

## THE PECULIARITIES OF SEEDS AND THE QUALITY OF THE GREEN MASS OF SOME NON-TRADITIONAL CROPS IN THE REPUBLIC OF MOLDOVA

### PARTICULARITĂȚILE SEMINTELOR ȘI CALITATEA MASEI VERZI LA UNELE CULTURI NETRADIȚIONALE ÎN REPUBLICA MOLDOVA

Valerian CEREMPEI<sup>1)</sup>, Victor ȚÎȚEI<sup>2)</sup>, Nicolae-Valentin VLĂDUT<sup>3)</sup>, Oana-Diana CRISTEA<sup>\*3)</sup>

<sup>1)</sup> Technical University of Moldova, Chisinau/ Republic of Moldova;

<sup>2)</sup> „Alexandru Ciobotaru” National Botanical Garden (Institute) of Moldova State University, Chisinau/ Republic of Moldova;

<sup>3)</sup> INMA Bucharest/ Romania;

Tel.: 0761052624, \*E-mail: diana10.cristea@gmail.com

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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 netradiționale în Republica Moldova: *Amaranthus hypochondriacus*, *Raphanus sativus*, *Sinapsis 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 netradiționale 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; Țiței, 2015, 2020b, 2023; Țiței and Roșca, 2021; Teleuță and Țiței, 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*), *Hydrophyllaceae* (*Phacelia tanacetifolia*), *Malvaceae* (*Malva crispa*, *Sida hermaphrodita*), *Poaceae* (*Pennisetum glaucum*, *Sorghum alnum*). 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; Teleuță and Țiței, 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; Aleksha 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; Teleuță and Țiței, 2016; Teleuță et al., 2008; Țiței, 2015, 2020, 2023; Țiței and Roșca, 2021; Teleuță and Țiței, 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  $\pm 0.05$  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

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

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  $L$ ,  $W$ ,  $T$ :

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

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  
 $L \simeq W \simeq T$ , characteristic of peas, soybeans, etc.;
2. *Flattened*: seed width is approximately equal to the length, and the thickness index is much smaller  
 $L \simeq W \gg T$  (lentil);
3. *Elliptical*: the thickness and the width are equal, while the length is bigger  $L > W \simeq T$  (legumes);
4. *Elongated*: all the dimensions differ from each other, with length having the greatest value:  
 $L \gg W \neq T$  (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  $\alpha$  and of the flow angle  $\alpha_1$  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  $\alpha$  were determined by 2 methods:

1. *The general method*, which is currently widely used by researchers (Ene and Mocanu, 2016; Aleksha 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  $\pm 0.2^\circ$ . The measurement of the angle  $\alpha$  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:

$$\text{tg } \alpha = 2h \cdot D^{-1} \quad (4)$$

The second criterion of seed friability, the flow angle  $\alpha_1$ , 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  $\alpha_1$  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  $\alpha$ , experiments were repeated 10 times, and for the angle  $\alpha_1$  – 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 (*NEI*) were calculated according to standard procedures:

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

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

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

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):  $LWT = 2.17 \times 1.2 \times 1.07$  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* ( $L > W \approx T$ ), 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  $LWT = 1.98 \times 1.67 \times 1.67$  mm ( $D_g = 1.77$  mm) and radish *Raphanus sativus* –  $LWT = 3.50 \times 2.43 \times 2.05$  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*-  $LWT = 0.68 \times 0.68 \times 0.68$  mm ( $D_g = 0.68$  mm) and white amaranthus –  $LWT = 1.0 \times 1.0 \times 1.0$  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]	[%]
<b>Fabaceae</b>						
<i>Medicago sativa</i> (control)	2.17±0.10	1.20±0.06	1.07 ± 0.06	2.03/1.12/1	1.48	68.2
<b>Amaranthaceae</b>						
<i>Amaranthus sp.</i>	0.68 ±0.06	0.68 ±0.06	0.68 ±0.06	1/1/1	0.68	100
<i>Amaranthus hypochondriacus</i>	1.00±0.08	1.00±0.08	1.00±0.08	1/1/1	1.00	100
<b>Brassicaceae</b>						
<i>Raphanus sativus</i> <i>var. oleifera</i>	3.50±0.24	2.43±0.21	2.05±0.04	1.71/1.19/1	2.59	74.0
<i>Sinapis alba</i>	1.98±0.11	1.67±0.03	1.67±0.03	1.19/1/1	1.77	89.4
<b>Linaceae</b>						
<i>Linum usitatissimum</i>	4.08±0.07	2.0±0.08	0.65±0.08	6.28/3.08/1	1.74	42.7
<b>Pedaliaceae</b>						
<i>Sesamum indicum</i>	2.97±0.04	1.38±0.07	0.5±0.1	5.94/2.76/1	1.27	42.8
<b>Polygonaceae</b>						
<i>Rumex tianschanicus</i> <i>× Rumex patientia</i>	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 –  $LWT=2.97 \times 1.38 \times 0.5$  mm ( $D_g=1.27$  mm) and flax –  $LWT=4.08 \times 2.0 \times 0.65$  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* ( $L \gg W \neq T$ ) 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*  $\times$  *Rumex patientia*, resulted in obtaining the following dimensional characteristics:  $LWT=3.1 \times 1.72 \times 1.72$  mm ( $D_g=2.09$  mm). 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  $\alpha_1$  was studied were identical for all seeds: steel C10, wood, enamel.

That is why the friability of the seeds (values of the angles  $\alpha$  and  $\alpha_1$ ) 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  $\alpha$  was measured by two methods: general and local. Because there is a relatively small difference between the values of the angle  $\alpha$ , determined by the general and the local methods (Table 2), in the following will be used the average value of the angle  $\alpha$  to simplify the analysis of the friability of the seeds, and, if necessary, will be used the  $\alpha$  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* x *Rumex patientia*.

In the *Fabaceae* family, alfalfa seeds, the control, had the following values of friability (Table 2): the angle of repose  $\alpha=30.9^\circ$  and flow angle  $\alpha_1=27.3^\circ$  (on steel),  $\alpha_1=33.6^\circ$  (on wood),  $\alpha_1=26.7^\circ$  (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  $\alpha=27.05^\circ$ - $33.21^\circ$ .

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  $\alpha=21.9^\circ$  and flow angle: on steel-  $\alpha_1=19.0^\circ$ , on wood-  $\alpha_1=20.4^\circ$ , on enamelled surface-  $\alpha_1=19.7^\circ$ ), for *Amaranthus* seeds (the angle of repose  $\alpha=22.3^\circ$  and flow angle: on steel-  $\alpha_1=19.7^\circ$ , on wood-  $\alpha_1=22.8^\circ$ , on enamelled surface –  $\alpha_1=20.7^\circ$ ) and white amaranthus seeds (the angle of repose  $\alpha=24.6^\circ$  and flow angle: on steel-  $\alpha_1=22.9^\circ$ , on wood-  $\alpha_1=27.2^\circ$ , on enamelled surface –  $\alpha_1=26.1^\circ$ ).

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* x *R. patientia*) had values of the angle of repose  $\alpha$  and flow angle  $\alpha_1$  in the range of the respective angles for the seeds of alfalfa and the seeds of the families *Linaceae*, *Amaranthaceae*: the angle of repose  $\alpha=24.15^\circ$ -  $28.2^\circ$  and flow angle on steel  $\alpha_1=21.3^\circ$ -  $27.0^\circ$ , on wood  $\alpha_1=26.0^\circ$ -  $31.6^\circ$ , on enamelled surface  $\alpha_1=22.7^\circ$ -  $28.2^\circ$ . 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

