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SOME AGRO-BIOLOGICAL FEATURES AND POTENTIAL USES OF VIRGINIA MALLOW, *Sida hermaphrodita* IN MOLDOVA

Mihai GADIBADI[1], Victor ŢÎŢEI[1], Valerian CEREMPEI[1], Ana GUŢU[1], Veceslav DOROFTEI[1], Dragoş COVALCIUC[1], Radu LÎSÎI[1], Veaceslav MAZĂRE[2], Andrei ARMAŞ[2]

[1]"Alexandru Ciubotaru" National Botanical Garden (Institute), 18 Padurii Street, Chisinau, Republic of Moldova
[2] Banat's University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania" from Timisoara, 119 Calea Aradului Street, Timisoara, Romania

Corresponding author email: vic.titei@gmail.com

Abstract

Plant biomass is a promising alternative to conventional, non-renewable sources of energy. The aim of this paper was to evaluate some biological peculiarities and the quality of green and dry biomass of Virginia mallow, Sida hermaphrodita cv. Energo, which has been cultivated in the experimental field of the National Botanical Garden (Institute), Chişinău. Corn, Zea mays, was considered as control. The results of our research revealed that the dry matter of the harvested Virginia mallow green mass contained 160 g/kg CP, 84 g/kg ash, 371 g/kg ADF, 529 g/kg NDF, 60 g/kg ADL, 311 g/kg cellulose and 158 g/kg hemicellulose; the biochemical biomethane potential of green mass substrates was 272 l/kg ODM. The dry stalks of Virginia mallow contained 46.03% carbon, 5.94% hydrogen, 0.32% nitrogen, 0.08% sulphur, 1.87% ash, 556 g/kg cellulose, 241 g/kg hemicellulose and 131 g/kg acid detergent lignin, but corn stalks –44.06% carbon, 5.65% hydrogen, 0.95% nitrogen, 0.21% sulphur, 4.40% ash, 417 g/kg cellulose, 250 g/kg hemicelluloses and 82 g/kg acid detergent lignin. The theoretical ethanol yield from structural carbohydrates averaged 578 L/t in Virginia mallow substrate, as compared with 485 L/t in corn substrate. The gross calorific value of biomass from Virginia mallow stalks averages 19.73 MJ/kg, but – from corn stalks – 17.8 MJ/kg. Sida hermaphrodita cv. Energo may serve as multi-purpose feedstock for renewable energy production.

Key words: *biomethane potential, calorific value, Sida hermaphrodita cv. Energo, pellets, theoretical ethanol yield.*

INTRODUCTION

In the past few years, major challenges such as climate change, population growth, food and energy security and intensive exploitation of natural resources have caused increasing concerns worldwide. The total energy consumption and pollutant emissions of the world have doubled in the last 40 years. Replacing fossil fuels with renewable energy alternatives has become a major global issue of the XXI century and a key to sustainable development. Biomass is one of the biggest renewable resources of energy, which may be utilized in different ways: directly by burning and indirectly by converting it into solid, liquid or gaseous fuels. Its use for energy purposes generates less pollution to the natural environment and climate. Lignocellulosic biomass, or plant cell walls, is the most abundantly available renewable resource on Earth and it has the potential to be converted to second-generation biofuels, chemicals, or materials without compromising global food security (Zoghlami&Paës, 2019).

Due to the high interest in biomass, the plantation of energy crops has gained more interest lately. The species selected as potential energy crops should be characterized by a high annual growth and productivity, resistance to diseases and pests, low habitat requirements and adaptation to climatic conditions (Ţîţei& Roşca, 2021).

Sida hermaphrodita (L.) Rusby syn. *Ripariosida hermaphrodita* (L.) Weakley & D.B. Poind., *Napaea hermaphrodita* L. is a perennial herbaceous species belonging to the *Malvaceae* family, and its common names include Virginia mallow and Virginia fanpetals. It is indigenous to North America, where it occurs in or near wetlands, floodplains and on river banks. It is a polycarpic perennial herb, looks like a dense bush with a few dozens of stems of 400 cm in height and of 5 to 35 mm in diameter. The leaves are simple, but palmately cleft into 3 to 7 elongated lobe tips, 10 to 20 centimeters long and borne on petioles. The inflorescences produce clusters of white flowers. The fruit is capsule with four brownish-grey triangular seeds. The weight of 1000 seeds is 3.30-3.90 g (Ţîţei, 2015).

