PERENNIAL HERBACEOUS SPECIES *SIDA HERMAPHRODITA* AND *POLYGONUM SACHALINENSE* FOR RENEWABLE AND SUSTAINABLE ENERGY IN THE REPUBLIC OF MOLDOVA

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Abstract. *The sources of renewable energy have acquired considerable interest in recent years, at global and national level. The investigation of introduced herbaceous plant species for further processing into diverse types of bio fuels is an important objective. We investigated the biochemical composition and some thermo physical properties of the biomass of local varieties of non native perennial herbaceous plant species: Energo of Sida hermaphrodita and Gigant of Polygonum sachalinense, created and cultivated in the Botanical Garden (Institute) of the Academy of Sciences of Moldova, maize (Zea mays) – control variant. It has been established that the gas forming potential of digestible organic dry matter from the green mass substrate of the studied perennial species varied from 454 to 460 l/kg and 451-458 l/kg – of silage substrate; in maize substrate – 536 l/kg and 557 l/kg. Polygonum sachalinense substrate had higher content of methane (54.6 %) and methane production potential (4000-4850 m^3/ha). The biomass of the studied perennial species was characterized by high bulk density (172-225 kg/m^3) and gross calorific value (18.7-19.3 MJ/kg) and reduced ash content (1.5-2.6 %), but maize stalks – by low bulk density (152 kg/m^3) and calorific value (17.9 MJ/kg) and high content of ash (4.6 %); the gross calorific value, as a solid fuel, accounted 350-435 GJ/ha. The dry biomass of local varieties was characterized by high content of cellulose (511-535 g/kg), hemicellulose (256 -307g/kg), pentose sugars (91-96 g/kg) and hexose sugars (47-51 g/kg), in comparison with maize stalks (417 g/kg; 250 g/kg; 75 g/kg and 41 g/kg). The theoretical ethanol potential was 19-26 % higher and constituted 557-614 l/t dry matter. The obtained results indicate the possibility of using the local varieties Energo of Sida hermaphrodita and Gigant of Polygonum sachalinense for the creation of plantations to produce biomass energy for multiple purposes in Moldova.*

Key words: *biochemical composition, bio methane, pellets, Polygonum sachalinense, Sida hermaphrodita, theoretical ethanol potential, thermo physical properties*

INTRODUCTION

The sources of renewable energy acquire considerable interest. In recent years, at global and national level, greater attention has been paid to the use of biomass for energy production, due to the depletion of fossil resources. Plant species are efficient users of solar energy for converting CO_2 into biomass (EL BASSAM, 2010).

The Republic of Moldova has few fossil energy resources, so being forced to import near 86 %, depending entirely on the supplying countries. Therefore, the issue of renewable energy sources was and still is an actual one. According to the Energy Strategy of the Republic of Moldova (2013), the total amount of energy produced from renewable sources should be increased to 20 % by the year 2020 and energy from biomass will make ¾ of this amount. Forests in Moldova cover less than 13 % of the territory; it becomes relevant to explore the suitability of using various types of biomass as renewable energy sources. The climatic conditions from the years 2007, 2012, 2015, which had serious consequences on the development of agriculture, revealed that only on the basis of agricultural remains – cereal straw, sunflower stalks and husk, maize stalks and cobs, the problem of biomass supply cannot be solved. This fact which has determined the orientation of the research and innovation policy towards identifying new plant species by analyzing their productivity, environmental impact, economic efficiency and ensuring that they didn't affect the food supply of the population. For biomass production on industrial scale, the most efficient crops that use to a great extent the photosynthetically active radiation (PAR) during the growing season, accumulate a considerable amount of dry matter and demand optimal expenses for establishment and low expenses for maintenance, harvesting and processing, should be selected and implemented.

Over more than half a century, as a result of the mobilization, introduction and acclimatization researches done in the Botanical Garden (Institute) of the ASM, collections and exhibitions of plants with multiple uses, necessary for the development of the national economy, were founded. Valorisation of plant resources for biofuel production is a new research direction in the Botanical Garden. *Sida hermaphrodita* and *Polygonum sachalinense* are two perennial species that have received considerable attention for use as bioenergy feedstock in Europe.

