestible carbohydrates, [g/kg].

RESULTS

Physico-mechanical properties of seeds. The results of the investigations demonstrate that the studied seeds have different dimensional characteristics and morphological structure, geometric mean diameter varying in a limited range: from the minimal value D_g=0.68 mm in *Amaranthus* seeds, to maximal values D_g=2.59 mm in the seeds of radish *Raphanus sativus.* The seeds of alfalfa (control crop) from the family Fabaceae have the following dimensional characteristics (Table 1): *LWT*=2.17×1.2×1.07 mm (D_g=1.48 mm). In the case of alfalfa seeds (*S*=68.2%) the criterion of dimensional proportionality (K_{dp}=2.03/1.12/1) has values that show convincingly that these seeds belong to the type 3. *Elliptical* ($L>W\simeq T$), which is common for legume crops. The seeds of the Brassicaceae family have the same morphological structure, *Elliptical*: the white mustard *Sinapis alba* with the dimensional characteristics *LWT*=1.98×1.67×1.67 mm (D_g=1.77 mm) and radish *Raphanus sativus* – *LWT*= 3.50×2.43×2.05 mm (D_g=2.59 mm). The seeds of the three species mentioned above, of the families *Fabaceae* and *Brassicaceae* are named in the preceding text with increasing sizes: from the value D_g=1.48 mm (alfalfa seeds) to D_g=2.59 mm (radish seeds).

The values of the criterion of dimensional proportionality K_{dp}=1.19/1/1 of white mustard (*S*=89.4%) and K_{dp}=1.71/1.19/1 of fodder radish (*S*=74.0%) serve as evidence that the seeds of the species of the *Brassicaceae* family have an *Elliptical* structure. It is important that the more the values of the component elements in the proposed criterion approach the value equal to one ($K_{dp}\rightarrow$1/1/1) the more the values of sphericity *S* approach 100%, close to the spherical shape. This phenomenon indicates the fact that the appropriate K_{dp} dimensional proportionality criterion reflects the morphological structure of the seeds.

The analysis of the outward appearance of the seeds of the families *Fabaceae* and *Brassicaceae* (Fig. 1, a-c) confirms the veracity of the conclusions made based on the dimensional characteristics of *LWT*, *S* and K_{dp}. The seeds of alfalfa and white mustard have a smooth integument (Fig. 1, a, b), and on the seeds of fodder radish, longitudinal grooves are observed.

The seeds of the *Amaranthaceae* family are *1. Spheroidal* in shape with the following dimensional characteristics (Table 1): *Amaranthus- LWT*=0.68×0.68×0.68 mm (D_g=0.68 mm) and white amaranthus – *LWT*=1.0×1.0×1.0 mm (D_g=1.0 mm). It is natural that in seeds of both species the criteria of proportionality and sphericity have equal values: K_{dp}=1/1/1 and *S*=100%. The integument of the above-mentioned seeds is smooth (Fig. 1, d).

Table 1

The values of the dimensional parameters of the seeds

Families, species	Dimensional parameters			Criterion K_{dp}	Geometric parameters	
	L	*W*	*T*		D_g	*S*
	[mm]				[mm]	[%]
Fabaceae						
Medicago sativa (control)	2.17± 0.10	1.20±0.06	1.07 ± 0.06	2.03/1.12/1	1.48	68.2
Amaranthaceae						
Amaranthus sp.	0.68 ±0.06	0.68 ±0.06	0.68 ±0.06	1/1/1	0.68	100
Amaranthus hypochondriacus	1.00±0.08	1.00±0.08	1.00±0.08	1/1/1	1.00	100
Brassicaceae						
Raphanus sativus var. oleifera	3.50±0.24	2.43±0.21	2.05± 0.04	1.71/1.19/1	2.59	74.0
Sinapis alba	1.98±0.11	1.67±0.03	1.67±0.03	1.19/1/1	1.77	89.4
Linaceae						
Linum usitatissimum	4.08±0.07	2.0±0.08	0.65±0.08	6.28/3.08/1	1.74	42.7
Pedaliaceae						
Sesamum indicum	2.97±0.04	1.38±0.07	0.5± 0.1	5.94/2.76/1	1.27	42.8
Polygonaceae						
Rumex tianschanicus × Rumex patientia	3.1±0.28	1.72±0.25	1.72± 0.26	1.8/1/1	2.09	67.4