Families, species	Angle of repose $\alpha$ , methods			Flow angle $\alpha_1$ , surfaces		
	general	local	average	steel	wood	enamel
	[degrees]			[degrees]		
<b>Fabaceae</b>						
<i>Medicago sativa</i>	30.2±0.3	31.5±0.4	30.9	27.3 ± 0.4	33.6 ± 0.9	26.7 ± 0.2
<b>Amaranthaceae</b>						
<i>Amaranthus sp.</i>	20.6±0.5	24.0±1.0	22.3	19.7±0.4	22,8±0,2	20,7±0,3
<i>Amaranthus hypochondriacus</i>	24.1±0.1	25.1±0.9	24.6	22.9±0.3	27,2±0,8	26,1±0,1
<b>Brassicaceae</b>						
<i>Raphanus sativus</i> <i>var. oleifera</i>	27.4±0.4	28.9±1.6	28.2	21.3±0.3	26.0±0.8	22.7±0.2
<i>Sinapsis alba</i>	25.3±0.5	29.3±1.3	27.3	22.0±0.6	27.4±1.5	24.7±0.3
<b>Linaceae</b>						
<i>Linum usitatissimum</i>	20.0 ±0.45	23.8±0.7	21.9	19.0±0,1	20.4±0,3	19.7±0.25
<b>Pedaliaceae</b>						
<i>Sesamum indicum</i>	24.0± 0.3	24.3±1.1	24.15	27.0± 0,8	31.6±0,4	28.2± 0.5
<b>Polygonaceae</b>						
<i>Rumex tianschanicus</i> × <i>Rumex patientia</i>	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  $\alpha$ , has higher values than the coefficient of external friction  $f_e$  between the seeds and the sliding surface, characterized by flow angle  $\alpha_1$ , that is  $\alpha > \alpha_1$ . The exception is mainly the values of the angle  $\alpha_1$  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. *Țiței 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.

*Țiței (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 NEI 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 NEI.

Table 3

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

Indices	Species						
	<i>Medicago sativa</i>	<i>Amaranthus hypochondriacus</i>	<i>Raphanus sativus var. oleifera</i>	<i>Sinapsis alba</i>	<i>Linum usitatissimum</i>	<i>Sesamum indicum</i>	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						
	<i>Medicago sativa</i>	<i>Amaranthus hypochondriacus</i>	<i>Raphanus sativus var. oleifera</i>	<i>Sinapsis alba</i>	<i>Linum usitatissimum</i>	<i>Sesamum indicum</i>	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						
	<i>Medicago sativa</i>	<i>Amaranthus hypochondriacus</i>	<i>Raphanus sativus var. oleifera</i>	<i>Sinapsis alba</i>	<i>Linum usitatissimum</i>	<i>Sesamum indicum</i>	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 *Sinapsis alba*.

Several publications have documented the biomethane potential of substrates from studied species. Also, Zubr (1986) reported the methane potential of *Sinapsis alba* was 300 l/kg VS. Murphy et al. (2011) reported that methane yield in *Raphanus sativus var. oleifera* substrate achieved 240-340 m<sup>3</sup>/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<sup>3</sup>/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 m<sup>3</sup> /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 291.0 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 m<sup>3</sup> /t DM. Tîrîei, (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* ( $L \approx W \approx T$ , the seeds of *Amaranthaceae* species); 3. *Elliptical* ( $L > W \approx T$ , alfalfa, family *Fabaceae*; white mustard and fodder radish, family *Brassicaceae*); 4. *Elongated* ( $L \gg W \neq T$ , sesame, family *Pedaliaceae*, and flax, family *Linaceae*); 5. *Pyramidal* (with triangular sides, the seeds of *hybrid Rumex tianschanicus* x *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  $\alpha \leq 28.2^\circ$  and flow angle  $\alpha_1 \leq 27.8^\circ$  (on steel),  $\alpha_1 \leq 31.6^\circ$  (on wood),  $\alpha_1 \leq 28.2^\circ$  (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 NEI.

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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## REFERENCES

- [1] Abbasi M., Rouzbehan Y., Rezaei J., Jacobsen S.E. (2018). The effect of lactic acid bacteria inoculation, molasses, or wilting on the fermentation quality and nutritive value of amaranth (*Amaranthus hypochondriacus*) silage. *Journal of Animal Science*, 96, 3983–3992.