Virginia mallow or Pennsylvanian malva, *Sida hermaphrodita* (L.) Rusby (syn. *Napaea hermaphrodita* L.) fam. *Malvaceae* Juss., polycarpic perennial herb, native to the south-eastern parts of North America, where it naturally grows in moist riverine habitats, has a bushy shape, with densely branched root and with a few dozen of stems with the length of 400 cm and diameter of 5 to 35 mm. For the first time, *Sida hermaphrodita* was brought to Europe in 1930 and introduced in Ukraine as fodder and fibre crop (RAKHMETOV, 2011).

The Sakhalin knotweed or giant knotweed, *Polygonum sachalinense* F. Schmidt (syn. *Fallopia sachalinensis* Ronse Decr., *Reynoutria sachalinensis* Nakai, *Tiniaria sachalinensis* Janch., *Pleuropterus sachalinensis* Moldenke) fam. *Polygonaceae* Juss. is widespread in the wild flora of northern Japan, Sakhalin Island and Kurile Islands, is a herbaceous perennial plant growing up to 2–4 m tall, with strong, extensively spreading rhizomes forming large clonal colonies. It appears in Europe the second half of the 19th century, being implemented as a crop during the 20th century due to its tolerance to the soil climatic factors and stable productivity, serving as fodder from early spring until late autumn. This species is a natural source of secondary metabolite compounds, which possesses biological activity (IVANOVA AND ȚÎȚEI, 2014). From different plant organs, there have been isolated the compounds of stilbene group (resveratrol and its glycoside derivatives) and flavonoids, phenylpropanoids and its glycoside derivatives (FAN ET AL., 2010).

Currently, the species *Sida hermaphrodita* and *Polygonum sachalinense* are studied in different academic centres and universities and implemented as crops with multiple use in different regions of the Earth (RAKHMETOV, 2011; OLESZEK ET AL., 2013; FRANZARING ET AL., 2014; STOLARSKI ET AL., 2014; JABLONOWSKI ET AL., 2016).

The objective of the present study has been to determine biochemical composition, thermo physical properties**,** the productivity and usability of biomass from *Sida hermaphrodita* and *Polygonum sachalinense* for multiple energy purposes in Moldova.

MATERIALS AND METHODS

The local varieties: *Energo* of Virginia mallow (*Sida hermaphrodita*) and *Gigant* of Sakhalin knotweed (*Polygonum sachalinense*), created in the Botanical Garden (Institute) of the Academy of Sciences of Moldova, registered in the in the Catalogue of Plant Varieties and patented by the State Agency on Intellectual Property of the Republic of Moldova (BOPI 9/2016) were used as research subjects, *Porumbeni 458* of maize (*Zea mays*) – as control variant.

The experiments were performed on experimental land from the Botanical Garden (Institute) of the ASM. The growth and development of plants as well as their productivity were assessed according to methodical indications NOVOSELOV ET AL., 1983. The green mass of *Sida hermaphrodita* was harvested in the budding stage (the 1st mowing in June and the 2nd mowing in September), *Polygonum sachalinense* - stage of branching of the stem (the 1st mowing in late May and the 2nd mowing in late August), *Zea mays* – in kernel milk-wax stage. Dry biomass was collected in December to early March. The yield was measured by weighing.

The green mass was shredded and compressed in well-sealed glass containers; the silage was prepared and evaluated in accordance with the Moldavian standard SM 108. After 45 days, the containers were opened. The biochemical composition of the green mass and silage was determined by PETUKHOV ET AL., 1989. The dry matter or total solid (TS) content was detected by drying samples up to constant weight at 105 °C. Crude protein – by Kjeldahl method, crude fat – by Soxhlet method, crude cellulose – by Van Soest method, ash – in muffle furnace at 550 °C. The nitrogen-free extract (NFE) was mathematically appreciated, as the difference between organic matter values and analytically assessed organic compounds. Organic dry matter or volatile solids (VS) were calculated through differentiation, the crude ash being subtracted from dry matter. The biogas and biomethane, litre per kg of volatile solids (L /kg VS), were calculated using the gas forming potential of nutrients according to BASERGA, 1998, corrected for the index of digestible nutrients.

The moisture content of biomass was determined by CEN/TS 15414, in an automatic hot air oven MEMMERT100-800. The content of ash was determined at 550 °C in a muffle furnace HT40AL, according to CEN/TS 15403. An automatic calorimeter LAGET MS-10A with accessories was used for the determination of calorific value, according to CEN/TS 15400. The harvested dry biomass was milled with aperture sizes of 6 mm and processed into pellets by the equipment for the production of bio fuels, developed in the Institute of Agricultural Technique "Mecagro", Republic of Moldova. The cylindrical containers were used for the determination of bulk density, calculated by dividing the mass over the container volume. 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.