The dimensional characteristics of the seeds of the *Pedaliaceae* and *Linaceae* families have the following values (Table 1): sesame – *LWT*=2.97×1.38×0.5 mm (D_g=1.27 mm) and flax – *LWT*=4.08×2.0×0.65 mm (D_g=1.74 mm), respectively. Seeds from both families demonstrated similar values of proportionality criterion and sphericity: sesame – K_{dp}=5.94/2.76/1, *S*= 42.8% and flax – K_{dp}=6.28/3.08/1, *S*= 42.7%, respectively.

The analysis of the geometric parameters and the external shape (Fig. 1, e, f) demonstrates that the sesame and flax seeds belong to type 4. *Elongated* ($L>>W\neq T$) according to their morphological structure. The integument of these seeds is smooth.

The analysis of the properties of the seeds of the representative of the family *Polygonaceae*, *Rumex tianschanicus* × *Rumex patientia*, resulted in obtaining the following dimensional characteristics: *LWT*=3.1×1.72×1.72mm (D_g=2.09mm). The particularity of these seeds consists in the fact that they have the shape of type 5. *Pyramidal*, which can be seen from the joint analysis of the values of the proportionality criterion (K_{dp}=1.8/1/1) and the external shape of these seeds (Fig.1, g).

In our previous research *(Cerempei et al., 2022)* it has been established that a range of factors influence the flow ability of the seeds: a) the particularities of the seeds (size and morphological structure, integument surface condition, humidity and physical purity); b) the condition of the working surface of the machine on which the seeds flow (material, roughness).

The highest flow capacity is characteristic of the seeds with a shape close to the spherical one (type 1), with a smooth surface of the integument, low humidity and with a small number of impurities. The studied seeds from the six families (Table 2) were conditioned at the initial stage according to humidity U and physical purity *P*. Surfaces on which the flow angle α_1 was studied were identical for all seeds: steel C10, wood, enamel.

That is why the friability of the seeds (values of the angles α and α_1) was studied according to the morphological structure and the state of the surface of their integument.

As mentioned in the research methodology, the angle of repose α was measured by two methods: general and local. Because there is a relatively small difference between the values of the angle α, determined by the general and the local methods (Table 2), in the following will be used the average value of the angle α to simplify the analysis of the friability of the seeds, and, if necessary, will be used the α values obtained by both methods.

Fig. 1 - The images of the studied seeds

a) Medicago sativa; b) Sinapsis alba; c) Raphanus sativus; d) Amaranthus hypochondriacus; e) Sesamum indicum; f) Linum usitatissimum; g) Rumex tianschanicus × Rumex patientia.

In the *Fabaceae* family, alfalfa seeds, the control, had the following values of friability (Table 2): the angle of repose α=30.9° and flow angle α_1=27.3° (on steel), α_1=33.6° (on wood), α_1=26.7° (on enamelled surface). The alfalfa seeds were chosen as control in our studies because, in the specialized literature, there are many sources of information regarding the friability of these seeds. For example, according to one source (*Togo et al., 2018*), for alfalfa seeds, the angle of repose varies in the range α=27.05°-33.21°.

The seeds of non-traditional plant species in the Republic of Moldova had, in most cases, higher flow capacity than alfalfa seeds. The seeds with the highest friability are from the families *Linaceae* (flax) and *Amaranthaceae* (*Amaranthus*, white amaranthus). As a result of the measurements, the following parameters were identified for flax seeds (the angle of repose α=21.9° and flow angle: on steel- α_1= 19.0°, on wood- α_1= 20.4°, on enamelled surface– α_1=19.7°), for *Amaranthus* seeds (the angle of repose α=22.3° and flow angle: on steel- α_1= 19.7°, on wood- α_1= 22.8°, on enamelled surface – α_1=20.7°) and white amaranthus seeds (the angle of repose α=24.6° and flow angle: on steel- α_1= 22.9°, on wood- α_1= 27.2°, on enamelled surface – α_1=26.1°).