Sida hermaphrodita is tolerant to almost any quality of soil; the pH of these soils varies between 5.4 and 7.5, with a medium to high organic matter content. It can withstand temperatures down to -35 °C without any problems, and it is considered resistant to temporary droughts. It is deemed rather insusceptible to pests and diseases, although it can be affected by *Sclerotinia sclerotiorum.* Virginia mallow plantations can be established using seeds, seedlings or root cuttings. It is sown in late autumn or early spring with layered seeds at a depth of 2-3 cm, in quantities of 2-3 kg/ha, the distance between rows – 45 cm or 70 cm, with soil compaction before and after sowing. The vegetative propagation is done by planting root cuttings, 3-7cm long, in the middle of March-April and – by seedlings – in the middle of May, at a density of 25-30 thousand plants per hectare. Once planted, *Sida hermaphrodita* can be productive over 10 years or more, and some authors have suggested that it can remain highly productive for 15–20 years. The crop biomass can be harvested with conventional harvesting techniques and stored without problems. In particular, in the last decade, an increasing number of researchers has admitted the potential of *Sida hermaphrodita* as an ecologically valuable raw material for fodder, fibre and energy production, as well as soil stabilization (Howaniec&Smoliński, 2011; Dezbowski et al., 2012; Jasinskas et al., 2014; Siaudinis et al., 2015; Jablonowski et al., 2017; Fijalkowska et al., 2017; Bilandžija et al., 2018; Wróbel et al., 2018; Jankowski et al., 2019; Szwaja et al., 2019; Cumplido-Marin et al., 2020).

The main objective of this research has been to evaluate the biomass quality of Virginia mallow, *Sida hermaphrodita*, as feedstock for the production of biomethane, cellulosic ethanol and solid biofuel – pellets.

MATERIALS AND METHODS

The cultivar ‘*Energo*’ of Virginia mallow, *Sida hermaphrodita,* created in the National Botanical Garden (Institute), registered in 2014, in the Catalogue of Plant Varieties** and patented in 2016, by the State Agency on Intellectual Property (AGEPI) of the Republic of Moldova, patent no. 207/31.05.2016*, has been cultivated in the experimental plot of the “Alexandru Ciubotaru” National Botanical Garden (Institute), Chişinău, latitude 46°58′25.7″N and longitude 28°52′57.8″E. It served as subject of the research, and corn, *Zea mays*, was used as control.

The green mass of *Sida hermaphrodita* cv. ‘Energo’, in the 7th year of growth, was cut for the first time in the end of May, but corn, *Zea mays* – in kernel milk-wax stage, in early August. The harvested green mass was chopped with a stationary forage chopping unit. The fractional composition of the chopped green mass was determined using a vibrating screen device. It used 400 mm diameter sieves, where sieves with round pores were put one on other (in the order from the top sieve): diameter of 63 mm, 31.5 mm, 16 mm, 8 mm, 3.15 mm and 1 mm. For chemical analyses, green mass samples were dried in a forced air oven at 60 °C, milled in a beater mill equipped with a sieve with diameter of holes of 1 mm and some assessments of the main parameters, such as crude protein (CP), crude fibre (CF), ash, acid detergent fibre (ADF), neutral detergent fibre (NDF), acid detergent lignin (ADL) and total soluble sugars (TSS), have been determined by near infrared spectroscopy (NIRS) technique using PERTEN DA 7200. The concentrations of hemicellulose (HC) and cellulose (Cel) were calculated according to standard procedures. The carbon content of the substrates was obtained using an empirical equation according to Badger et al. (1979). The biochemical biogas potential (Yb) and the methane potential (Ym) were calculated according to the equations of Dandikas et al. (2014), based on the concentration of acid detergent lignin (ADL) and hemicellulose (HC):

$Yb=727+0.25\ HC-3.93\ ADL$
$Ym=371+0.13HC-2.00ADL$

The Virginia mallow and corn dry stalks were harvested manually in February. For the production of solid biofuel, the harvested stalks were chopped into chaff using a stationary forage chopping unit. The chopped biomass of Virginia mallow and corn stalks were milled in a beater mill equipped with a sieve with diameter of holes of 6 mm.