- [2] Ahlberg I., Nilsson T.L.S. (2015). *Investigation on the use of intermediate crops for anaerobic digestion as a renewable source of energy*. Lund University. <https://lup.lub.lu.se/luur/download?func=downloadFile&recordId=5472252&fileId=5472409>
- [3] Aleksha Kudos S.K., Chandan S. (2018). Evaluation of physical properties of amaranth grain (*Amaranthus paniculatus*) *International Journal of Chemical Studies*, 6(2), 2197-2201.
- [4] Amorim D.S., Edvan R.L., Nascimento R.R., Bezerra L.R., Araújo M.J., Silva A.L., Diogénes L.V., Oliveira R.L. (2019). Sesame production and composition compared with conventional forages. *Chilean journal of agricultural research*, 79(4), 586-595. <https://dx.doi.org/10.4067/S0718-58392019000400586>
- [5] Badger C.M., Bogue M.J., Stewart D.J. (1979). Biogas production from crops and organic wastes. *New Zealand Journal of Science*, 22, 11-20.
- [6] Baserga U., 1998. Agricultural co-digestion biogas plants – biogas from organic residues and energy grass (Landwirtschaftliche Co-Vergärungs-Biogasanlagen – Biogas aus organischen Reststoffen und Energiegras). *FAT Reports*, 512: 1-11.
- [7] Biel W., Jendryczak E., Jaroszewska A., Witkiewicz R., Piatkowska E., Telesinski A. (2017). Nutritional content and antioxidant properties of selected species of *Amaranthus* L. *Italian Journal of Food Science*, 29(4), 728–740.
- [8] Bhat V., Madhusudhan B. Naik N.J. (2018). Studies on physical properties and chemical make-up of hybrid and native varieties of flaxseeds. *International Journal of Advanced Research*, 6, 369-373.
- [9] Bojariu R., Nedealcov M., Boincean B., Bejan I., Rurac M., Pîntea M., Caisîn L., Cerempei V., Hurmuzachi I., Baltag G., Zaharia N. (2021). *Best practice guide to adapting to climate change and implementing climate change mitigation measures in the agricultural sector. (Ghid de bune practici întru adaptarea la schimbările climatice și implementarea măsurilor de atenuare a schimbărilor climatice în sectorul agricol)*. UCIP IFAD. Print-Caro, Chișinău. 120p. (in Romanian) [http://dspace.uasm.md/bitstream/handle/123456789/6570/Ghid\\_agricultura\\_web.pdf?sequence=1&isAllowed=y](http://dspace.uasm.md/bitstream/handle/123456789/6570/Ghid_agricultura_web.pdf?sequence=1&isAllowed=y)
- [10] Cagatay Selvi, K., Pinar Y., Yesiloglu E. (2006). Some physical properties of linseed. *Biosystems Engineering*, 95, 607-612.
- [11] Cerempei V., Țiței V., Guțu A., Cârlig N., Gadibadi M. (2022). Some physical and technological properties of seeds of non-traditional plant species in the Republic of Moldova. *Scientific Papers. Series A. Agronomy*, 65 (1), 643-654, [http://agronomyjournal.usamv.ro/pdf/2022/issue\\_1/Art91.pdf](http://agronomyjournal.usamv.ro/pdf/2022/issue_1/Art91.pdf)
- [12] Cerempei V., Țiței V., Vlăduț V., Moiceanu G. A. (2023). Comparative study on the characteristics of seeds and phytomass of new high-potential fodder and energy crops. *Agriculture*, 13,1112., <https://doi.org/10.3390/agriculture13061112>
- [13] Cerempei V. (2016). *Technology and technical means of production and use of biofuels based on monoatomic alcohols*: [Doctoral dissertation. ITA Mecagro-UASM, Chisinau] (Tehnologia și mijloacele tehnice de producere și utilizare a biocombustibililor în baza alcoolilor monoatomici: [Tz. de doct. habilitat în tehnică. ITA Mecagro-UASM, Chișinău]. 239 p., [http://www.cnaa.md/files/theses/2016/50722/valerian\\_cerempei\\_thesis.pdf](http://www.cnaa.md/files/theses/2016/50722/valerian_cerempei_thesis.pdf). (in Romanian)
- [14] Chisnicean L., Țiței V., Teleuță A., Colțun M. (2011). Cultivation of aromatic plants (guide) (*Cultivarea plantelor condimentar – aromatice* (îndrumar). Chișinău, Moldpres, 24 p. (in Romanian).
- [15] Coşkuner Y., Karababa E. (2007). Some physical properties of flaxseed (*Linum usitatissimum* L.). *Journal of Food Engineering*, 78, 1067-1073. 10.1016/j.jfoodeng.2005.12.017.
- [16] Coșman S., Ciopată A.C., Coșman V., Bahcivanji M., Țiței V. (2017). Study on the chemical composition and nutritional value of the *Galega orientalis* Lam. and the prospects of its valorification in the Republic of Moldova. *Scientific papers, series D, Animal Science*, 60, 75-80, <http://animalsciencejournal.usamv.ro/pdf/2017/Art12.pdf> .
- [17] Cumplido-Marin L., Graves A.R., Burgess P.J., Morhart C., Paris P., Jablonowski N.D., Facciotto G., Bury M., Martens R., Nahm M. (2020). Two novel energy crops: *Sida hermaphrodita* (L.) Rusby and *Silphium perfoliatum* L.—State of knowledge. *Agronomy* 2020, 10, 67. <https://doi.org/10.3390/agronomy10070928>.
- [18] Das S. (2016). *Amaranthus: A promising crop of future*. Springer. 208p. <https://doi.org/10.1007/978-981-10-1469-7>.
- [19] Dubrovskis V., Adamovics A. (2015). Anaerobic digestion of hemp, sunflower silage and amaranth silage with catalyst metaferm. 23rd European Biomass Conference and Exhibition, 845–850 DOI: 10.5071/23rdEUBCE2015-2DV.1.45