The high level of friability of flax seeds (type 4. *Elongated*) is due to the outer surface that is smooth, shiny and with little roughness *(Fig.1, f),* and – of the seeds of the Amaranthaceae family (*Amaranthus*, white amaranthus) – due to the morphological structure 1. *Spheroidal* (*Table 1; Fig.1, d)*. The seeds of representatives of other three families *Brassicaceae* (fodder radish*,* white mustard)*, Pedaliaceae* (sesame) and *Polygonaceae* (the hybrid *Rumex tianschanicus*× *R. patientia*) had values of the angle of repose α and flow angle α_1 in the range of the respective angles for the seeds of alfalfa and the seeds of the families *Linaceae*, *Amaranthaceae*: the angle of repose α=24.15°- 28.2° and flow angle on steel α_1= 21.3°- 27.0°, on wood α_1= 26.0°- 31.6°, on enamelled surface α_1=22.7°- 28.2°. The highest flow capacities on the studied surfaces (steel, wood, enamel) are characteristic of the fodder radish seeds that have the 3. *Elliptical* type structure (Fig.1, c) and geometric mean diameter with the highest value D_g= 2.59 mm.

Table 2

Values of seed friability parameters

Families, species	Angle of repose α, methods			Flow angle $α_1$, surfaces		
	general	local	average	steel	wood	enamel
	[degrees]			[degrees]		
Fabaceae						
Medicago sativa	30.2±0.3	31.5±0.4	30.9	27.3 ± 0.4	33.6 ± 0.9	26.7 ± 0.2
Amaranthaceae						
Amaranthus sp.	20.6±0.5	24.0±1.0	22.3	19.7±0.4	22,8±0,2	20,7±0,3
Amaranthus hypochondriacus	24.1±0.1	25.1±0.9	24.6	22.9±0.3	27,2±0,8	26,1±0,1
Brassicaceae						
Raphanus sativus *var. oleifera*	27.4±0.4	28.9±1.6	28.2	21.3±0.3	26.0±0.8	22.7±0.2
Sinapsis alba	25.3±0.5	29.3±1.3	27.3	22.0±0.6	27.4±1.5	24.7±0.3
Linaceae						
Linum usitatissimum	20.0 ±0.45	23.8±0.7	21.9	19.0±0,1	20.4±0,3	19.7±0.25
Pedaliaceae						
Sesamum indicum	24.0± 0.3	24.3±1.1	24.15	27.0± 0,8	31.6±0,4	28.2± 0.5
Polygonaceae						
Rumex tianschanicus* × Rumex *patientia	27.3±1.0	29.0±1.1	28.2	23.0±0,1	31.2±0,8	27.4±0.6

The results of the measurements (Table 2) indicate that in the studied seeds, usually, the coefficient of internal friction between the seeds f_i, characterized by angle of repose *α,* has higher values than the coefficient of external friction f_e between the seeds and the sliding surface, characterized by flow angle $α_1$, that is $α>α_1$. The exception is mainly the values of the angle $α_1$ in the case of flow on a wooden surface.

Data on seeds parameters of studied botanical family are presented in other publications (*Bhat et al. 2018; Cagatay Selvi et al. 2006; Coşkuner and Karababa, 2007; Elleuch et al. 2007; Gautam et al. 2016; Kaliniewicz et al. 2015; Rakhmetov and Rakhmetova, 2006, 2011; Togo et al. 2018; Tunde-Akintunde and Akintunde, 2004; Uteush,1990*).