To perform the analyses of the content of cell walls, the biomass samples were dried in an oven at 85 °C and then milled (<1 mm) and homogenized. After that, the total carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) amounts were determined by dry combustion in a Vario Macro CHNS analyzer (Elemental Analyzer, GmbH, Langenselbold, Germany), according to standard protocols at the State Agrarian University of Moldova. The pelleting was carried by the equipment developed at the Institute of Agricultural Technique "Mecagro", Chişinău. The physical and mechanical properties of dry biomass and pellets were determined according to the standards: the moisture content of the plant material was determined by SM EN ISO 18134 in an automatic hot air oven MEMMERT100-800; the content of ash was determined at 550 ºC in a muffle furnace HT40AL according to SM EN ISO 18122; the automatic calorimeter LAGET MS-10A with accessories was used for the determination of the calorific value, according to SM EN ISO 18125; the particle size distribution was determined according to SM EN ISO 17827 using standard sieves, the collected particles in each sieve were weighed; the cylindrical containers were used for the determination of the bulk density, calculated by dividing the mass over the container volume according to SM EN ISO 17828, SM EN ISO 18847. The mean compressed (specific) density of the pellets was determined immediately after removal from the mould as a ratio of measured mass over calculated volume.

To determine the cell wall components in the dry mass of tested species, the amounts of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were assessed using the near infrared spectroscopy (NIRS) technique PERTEN DA 7200. The amount of cellulose was calculated as ADF minus ADL and hemicelluloses – NDF minus ADF. The Theoretical Ethanol Potential (TEP) was calculated according to the equations of Goff et al. (2010) based on conversion of hexose (H) and pentose (P):

$H = [\%Cel+(\%HC \times 0.07)] \times 172.82$
$P = [\%HC \times 0.93] \times 176.87$
$TEP = [H + P] \times 4.17$

RESULTS AND DISCUSSIONS

As we mentioned in our previous study, in the first growing season, *Sida hermaphrodita* cv. ‘*Energo*’ stopped growing in the flower bud stage, when the stems were about 171 cm tall and 6-13 mm thick at base. In the second year and in the further years, in spring, when the air temperature exceeded 6 °C, plant development started from the generative buds. A high growth rate (5-6 cm/day) was observed during May and June (Ţîţei, 2015). The studied plants of *Sida hermaphrodita* cv. ‘Energo’, in the 7th year, were cut for the first time at the end of May, when the shoots with 37-40 leaves were about 235-265 cm tall, the green mass yield reached 70.5 t/ha. A high aerial biomass productivity of *Sida hermaphrodita* plants was also mentioned in other studies. So, Rakhmetov (2011) stated that, under the climatic conditions of Ukraine, *Sida hermaphrodita* could have a productivity of 123.9-187.7 t/ha natural fodder, depending on the genotype.

The sustainable management of biogas production via anaerobic digestion involves the use of alternative biomass sources that are not competitive with food production. Energy crops have been largely used as lignocellulosic biomass feedstock in the production of biogas via anaerobic digestion in recent years. Particle size distribution of chopped green mass influenced the costs of transport and particle size reduction has been reported as one of the major effects of different substrate pre-treatments of lignocellulosic biomasses. The results, Table 1, show that a higher amount of particles (57.7%) with a size < 8 mm was found in *Sida hermaphrodita* ‘*Energo*’ green mass, but in *Zea mays* green mass, on average 66.8% of the particles were larger than 8 mm.