- [20] Elleuch M., Besbes S., Roiseux O., Blecker C., Attia H. (2007). Quality characteristics of sesame seeds and by-products. *Food Chemistry*, 103, 641–650.
- [21] Eberl V., Fahlbusch W., Fritz M., Sauer B. (2014). *Screening and selection of amaranth varieties and lines as a biogas substrate rich in trace elements* (No.37), *Screening und Selektion von Amaranthsorten und -linien als spurenelementreiches Biogassubstrat*, reports from the TFZ. Technology and support centre in the Competence Centre for Renewable Raw Materials, Straubing, 114 p.
- [22] Ene T. A., Mocanu V. (2016). Production, conditioning and storage of seeds of perennial grassland grasses and legumes – Technologies, equipment and facilities (Producerea, condiționarea și stocarea semințelor de graminee și leguminoase perene de pajiști – Tehnologii, echipamente și instalații). Brașov, 116p. <http://www.madr.ro/attachments/article/224/ADER-1112-ghid.pdf> (in Romanian)
- [23] Gautam A. Khurana R., Manes G.S., Dixit A.K. (2016). Studies on physical properties of pelleted radish (*Raphanus sativus*) seeds. *Research in Environment and Life Sciences*, 9(4), 473-476.
- [24] Herrmann C., Idler C., Heiermann M. (2016). Biogas crops grown in energy crop rotations: linking chemical composition and methane production characteristics. *Bioresource Technology*, 206, 23-35. <https://doi.org/10.1016/j.biortech.2016.01.058>
- [25] Heuzé V., Tran G., Lebas F. (2015). Flax straw and flax crop by-products. *Feedipedia*, a programme by INRAE, CIRAD, AFZ and FAO. <https://www.feedipedia.org/node/132>.
- [26] Kaliniewicz Z., Markowski P., Anders A., Jadwisienczak K. (2015). Frictional properties of selected seeds. *Tech. Sci.*, 18(2), 85–101.
- [27] Kshnikatkina, A.N., Gushchina, V.A., Galiullin, A.A., Varlamov, V.A., Kshnikatkin, S.A. (2005). Nontraditional fodder crops. RIO PGSKHA, Penza. 240 p. (in Russian).
- [28] Kukusheva, A., Stepanov, A. (2016). Effect of mowing term on biometrics, yield and nutritional properties of hybrid (*Rumex patientia* x *Rumex tianschanicus*). *Bulgarian Journal of Agricultural Science*, 22(6), 948–954.
- [29] Leukebandara I.K., Premaratne S., Peiris B.L. (2015). Nutritive quality of thampala (*Amaranthus* spp.) as a forage crop in Sri Lanka. *Tropical Agricultural Research*, 26(4), 624–631.
- [30] Matei, G., Feher, E. (2010). Conditioning and preservation of agricultural products (*Condiționarea și conservarea produselor agricole*). *Universitaria, Craiova*, 168p, (in Romanian).
- [31] Medvedev P.F., Smetannikova A.I. (1981). *The forage crops of European part of the USSR*. Leningrad, Kolos. (in Russian).
- [32] Mohsenin N. N. (2020). Physical properties of plant and animal materials: structure, physical characteristics and mechanical properties. *New York, Imprint Routledge*, 758p. e-Book ISBN 9781003062325, DOI <https://doi.org/10.4324/9781003062325>.
- [33] Molinuevo-Salces B., Ahring B.K., Uellendahl H. (2013). Catch crops as an alternative biomass feedstock for biogas plants. In Proceedings of the International Anaerobic Digestion Symposium on "Dry Fermentation, Substrate Treatment and Digestate Treatment" within the BioGasWorld 2013. Berlin (pp. 92-98). FNBB. <http://ibbk.fachgruppe-biogas.de/index.php?id=32&L=1&eventId=91>.
- [34] Mursec B., Vindis P., Janzekovic M., Brus M., Cus F. (2009). Analysis of different substrates for processing into biogas. *Journal of Achievements in Materials and Manufacturing Engineering*, 37(2), 652–659.
- [35] Peiretti P.G. (2018). *Amaranth* in animal nutrition: A review. *Livestock Research for Rural Development*. 30. <http://www.lrrd.org/lrrd30/5/peir30088.html>.
- [36] Peni D., Stolarski M.J., Bordiean A., Krzyzaniak M., Debowski M. (2020). *Silphium perfoliatum*—a herbaceous crop with increased interest in recent years for multi-purpose use. *Agriculture*, 10, 640. <https://doi.org/10.3390/agriculture10120640>.
- [37] Pisaoikova B., Peterka J., Trakova M., Moudr J., Zral Z., Herzig I. (2006). Chemical composition of the above-ground biomass of *Amaranthus cruentus* and *A. hypochondriacus*. *Acta Veterinaria Brno*, 75, 133–138.
- [38] Pospisil A., Pospisil M., Macesic D., Svecnjak Z. (2009). Yield and quality of forage sorghum and different amaranth species (*Amaranthus* spp.) biomass. *Agriculturae Conspectus Scientificus*, 74(2), 85–89.
- [39] Póti P., Pajor F., Bodnár Á., Penksza K., Tózsér J., Gyuricza C. (2014). Potential of second crops of oil radish and white mustard as fall grazing pasture for German mutton merino sheep. *Notulae Botanicae Horti Agrobotanici*, 42(1), 286–288.