Biochemical composition, nutritional value of feed and biomethane production potential. The forage yield and seasonal distribution may be of great importance to the livestock breeders. Sometimes the balance of nutrients in the forage will have positive or negative effects on animal health and production indices. The quality indices of the harvested green mass from studied species, is presented in Table 3. It was found that, in forage dry matter the crude protein varied from 144.3 to 198.1 g/kg, crude fats - from 18.5 to 65.2 g/kg, crude cellulose – from 254.8 to 324.3 g/kg, nitrogen free extract - from 375.8 to 425.5 g/kg, ash - from 70.1 to 137.4 g/kg, calcium - from 6.3 to 19.0 g/kg, phosphorus - from 2.8 to 5.2 g/kg. We would like to mention that fodder from *Raphanus sativus*, hibrid *Rumex* and *Sinapis alba* was characterised by a significantly higher content of proteins, as compared with *Medicago sativa*. The concentrations of crude fats in fodder from *Sesamum indicum*, *Sinapsis alba*, *Raphanus sativus*, *Linum usitatissimum* and *Amaranthus hypochondriacus* also were very high. The level of crude cellulose in fodder from studied species is optimal and low as compared with *Medicago sativa.* The nitrogen free extract content in *Sesamum indicum, Linum usitatissimum, Amaranthus hypochondriacus* and hibrid *Rumex* fodders reached 40.00-42.55%, which were higher than in *Medicago sativa* green mass. The fodder from *Brassicaceae* species contained a low amount of nitrogen free extract. The concentrations of ash in fodder from the studied species were higher as compared with *Medicago sativa,* except *Linum usitatissimum* green mass, where this index was lower (7.01%). It was found that the concentrations of phosphorus in the investigated fodders also were significantly high.

The concentration of nutrients and their digestibility influence the energy value of fodder. It should be mentioned that the concentrations of metabolizable energy and net energy for lactation were high in fodder from studied species as compared with *Medicago sativa,* very higher energy level in fodder from *Sesamum indicum*, *Amaranthus hypochondriacus* and *Sinapis alba*.

Several literature sources describe the biochemical composition and nutritional performance of fodder from investigated species. Also, *Medvedev and Smetannikova (1981)* mentioned that nutrient content of dry matter white mustard plants was 19.8% crude protein, 2.3% crude fats, 28.1% crude cellulose, 36.6% nitrogen free extract and 13.1% ash; oil radish - 15.0-25.9% crude protein, 2.0-4.5% crude fats, 19.0-24.0% crude cellulose, 35.5-57.0% nitrogen free extract and 14.7-23.6% ash; sorrel-11.9-26.2% crude protein, 0.8-1.8% crude fats, 14.5-24.5% crude cellulose, 40.8-49.4% nitrogen free extract and 8.1-11.4% ash.

Kshnikatkina et al. (2005) reported that the dry matter from *Sinapis alba* forage 21.26-22.18% crude protein, 1.60-3.31% crude fats, 19.45- 34.00% crude cellulose, 14.82-15.80% ash, 0.58-0.90% Ca, 0.06-0.10% P, but *Raphanus sativus* -16.0-19.0% crude protein, 19.0-24.0% crude cellulose, 10.0-14.0% ash, 0.8-0.9% Ca, 0.9-1.1% P. *Póti et al. (2014)* reported that the nutritive and energy value of white mustard was 154 g/kg dry matter, 20.6% crude protein, 2.9% crude fats, 19.4% crude cellulose, 8.9% ash, 48.2% nitrogen free extract, 629 g/kg TDN, 11.61 MJ/kg DE, 9.52 MJ/kg ME and 5.88 MJ/kg net energy for maintenance, but oil radish fodder contained, respectively, 135 g/kg dry matter, 14.8% crude protein, 3.1% crude fats, 14.1% crude cellulose, 13.0% ash, 55.0% nitrogen free extract, 616 g/kg TDN, 11.31 MJ/kg DE, 9.32 MJ/kg ME and 5.70 MJ/kg net energy for maintenance.