The content of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were evaluated using the near infrared spectroscopy (NIRS) technique of the Research-Development Institute for Grassland Brasov, Romania. Ethanol yields from structural material were calculated according to the equations of GOFF ET AL., 2010 based on NDF, ADF and ADL values corrected for moisture concentration.

H = [% Cellulose + (% Hemicellulose x 0.07)] x 172.82

P = [% Hemicellulose x 0.93] x 176.87

Theoretical Ethanol Potential (L/t) = [H + P] x 4.17

H and P are theoretical ethanol production from the conversion of hexose and a pentose sugars, cellulose is ADF minus ADL, and hemicellulose is NDF minus ADF.

RESULTS AND DISCUSSIONS

In our previous papers, we mentioned that the seedlings of local varieties of studied perennial species, after being transplanted in the field, in the first 30-45 days of the growing season, had a slow rate of growth and development of aerial parts. Then, the rate was accelerating, and the flower bud formation started at end of August or in September. In the soil, there was developed the tap root system, which consisted of a main root, lateral roots and viable forms of rhizomes with dormant buds. The majority of the roots were concentrated in the soil layer of 5…30 cm, but some roots penetrated to a depth of 65…70 cm. The stems grew about 164-171 cm tall and 6-13 mm thick at the base, the productivity of green mass reached 23-28 t/ha or 5-6 t/ha dry matter, with high leaf content, 48 % leaves. In the second year and the in further years of vegetation, in spring, when the air temperature exceeded 6 °C, the local varieties of studied perennial species, started the plant development from generative buds, which went through all stages of ontogenetic development, finishing with seed formation and growth of a larger number of stems in a bush. A high rate of growth of stems was observed during late April to May (4-8 cm/day), in early June, plants reached a height of 290-350 cm, depending on the weather conditions. We observed that stems of cv. *Gigant* of *Polygonum sachalinense* were significantly taller and thicker than the plants of cv. *Energo* of *Sida hermaphrodita*. The research data demonstrated that the studied perennial species were characterized by intensive growth and development, which allowed obtaining up to 45.7-79.1 t/ha at the 1st mowing, and by the capacity to recover fast after mowing. The annual yield (90 -124 t/ha) largely depended on the weather conditions, harvesting period and number of mowing cycles in a season (IVANOVA AND ŢÎŢEI, 2014; ŢÎŢEI, 2015; ŢÎŢEI AND TELEUŢĂ, 2014)

A high aerial biomass productivity of *Sida hermaphrodita* plants was also mentioned in other studies. So, RAKHMETOV (2011) stated that, in the conditions of Ukraine, *Sida hermaphrodita* could have a productivity of 123.9-187.7 t/ha natural fodder depending on the genotype.

For the implementation of new plant species, it is necessary to assess their productivity and quality in comparison with traditional crops. Maize, *Zea mays*, is a well-known and appreciated energy crop (EL BASSAM, 2010). Organic dry matter is an important factor, influencing biogas and methane yield. Analyzing the results of the determination of the organic dry matter from the green mass and silage substrate of the studied perennial species and its biochemical composition, we saw that it differed from *Zea mays* (Tab.1). The amount of digestible organic dry matter in the green mass substrate varied from 577.0 to 597.7 g/kg and silage substrate - 574.9 to 579.3 g/kg , in comparison with 673.3- 695.6 g/kg in maize substrates. We can state that the dry matter of *Sida hermaphrodita* and *Polygonum sachalinense* had high content of digestible proteins, but inferior level of digestible carbohydrates as compared with *Zea mays*. The gas forming potential of digestible organic dry matter from green mass substrate of the studied perennial species varied from 454 to 460 l/kg and 451-458 l/kg of silage substrate, in maize – 536 l/kg and 557 l/kg. The calculated methane content in the biogas ranged from 53.1 to 54.6 %. The best results of annual methane production, 4000-4850 m^3/ha, were achieved by *Polygonum sachalinense* substrate, in comparison with 4000-4050 m^3/ha, produced by *Sida hermaphrodita*. The maize substrates had a higher gas forming potential, but it was distinguished by reduced productivity and methane content.