Table 1. Particle size distribution of chopped green mass from the studied species, %

Particle size	*Sida hermaphrodita*	*Zea mays*
3.15 mm	4.9	5.5
3.15-8.00 mm	52.6	27.2
8.00-16.00mm	24.7	48.4
16.00-31.50 mm	12.7	18.4

The biodegradation of different types of lignocellulosic biomass feedstock depends on the chemical structure, primarily on the content of cellulose, hemicellulose, lignin and the C/N ratio. The results regarding the quality of the investigated substrates and the potential biomethane are illustrated in Table 2. We found that the dry matter of the harvested green mass of *Sida hermaphrodita* '*Energo*' contained 160 g/kg CP, 369 g/kg CF, 60 g/kg ash, 371 g/kg ADF, 529 g/kg NDF, 60 g/kg ADL, 60 g/kg TSS, 311 g/kg Cel, 158 HC g/kg TSS, but the corn green mass substrates – 88 g/kg CP, 303 g/kg CF, 60 g/kg ash, 310 g/kg ADF, 520 g/kg NDF, 31 g/kg ADL, 294 g/kg TSS, 279 g/kg Cel, 210 g/kg HC, respectively.

Table 2. The biochemical composition and biomethane production potential of the investigated green mass substrates

Indices	*Sida hermaphrodita*	*Zea mays*
Crude protein, g/kg DM	160	88
Crude fibre, g/kg DM	369	303
Ash, g/kg DM	60	60
Acid detergent fibre, g/kg DM	371	310
Neutral detergent fibre, g/kg	529	520
Acid detergent lignin, g/kg DM	60	31
Total soluble sugars, g/kg DM	60	294
Cellulose, g/kg DM	311	279
Hemicellulose, g/kg DM	158	210
Nitrogen, g/kg DM	25.60	14.08
Carbon, g/kg DM	522.22	522.22
Ratio carbon/nitrogen	20.40	35.43
Biogas potential, L/kg VS	525	591
Biomethane potential, L/kg VS	272	302

The nitrogen content in the studied substrates ranged from 1.41% in corn substrates to 2.56% in *Sida hermaphrodita* '*Energo*' substrates, the estimated content of carbon was the same – 52.2%, the C/N ratio varied from 35 to 20, respectively. Essential differences were observed between the protein, fibre and lignin contents, which played an important role in degradation and biomethane production. The biochemical methane potential of *Sida hermaphrodita* green mass substrate reached 272 l/kg ODM and corn substrate - 302 l/kg ODM.

Several literature sources describe the biochemical composition and biomethane potential of *Sida hermaphrodita* green mass. In Poland, in the herbage harvested in the bud formation stage, the dry matter content was 197 g/kg, its biochemical composition – 199 g/kg CP, 8.35 % ash, 73 g/kg WSC and structural carbohydrates – 403 g/kg NDF, 308 g/kg ADF and 38 g/kg ADL (Fijalkowska et al. 2017). The anaerobic digestion batch tests on *Sida hermaphrodita* biomass harvested in July revealed the following results: 435 l/kg ODM biogas or 220 l/kg ODM methane (Oleszek et al. 2013). According to Hartmann & Haller (2014), the methane yields varied from 280 to 293 l/kg ODM. Siwek et al. (2019) reported that the specific biogas yield of *Sida hermaphrodita* ranged from 505 to 514 l/kg, and for *Silphium perfoliatum* biomass – from 483 to 504 l/kg, methane concentrations from 50.8 to 52.8 % and from 51.1 to 52.9 %, respectively.

The elemental composition of dry biomass is a significant asset that defines the amount of energy and evaluates the clean and efficient use of biomass materials, provides significant parameters used in the design of almost all energy conversion systems and projects, for the assessment of the complete process of any thermochemical conversion techniques (Lawal et al., 2021).