Heuze et al. (2015), reported the average dry matter content and feed value of *Linum usitatissimum* aerial part was: 219 g/kg dry matter, 13.6% crude protein, 3.6% crude fats, 57.0% NDF, 46.7% ADF, 12.1% lignin, 6.6% ash, 65.9% DOM, 18.7 MJ/kg GE. Leukebandara et al. (2015) mentioned that the *Amaranthus hypochondriacus* plants harvested the mid-bloom stage contained 132.0 g/kg dry matter, 18.43 crude protein, 3.17% crude fats, 24.50% crude cellulose, 16.83% ash. *Țîței and Țeleuță (2015)* found that depending on cut period the dry matter content and biochemical composition of fodder from the hybrid *Rumex* was 107.5-206.7 g/kg dry matter, 9.71-24.88% crude protein, 1.03-2.86% crude fats, 15.03-44.43% crude cellulose, 6.28-15.62% ash and 36.82-41.56% nitrogen free extract, but *Medicago sativa* fodder first cut - 243.0 g/kg dry matter, 16.66% crude protein, 1.88% crude fats, 34.24% crude cellulose, 10.0% ash and 37.22% nitrogen free extract. *Biel et al. (2017)* mentioned that biochemical composition and nutritive value of *Amaranthus hypochondriacus* aerial part was 101 g/kg crude protein, 17.6 g/kg crude fats, 240 g/kg crude cellulose, 440 g/kg NDF, 332 g/kg ADF, 63.1 g/kg lignin, 269 g/kg Cel, 109 g/kg HC, 144 g/kg ash, 13.7 g/kg Ca and 6.8 g/kg P, 63.8% DMD, 10.8 MJ/kg DE and 8.7 MJ/kg ME.

Rahnama and Safaeie (2017) revealed that *Amaranthus hypochondriacus* can produce 75.86-90.30 t/ha fresh forage or 11.0-13.05 t/ha dry matter with 11.5-12.00% crude protein, 2.1-2.4% crude fats, 67.4-69.1% DMD, RFV= 157.1-171.5, RFQ =158-174.6. *Abbasi et al. (2018)* reported that harvested amaranth forage contained 233 g/kg dry matter with 18.7% crude protein, 42.0 %NDFom, 27.5 %ADFom, 4.46 %ADL, 5.7 %EE, 6.25 %WSC, 14.5 %ash, 1.11% Ca, 0.66 % P and 8.4 MJ/kg ME.

Rolinec et al. (2018) reported that hybrid sorrel Rumex OK 2 depends on growth phase contained 74.2-169.1 g/kg dry matter with 10.09-26.17% crude protein, 1.16-2.23% crude fats, 14.48-39.48% crude cellulose, 43.82-55.38% nitrogen free extract, 1.36-6.46% ash, 21.6-51.1% NDF, 17.2-45.2% ADF, 1.84-11.5% ADL, 4.4-6.0% HC, 15.3-33.7%Cel.

Amorim et al. (2018) remarked the dry matter content and chemical composition of forage from *Sesamum indicum* plans was: 233 g/kg dry matter with 11.7% crude protein, 10.54% crude fats, 6.08% ash, 56.24% NDF, 36.29% ADF, 3.14% ADL, 19.25% HC, 33.85%Cel and 56.41% TDN.

Țîței (2020a, 2022) found that biochemical composition and nutritive value of *Amaranthus hypochondriacus* whole plant was 17.2 % crude protein, 33.0 % ADF, 46.2 %NDF, 5.5 %ADL, 6.8 %TSS, 8.8 % ash, RFV = 127, 12.44 MJ/kg DE, 10.22 MJ/kg ME and 6.23 MJ/kg NEl and *Sinapis alba* whole plant respectively 18.3-22.9% crude protein, 9.2-10.9% ash, 43.9-51.8% NDF, 28.3-34.7% ADF, 4.8-5.6% ADL, 23.5-29.1 % Cel, 15.6- 17.1 % HC, 6.3-8.7% TSS, 63.3-75.9% DMD, 57.3-66.1% DOM, RFV=111-142, 12.22-13.08 MJ/kg DE, 10.03-10.74 MJ/kg ME and 6.04- 6.77 MJ/kg NEl.