- [40] Rahnema A., Safaeie A.R. (2017). Performance comparison of three varieties of amaranth (*Amaranthus hypochondriacus* L.) at different harvest time. *Journal of Asian Scientific Research*, 7(6), 224– 230.
- [41] Rakhmetov D. (2018). *Non-traditional plant species for bioenergetics*. Nitra: Slovak University of Agriculture in Nitra, 103 p. <https://doi.org/10.15414/2018.fe-9788055218557> (in Russian).
- [42] Rakhmetov D.B. (2011). *Theoretical and practical aspects of plant introduction in Ukraine*. Ed. Agrar Media Grup, Kyiv, 398 p. (in Ukrainian).
- [43] Rakhmetov D.B., Rakhmetova S.O. (2006). Varietal diversification of shchavnat (*Rumex patientia* L. × *R. tianschanicus* Losinsk) and directions of its use. *Plant Introduction*, 1, 11-16. <http://www.nbg.kiev.ua/upload/introd/Intr-N1-06.pdf> (in Ukrainian).
- [44] Rakhmetov D.B., Rakhmetova S.O. (2011) Shchavnat: both fruit, and feed and biofuels. *Cereal*, 3, 8-10. <http://www.zerno-ua.com/journals/2011/mart-2011-god/shchavnat-i-ovoshch-ikorm-i-fitotoplivo> (in Russian).
- [45] Rakhmetov D., Ust'ak S., Ust'aková M. (2004). Perennial spinach-sorrel hybrid– schavnat as a new perspective multipurpose crop. *VIII ESA Congress*, Copenhagen, p. 86-94.
- [46] Rolinec M., Rakhmetov D., Bíro D., Juráček M., Šimko M., Gálik B., Hanušovský O. (2018). Nutritional value of hybrid *Rumex patientia* L. × *Rumex tianschanicus* A. Los (Rumex OK 2) in different periods. *Acta fytotechn zootechn*, 21(4), 197-200.
- [47] Roman Gh. V., Ion V., Epure L.I., Bășă A. Gh. (2016). *Biomass. Alternative Energy Source (Biomasa. Sursă alternativă de energie)*. București, 432 p. DOI: 10.5682/978-606-28-0506-7 (in Romanian).
- [48] Schäfer A., Damerow L., Schulze Lammers P. (2017). Determination of the seed geometry of cup plant as requirement for precision seeding. *Landtechnik*, 72, 122–128, <https://www.landtechnik-online.eu/landtechnik/article/view/2017-72-3-122-129>.
- [49] Seppälä M. (2013). *Biogas production from high yielding energy crops in boreal conditions*. Jyväskylä University Printing House. 92p.
- [50] Słomka A., Wójcik Oliveira K. (2021). Assessment of the biogas yield of white mustard (*Sinapis alba*) cultivated as intercrops. *Journal of Ecological Engineering*, 22(7), 67–72.
- [51] Tunde-Akintunde, T. Y., Akintunde, B. O. (2004). Some physical properties of sesame seeds. *Biosystems Engineering*, 88, 127– 129.
- [52] Teleuță A., Colțun M., Mihailescu C., Ciocarlan N. (2008). *Medicinal herbs (Plante medicinale)*. Chișinău. 335 p. (in Romanian).