Table 1.

The biochemical composition and the gas forming potential of the studied species

Indices	*Sida hermaphrodita*		*Polygonum sachalinense*		*Zea mays*	
	green mass	silage	green mass	silage	green mass	silage
Organic dry matter (ODM), g/kg	926.9	912.3	924.7	919.9	954.5	957.4
Digestible ODM , g/kg	577.0	579.3	597.7	574.9	673.3	695.6
Digestible proteins, g/kg	95.4	75.6	133.4	120.9	41.5	34.6
Digestible fats, g/kg	15.1	14.4	21.2	17.0	17.4	23.3
Digestible carbohydrates, g/kg	466.5	489.3	443.1	437.0	614.4	637.7
Biogas, l/kg ODM	454	458	460	451	536	557
Biomethane, l/kg ODM	244	243	251	246	278	292
Methane, %	53.7	53.1	54.6	54.6	51.9	52.4
Methane production, m^3/ha	4050	4000	4850	4000	3296	3127

The biogas batch tests with *Sida hermaphrodita* showed a potential of 435 l/kg ODM from silage made from biomass harvested in July, or 220 l/kg methane (OLESZEK ET AL., 2013).

The stems of the studied perennial species quickly dry in autumn-winter; they are resistant, cannot be flattened easily and can be used to produce solid fuels. The heating value of solid biofuel depends on humidity and mineral content. The leaves have higher ash content than the stems. The rate of tissue dehydration and fall of the leaves from stems were investigated in order to determine the optimal period of biomass harvesting. At the end of the growing season and with the establishment of temperatures below 0 °C, the leaves of the studied species fell and the tissues dehydrated rapidly. The degree of foliage of *Polygonum sachalinense*, at the end of the growing season (October) was about 25 %, while the degree of foliage of *Sida hermaphrodita* and *Zea mays* – 20 %. Over 15-35 days, depending on weather conditions, *Sida hermaphrodita* and *Polygonum sachalinense* stems were completely defoliated, while the leaves of *Zea mays* were kept for a long time. *Sida hermaphrodita*, in field, dehydrated faster than *Polygonum sachalinense* (Tab. 2). The biomass of the studied perennial species was characterized by high bulk density (172-225 kg/m^3 dry matter) and gross calorific value (18.7-19.3 MJ/kg abs. dry mass) and reduced content of ash (1.5-2.6 %), but maize stalks – by low bulk density (152 kg/m^3 dry matter) and calorific value (17.9 MJ/kg dry matter) and high content of ash (4.6 %). For the plants grown in Poland, the respective gross calorific values of *Sida hermaphrodita* and *Polygonum sachalinense* were 18.71-18.91 MJ/kg and 18.90-19.05 MJ/kg (STOLARSKI ET AL., 2014), in Germany *Sida hermaphrodita* - 19.5 MJ/kg (JABLONOWSKI ET AL., 2016).

The low density of biomass materials poses a challenge for the handling, transportation, storage and combustion processes. These problems may be addressed through densification, a process that produces solid fuel with denser and more uniform properties than the raw biomass.

It has been established that the specific and bulk density of *Zea mays* pellets was significantly higher. We could mention that the specific and bulk density of pellets made from milled chaffs of *Sida hermaphrodita* was low (487 kg/m^3 dry matter) in comparison with *Polygonum sachalinense* (570 kg/m^3), probably because of the high content of fibre. According to STOLARSKI ET AL., 2005, in the bulk density of pellets produced from *Salix* spp. biomass was 635.6 kg/m^3, whereas in that of the pellets from *Sida hermaphrodita* biomass was lower – 517.2 kg/m^3. The potential of energy production of the studied species constituted 350-435 GJ/ha (Tab. 2). The total heating value of *Sida hermaphrodita*, as a solid fuel, accounted 447 GJ/ha (JABLONOWSKI ET AL., 2016).

Table 2.