Table 3

Biochemical composition and fodder value of the green mass from studied species

Indices	Species						
	Medicago sativa	***Amaranthus hypochondriacus***	***Raphanus sativus var. oleifera***	***Sinapsis alba***	***Linum usitatissimum***	***Sesamum indicum***	**Rumex**
Crude protein, [% DM]	16.28	16.08	19.81	18.94	14.62	14.43	19.22
Crude fats, [% DM]	2.75	4.09	5.03	5.54	4.54	6.52	1.85

Indices	Species						
	Medicago sativa	*Amaranthus hypochondriacus*	*Raphanus sativus var. oleifera*	*Sinapsis alba*	*Linum usitatissimum*	*Sesamum indicum*	**Rumex**
Crude cellulose, [% DM]	33.25	26.04	27.89	27.93	32.43	25.48	26.02
Nitrogen free extract, [% DM]	39.50	40.05	38.98	37.58	41.40	42.55	40.00
Ash, [% DM]	8.22	13.74	12.40	10.01	7.01	11.02	13.00
Gross energy, [MJ/kg]	18.56	19.71	19.39	18.92	19.06	18.61	17.56
Metabolizable energy, [MJ/kg]	8.26	9.67	9.14	9.34	8.95	10.46	8.82
Net energy for lactation, [MJ/kg]	4.57	5.50	5.11	5.22	4.94	5.91	5.04
Calcium, [g/kg DM]	14.3	19.0	14.9	15.9	6.3	10.4	14.4
Phosphorus, [g/kg DM]	2.2	4.0	3.6	2.9	3.9	4.3	5.2

Phytomass is an important source for renewable energy production. The production of biomethane gas via anaerobic digestion using lignocellulosic phytomass as a renewable energy source is both sustainable and environmentally friendly. The stability and the productivity of biogas digesters are mostly influenced by nutrient concentration and rhythm biodegradability, ratio of carbon and nitrogen (C/N) of substrate. It is known the optimal C/N ratio in substrate should range from 10 to 30, which does not affect the development of bacteria involved in anaerobic digestion. The quality indices of the substrate and its biochemical methane potential from the investigated species are shown in Table 4.

Table 4

The biochemical biomethane production potential of the green mass substrates from the studied species

Indices	Species						
	Medicago sativa	*Amaranthus hypochondriacus*	*Raphanus sativus var. oleifera*	*Sinapsis alba*	*Linum usitatissimum*	*Sesamum indicum*	*Rumex*
Digestible protein, g/kg DM	122.1	119.0	170.4	153.4	108.2	106.8	148.0
Digestible fats, g/kg DM	12.7	24.1	28.2	42.1	26.8	25.1	10.0
Digestible carbohydrates, g/kg DM	446.1	439.9	557.8	405.4	483.5	449.0	430.3
Nitrogen, g/kg DM	26.0	25.7	31.7	30.3	23.4	23.1	30.8
Carbon, g/kg DM	509.8	479.2	486.7	500.0	516.6	494.3	483.3
Carbon/ Nitrogen	19.6	18.6	15.4	16.5	22.1	21.4	15.7
Biogas, l/kg ODM	453	457	591	480	507	461	456
Biomethane, l/kg ODM	246	251	328	271	267	251	251
Methane content, %	54.4	54.8	55.5	56.5	52.6	54.4	55.0

It should be mentioned that in the investigated substrates from non-traditional crops, the carbon and nitrogen ratio varied from 15.4 to 22.1, but in *Medicago sativa* substrates C/N = 19.6. The calculated biochemical biomethane potential of the non-traditional crops substrates varied from 251 l/kg to 328 l/kg, but *Medicago sativa* green mass substrates reached 246 l/kg. The best biomethane potential was achieved in Brassicaceae plants *Raphanus sativus* and *Sinapis alba*.

Several publications have documented the biomethane potential of substrates from studied species. Also, *Zubr (1986)* reported the methane potential of *Sinapis alba* was 300 l/kg VS. *Murphy et al. (2011)* reported that methane yield in *Raphanus sativus* var. *oleifera* substrate achieved 240-340 m^3/t VS.

Ust'ak et al. (2011, 2021) remarked that the specific methane yield of hybrid *Rumex* green mass substrate was 362 l /kg DM, but in ensiled substrate 284 l/kg DM, the total methane yield varied from 2500 to 3600 m^3/ha.