Table 3. Elemental composition of dry biomass from the studied species, %

Indices	*Sida hermaphrodita*	*Zea mays*
Carbon	46.03	44.06
Hydrogen	5.94	5.65
Nitrogen	0.32	0.95
Sulphur	0.08	0.21

The main constituents of dry biomass are carbon (C), oxygen (O) and hydrogen (H). As carbon and hydrogen are oxidised in the combustion process, they release energy. Carbon is obviously representing foremost contributions to overall heating value. Furthermore, higher hydrogen content determines and leads to a higher net caloric value (Demirbaş, 2007). Nitrogen (N), sulphur (S) and chlorine (Cl) contents are some of the main causes of air pollution from biomass combustion. A higher percentage of these elements generally results in a higher level of air contaminants being released. The average elemental composition of studied species biomass is presented in Table 3. We found that *Sida hermaphrodita* '*Energo*' biomass is characterized by an optimal content of carbon (46.03%) and hydrogen (5.94%), and very low content of nitrogen (0.32 %) and sulphur (0.08%), as compared with *Zea mays* stalks.

Stolarski et al. (2014) found that *Sida hermaphrodita* biomass contained 46.08-48.89% C, 5.46-5.80% H, 0.023-0.038% S. Howaniec and Smolinski (2011) reported the nitrogen and sulphur contents in the biomass of *Sida hermaphrodita* to be at rather low levels, i.e. 0.01% N and 0.04% S, while Šiaudinis et al. (2015) and Krička et al. (2017) determined nitrogen to be 0.75% and sulphur 0.17-0.29%, respectively. Kron et al. (2017) remarked that harvested biomass contained 40.94-43.74% C, 5.68-6.44% H, 0.77-1.62% N, 0.03-0.10 % S and 49.14-51.26% O. Bilandžija et al. (2018) mentioned that the *Sida hermaphrodita* biomass harvested in March contained 18.64% moisture, 1.94% ash, 50.08% C, 6.10% H, 0.65% N, 0.10% S.

Majlingova et al. (2021) reported that *Sida hermaphrodita* contained 43.74% C, 5.68% H, 0.77% N, 0.24 % S and 50.96% O.

Voicea et al., 2013, mentioned that corn stalks contained 1.8% ash, 50% C, 6.2% H, 0.6% N, 43.10% O, 0.9% S, but Antonenko et al. (2018) - 6.37% ash, 42.76% C, 5.36% H, 1.17% N, 39.83% O, 0.23% S, respectively.

Particle size distribution is one of the most important physical properties of solid biomass that is used in biofuel processing. Therefore, biomass size reduction and related particle physical property quantification are indispensible in investigating the biomass feedstock supply-conversion chain. Fractional composition of chopped dry stem mass is presented in Table 4. Having evaluated the fractional composition of chopped mass, we may see that the highest fraction of *Sida hermaphrodita* '*Energo*' mass accumulated on a sieve with holes of 3.15-8.00 mm diameter – 54.1%, and the lowest amount accumulated on a sieve with holes of 16.00-31.50 mm diameter – 13.0%. At the same time, the highest fraction of *Zea mays* – 50.3% –accumulated on a sieve with holes of 8.00-16.00 mm diameter.

Table 4. Particle size distribution of chopped dry stem mass from the studied species, %

Particle size	*Sida hermaphrodita*	*Zea mays*
<3.15mm	14.1	5.0
3.15-8.00 mm	54.1	24.2
8.00-16.00mm	18.7	50.3
16.00-31.50 mm	13.1	20.5

To enhance packing density of biomass and produce pellets and briquettes, for instance, biomass feedstock has to be ground into 3-8 mm particles before compacting the material into a denser product (Mani et al., 2006). Particle size reduction and its distribution is an important parameter used for handling, storage, conversion, dust control systems and the combustion of biomass solid fuels. In the case of Virginia mallow milled chaffs, the highest percentage of particles obtained by us was larger than 3 mm (30.1%), and the lowest – particles with a size of 1 mm (13.3%). Moreover, the proportion of 1-3 mm particles was relatively high in the case of milled corn chaffs (Table 5). This is probably an effect of the anatomical structure of *Sida hermaphrodita* stalks; the high level of pith microstructures and the fibre content in biomass influences the passage of particles through the sieve meshes.