- [53] Teleuță A., Țiței V. (2016). Mobilization, acclimatization and use of fodder and energy crops. *Journal of Botany*. 1(12), 112-120. [https://ibn.idsi.md/en/vizualizare\\_articol/48812](https://ibn.idsi.md/en/vizualizare_articol/48812) .
- [54] Titei V. (2015). Plant species for renewable energy production in the Republic of Moldova. *Scientific Papers. Series A. Agronomy*, 58, 425-431. [www.agronomyjournal.usamv.ro/pdf/2015/vol.LVI/II/art77.pdf](http://www.agronomyjournal.usamv.ro/pdf/2015/vol.LVI/II/art77.pdf).
- [55] Țiței, V. (2020a). The quality of green mass and silage from *Amaranthus hypochondriacus* growing under the conditions of the Republic of Moldova. *Scientific Papers. Series A. Agronomy*, 63 (1), 594-601. [http://agronomyjournal.usamv.ro/pdf/2020/issue\\_1/Art83.pdf](http://agronomyjournal.usamv.ro/pdf/2020/issue_1/Art83.pdf).
- [56] Țiței V. (2020b) The mobilization and use of plant genetic resources with high potential as fodder, honey and energy crops: achievements and prospects. (Mobilizarea și valorificarea resurselor genetice vegetale cu potențial furajer, melifer și biomasă energetică: realizări și perspective). *Journal of Botany*, 2 (21), 92-105. DOI: [https://doi.org/10.52240/1857-2367.2020.2\(21\).9](https://doi.org/10.52240/1857-2367.2020.2(21).9) (in Romanian).
- [57] Țiței V. (2023). The mobilization of energy crop resources in Moldova. *Romanian Agricultural Research*, 40, 646-654. <https://www.incada-fundulea.ro/rar/nr40/rar40.3.pdf> .
- [58] Țiței V., Roșca I. (2021). *Good practices for the use of degraded lands in the cultivation of crops with energy biomass potential (Bunele practici de utilizare a terenurilor degradate în cultivarea culturilor cu potențial de biomasă energetică)*. Chișinău: S. n., 80p. (in Romanian).
- [59] Țiței V., Teleuță, A. (2015). The perspective of cultivation and utilization of the hybrid *Rumex tianschanicus* × *Rumex patientia* in Moldova. *Scientific papers, series Agronomy*, 58 (2), 163-168.
- [60] Togo J.M., Decheng W., Wenpeng M., Changbin H. (2018). Effects of moisture content on selected physical and mechanical properties of alfalfa seeds. *Journal of Biology, Agriculture and Healthcare*, 8, 8-18. <https://www.iiste.org/Journals/index.php/JBAH/article/view/43338>.
- [61] Ustak S., Šimko J., Muñoz J. (2021). Hybrid sorrel: cultivation potential and use as a novel non-food multipurpose crop. *Biofuels Bioproducts and Biorefining*. 15(1). <https://doi.org/10.1002/bbb.2157>.