Molinuevo-Salces et al. (2013), reported that the methane potential of white mustard substrates ranged between 251 and 379 l/kg VS and from fodder radish 356- 474 l/kg VS. *Seppälä (2013)* found that under boreal conditions the methane yield from amaranth biomass reached 290 l/kg VS or 2 700 m3 /ha.

Eberl et al., (2014), reported that the specific methane yield of amaranth substrate was 270 l/kg compared to maize substrate 350 l/kg. *Ahlberg & Nilsson (2015)* found that the specific methane yield for the intermediate crops after 30 days BMP tests ranged from 278 to 290 l/kg VS in the *Sinapis alba* and 297-304 l/kg VS in *Raphanus sativus* substrates.

Herrmann et al., (2016), reported that the tested amaranth substrate had C/N = 27, and biochemical methane potential 278.4 l/kg VS; the *Raphanus sativus* substrate had C/N=17 and biochemical methane potential 29l.0 l/kg VS, but alfalfa grass mixtures silage: C/N=18 and biochemical methane potential 280.0 l/kg VS.

According to *Von Cossel, (2019)*, the specific methane yield of Amaranthus hypochondriacus substrate was on average 266 l/kg VS, which was negatively affected by the high contents of ash (13.6%), lignin (6.5%) and cellulose (32.9%). *Słomka and Wójcik Oliveira, (2021),* mentioned that in the white mustard substrate C/N=15.5-19.9, whereas its biogas potential amounted to 350–440 m3 /t DM. *Ţîţei, (2020a, 2022),* found that *Amaranthus hypochondriacus* green mass substrate had C/N = 18.4 and biochemical methane potential 278 l/kg VS; the *Sinapis alba* green mass substrates have C/N=13.5-17.2 and biochemical methane potential 281-2950 l/kg VS, but the Medicago sativa green mass substrate C/N = 18.4 and biochemical methane potential 270 l/kg VS.

CONCLUSIONS

The obtained results indicate the fact that the criterion of dimensional proportionality K_{dp}, chosen and used in our research, has values that correlate with those of the sphericity S of seeds, objectively reflecting their morphological structure. Therefore, the following types of seeds have been identified: 1. *Spheroidal* (*L≃W≃T,* the seeds of *Amaranthaceae species);* 3. *Elliptical* (L>W≃T, alfalfa, family *Fabaceae*; white mustard and fodder radish, family *Brassicaceae*); 4. *Elongated* (*L>>W≄T*, sesame, family *Pedaliaceae*, and flax, family *Linaceae*); 5. *Pyramidal* (with triangular sides, the seeds of *hybrid Rumex tianschanicus × R. patientia,* family *Polygonaceae*). Besides, a correlation between the values of the criterion K_{dp} and sphericity S was identified.

The seeds of the non-traditional plant species, included in this study, have high friability in comparison with the seeds of alfalfa, the traditional control crop: angle of repose $\alpha \leq 28.2^0$ and flow angle- $\alpha_1 \leq 27.8°$ (on steel), $\alpha_1 \leq 31.6°$ (on wood), $\alpha_1 \leq 28.2°$ (on enamelled surface). These features are due to the appropriate morphological structure and the low roughness of the seed coat. The dimensional characteristics of seeds from non-traditional plant species are characterized by relatively small sizes, the geometric mean diameter value varying within the range D_g= 0.68- 2.59 mm.

The analysis of the physico-mechanical and technological properties of the studied seeds confirms that it is possible to use the facilities and technical means, available in the agro-food sector, to transport, process and store these seeds, which is a great advantage in making good use of the biological potential of these crops with minimal expenses.

The harvested green mass from non-traditional crops has the optimal content of nutrients: protein 14.43-19.81 % crude protein, 25.48-32.43 % crude cellulose, 37.58-42.55 % nitrogen free extract, 0.63-1.9% Ca, 0.28 -0.52% P with nutritive energy values 8.82-9.67 MJ/kg ME and 4.94-5.91 MJ/kg NEl.

The biochemical methane potential of the studied green mass substrates from studied non-traditional crops reaches 251-328 l/kg VS. The studied non-traditional crops can be used as a source of nutrients in livestock nutrition, or as a source of biomass for biomethane production.

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