Table 5. Particle size distribution of milled stem chaffs from the studied species, %

Particle size	*Sida hermaphrodita*	*Zea mays*
<5mm	3.0	0.5
4-5mm	8.9	1.4
3-4mm	18.2	10.4
2-3mm	34.2	34.3
1-2mm	21.9	32.0
1mm	13.3	21.4

One of the most economically advantageous methods of densification is pelletization. Thus, raw biomass can be converted into pellets with improved fuel quality, such as increased bulk density, and even shape and size. Pelletized fuels are also more consistent in their structure, which is beneficial for the automated fuel system in the corporate and individual boilers.

The physical and mechanical properties of biomass and pellets from *Sida hermaphrodita* '*Energo*' is illustrated in Table 5. Ash content is one of the main factors of biomass quality, since higher amounts of ash decrease the quality of fuels, especially solid ones. The Virginia mallow biomass is characterized by very low ash content (2.1%), lower than corn stalks (4.4%), excellent gross calorific value (19.73 MJ/kg), which is higher than that of corn stalks (17.84 MJ/kg), due to the total stem defoliation and higher concentrations of cellulose, hemicellulose and lignin. The bulk density of the *Sida hermaphrodita* '*Energo*' chopped chaffs reached 130 kg/m^3 and milled chaffs – 204 kg/m^3. The specific density of the pellets made from Virginia mallow milled chaffs reached 870 kg/m^3 and the bulk density – 570 kg/m^3, so, they had still lower density than corn pellets, perhaps because of the anatomical structure of this plant. Thus, most of the particles of *Sida hermaphrodita* milled chaffs were larger than 3 mm.

Table 6. Some physical and mechanical properties of biomass and pellets

Indices	*Sida hermaphrodita*	*Zea mays*
Ash content of biomass, %	1.87	4.40
Gross calorific value, MJ/kg	19.73	17.84
Density of chopped mass, kg/m^3	130	87
Density of milled chaffs, kg/m^3	204	165
Specific density of pellets, kg/m^3	870	1174
Bulk density of pellets, kg/m^3	570	701

Some authors mentioned various findings about the physical and mechanical properties of *Sida hermaphrodita* biomass and pellets. Nahm & Morhart (2018) reported average high heating values of 18.4 MJ/kg and low heating values of 16.1 MJ/kg. According the review of Cumplido-Marin et al. (2020), the energy value of stems ranged from 15.0 MJ/kg low heating values to 19.4 MJ/kg high heating values. Jankowski et al. (2019) noted an increase of the energy value with the age of the *Sida hermaphrodita* plantation, from 18.5 to 19.4 MJ/kg HHV. Jablonowski et al. (2017) mentioned that calculated values for the energy yield of biomass used as solid fuel varied from 19.2 to 19.6 MJ/kg HHV and 16.62 to 16.96 MJ/kg LHV. Siaudinis et al. (2015) reported that Virginia mallow pellets had an average density of 969.3 kg/m^3. Zajac, et al. (2017) remarked that *Sida* pellets contained 7.1% moisture, 2.9% ash, 82.69% volatile materials, 48.1 % C, 5.78% H, 0.42% N, 0.07% S, 19.08 MJ/kg HHV and 16.80 MJ/kg LHV. Jablonowski et al. (2020) mentioned that *Sida hermaphrodita* pellets contained 7.1% water, 3.59% ashes, 1.1% N, 0.04% S, and reached a density of 662 kg/m^3 and low heating values of 16.13–17.21 MJ/kg. Styks et al. (2020) reported that specific density of pellets from *Sida* raw material in grain size below 1 mm varied from 860 to 980 kg/m^3 depending on the compaction pressure and moisture content. Majlingova et al. (2021) reported that *Sida hermaphrodita* had 18.75 MJ/kg HHV and 13.35 MJ/kg LHV. Antonenko et al. (2018) remarked that corn stalks had 18.4 MJ/kg HHV or 17.1 MJ/kg LHV.