- [62] Ust'ak S., Váňa J., Petříková V. (2011). Non-traditional fodder sorrel as suitable raw material for biogas production (Netradiční píceňina šťovík krmný jako vhodná surovina pro výrobu bioplynu). *Agritech Science*, 11, 1-7. (in Czech).
- [63] Uteush Y.A. (1990). *New promising forage crops*. Edit. Naukova dumka, Kyiv. 192. (in Russian).
- [64] Von Cossel, M. (2019). Agricultural diversification of biogas crop cultivation. Dissertation, University of Hohenheim, Stuttgart, Germany. <https://opus.unihohenheim.de/volltexte/2019/1600/>.
- [65] Zarczynski P., Sienkiewicz S., Wierzbowska J., Krzebietke S. (2021). Fodder galega—a versatile plant. *Agronomy* 2021, 11, 1797. <https://doi.org/10.3390/agronomy11091797> .
- [66] Zubr J. (1986). Methanogenic fermentation of fresh and ensiled plant materials. *Biomass*, 11. 156–171,
- [67] \*\*\*“Key World Energy Statistics” (PDF). International Energy Agency. 2023, <https://www.eia.gov/international/data/world>, (accessed on 17 August 2023).
- [68] \*\*\* Strategy the European Environment Agency EEA–Eionet 2021–2030, Luxemburg: Publications Office of the European Union, 2021 ISBN 978-92-9480-360-3 Doi:10.2800/92395, <https://www.eea.europa.eu/ro/publications/strategia-aem2013eionet-202120132030> (accessed on 18 August 2023).
- [69] \*\*\* FAO. (2016). The State of Food and Agriculture: Climate change, Agriculture and Food security Food and Agriculture Organization of the United Nations (FAO), Rome, 194p. ISBN 978-92-5-109374-0, ISSN 0081-4539, <http://www.fao.org/3/a-i6030e.pdf> .
- [70] \*\*\* The World at un.org.: <https://www.un.org/en/site-index> (accessed on 12 August 2023).
- [71] \*\*\* U.S. Census Bureau – World POP Clock Projection. <https://www.census.gov/popclock/> (accessed on 17 August 2023).
- [72] \*\*\* World population prospects: The 2023 Revision Population Database. <https://www.un.org/esa/population/publications/> (accessed on 15 August 2023).