Thermophysical properties of biomass and the potential of energy production of the studied species

Indices	*Sida hermaphrodita*	*Polygonum sachalinense*	*Zea mays*
Humidity of the stems December, %	17	23	16
Humidity of the stems January, %	13	18	12
Humidity of the stems March, %	9	13	8
Bulk density of the chopped stems, kg/m^3	172	225	152
Ash content, %	1.5	1.5	4.6
Gross calorific value, MJ/kg	18.7	19.3	17.9
Specific density of pellets, kg/m^3	744	923	1033
Bulk density of pellets, kg/m^3	487	570	617
Potential of energy production, GJ/ha	350	435	90
- equivalent coal, t	13	16	3.3
- equivalent to conventional oil, t	9	11	2.2

Biomass composition, in addition to yield, determines biofuel yield potential from second- and third-generation conversion technologies. Cellulosic ethanol production makes use of the structural sugar polymers found in the cell wall of plants, cellulose and hemicellulose, as sugar sources for microbial fermentation. Cellulose is composed solely of linked six-carbon glucose monomers, while hemicellulose is composed primarily of the five-carbon sugar xylose with a significant percentage of glucose and minor amounts of other five- and six-carbon sugars (VERMERRIS ET AL., 2007).

Analyzing the cell wall composition of dehydrated stems of local varieties perennial species, we could mention that cellulose ranged from 511 to 535 g/kg, hemicellulose ranged from 256 to 307 g/kg (Tab. 3). Cellulose and hemicellulose concentrations were greater in *Sida hermaphrodita* biomass, as compared with *Polygonum sachalinense.* It has been found that cellulose concentrations in *Polygonum sachalinense* stems were significantly higher, but hemicellulose concentrations do not significantly differ from maize stalks.

Table 3.

The cell wall composition and the theoretical ethanol potential of the studied species

Indices	*Sida hermaphrodita*	*Polygonum sachalinense*	*Zea mays*
Cellulose, g/kg	535	511	417
Hemicellulose, g/kg	307	256	250
Hexose sugars, g/kg	96.17	91.40	75.09
Pentose sugars, g/kg	51.07	42.10	41.12
Theoretical ethanol potential, l/t	614.0	557.0	485.0
Theoretical ethanol yield, l/ha	11670	12800	2420

Total ethanol yields are influenced by a several factors, including yields and tissue composition. Higher yields increase the amount of biomass available for hydrolysis, but ratios of cellulose, hemicellulose and lignin are also important. Thus, based on cell wall composition of dehydrated stems, the theoretical ethanol potential from structural sugars per unit of dry biomass averaged 614 l/t for *Sida hermaphrodita*, which was greater than *Polygonum sachalinense* at 557 l/t, compared to 485 l/t maize stalks. For sorghum crop theoretical ethanol potential ranged from 560 to 610 l/t of dry biomass (GOFF ET AL., 2010). Theoretical ethanol yield studied perennial species ranged from 11 670 to 12 800 l/ha depending on variety and total biomass yield. For giant miscanthus biomass, estimated theoretical ethanol yields 12 400 l/ha (SOMERVILLE ET AL., 2010).

CONCLUSIONS

The local varieties of studied perennial species differ in productivity and biochemical composition of the harvested mass, which have influenced the methane yield. The gas forming potential of digestible organic matter from green mass substrate made from the studied perennial species varied between 454 and 460 l/kg and 451-458 l/kg – of silage substrate; in maize substrate – 536 l/kg and 557 l/kg. *Polygonum sachalinense* substrate had higher content of methane (54.6 %) and methane production yield (4000-4850 m^3/ha).

The harvested dry biomass of the studied perennial species was characterized by high bulk density (172-225 kg/m^3) and gross calorific value (18.7-19.3 MJ/kg) and reduced content of ash (1.5-2.6 %), but maize stalks – by low bulk density (152 kg/m^3) and calorific value (17.9 MJ/kg) and high content of ash (4.6 %). The gross calorific value, as a solid fuel, accounted 350-435 GJ/ha.

The dehydrated stems of local varieties were characterized by high content of cellulose (511-535 g/kg), hemicellulose (256 -307g/kg), pentose sugars (91-96 g/kg) and hexose sugars (47-51 g/kg), in comparison with maize stalks (417 g/kg; 250 g/kg; 75 g/kg and 41 g/kg). The theoretical ethanol potential was 19-26 % higher and constituted 557-614 l/t dry matter. The theoretical ethanol yield ranged from 11 670 to 12 800 l/ha depending on variety and total biomass yield.

The obtained results indicate the possibility of using the local varieties *Energo* of *Sida hermaphrodita* and *Gigant* of *Polygonum sachalinense* for the creation of plantations, in Moldova, to produce energy biomass for multiple purposes.

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