Biofuels such as bioethanol are an alternative to fossil fuels that is gaining popularity. Bioethanol is produced through sugar fermentation by some microorganisms. Second generation bioethanol produced from lignocellulosic biomass is attracting attention as an alternative energy source and it is currently a topic of great interest for researchers around the world. From structural point of view, lignocellulose is basically composed of secondary cell walls of structural and parenchymatous plant tissues. The structure of lignocellulose consists of cellulose, the skeleton of which is surrounded by hemicellulose and lignin. The contents of these components vary significantly depending on the plant species, type of biomass and harvesting period. The effective decomposition of lignocellulose biomass should be preceded by conversions of these polysaccharides into monosaccharides.

Table 7. The composition of cell walls and the theoretical ethanol potential of Sida hermaphrodita 'Energo' dry matter

Indices	*Sida hermaphrodita*	*Zea mays*
Acid detergent fibre, g/kg	687	499
Neutral detergent fibre, g/kg	928	749
Acid detergent lignin, g/kg	131	87
Cellulose, g/kg	556	417
Hemicellulose, g/kg	241	250
Hexose sugars, g/kg	99.0	75.1
Pentose sugars, g/kg	39.6	41.1
Theoretical ethanol potential, L/t	578	485

Analyzing the cell wall composition of dehydrated stems, Table 7, we could mention that the concentrations of structural carbohydrates in *Sida hermaphrodita* '*Energo*' substrate are much higher in comparison with *Zea mays* substrate. The analysis of lignocellulose composition suggested that the dry matter of the whole *Sida hermaphrodita*

'*Energo*' plants contained 556 g/kg cellulose, 241 g/kg hemicellulose and 131 g/kg acid detergent lignin, but corn stalks – 417 g/kg cellulose, 250 g/kg hemicellulose and 82 g/kg acid detergent lignin. The estimated content of monosaccharides in Virginia mallow biomass was 99.0 g/kg pentose sugars and 39.6 g/kg hexose sugars, but in corn stalks – 75.1 g/kg and 41.1 g/kg, respectively. The estimated theoretical ethanol yield from cell wall carbohydrates averaged 578 L/t in *Sida hermaphrodita* '*Energo*' substrate, as compared with 485 L/t in corn substrates.

Several literature sources describe the composition of cell walls in energy biomass and ethanol potential. Kricka et al. (2017) remarked that the contents of cellulose, hemicellulose, and lignin in *Sida hermaphrodita* biomass were about 40.1%, 27.2% and 26.4%, respectively. Majlingova et al. (2021) reported that *Sida hermaphrodita* contained 17.92% lignin, 36.30% cellulose and 44.00% hemicellulose. For sorghum crop, the theoretical ethanol potential ranged from 560 to 610 L/t of dry biomass (Goff et. al., 2010).

CONCLUSIONS

The substrate prepared from green mass of *Sida hermaphrodita* '*Energo*' contains about 160 g/kg CP, 84 g/kg ash, 371 g/kg ADF, 529 g/kg NDF, 60 g/kg ADL, 311 g/kg cellulose and 158 g/kg hemicellulose, and its biochemical biomethane potential averages 272 l/kg ODM.

The harvested Virginia mallow dry stalks contain 46.03% carbon, 5.94% hydrogen, 0.32% nitrogen, 0.08% sulphur, 1.87% ash, 556 g/kg cellulose, 241 g/kg hemicellulose and 131 g/kg acid detergent lignin.

The theoretical ethanol yield from structural carbohydrates averages 578 L/t in Virginia mallow substrate and 485 L/t – in corn substrate.

The gross calorific value of the biomass consisting of Virginia mallow stalks is on average 19.73 MJ/kg, but – of corn stalks 17.8 MJ/kg.

The specific density of densified solid fuel – pellets – made from *Sida hermaphrodita* '*Energo*' milled chaffs reached 870 kg/m^3 and the bulk density – 570 kg/m^3.

Sida hermaphrodita cv. '*Energo*' can serve as multi-purpose feedstock for renewable energy production.

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