EVALUATION OF BIOMASS QUALITY OF ENERGY CROPS *POLYGONUM SACHALINENSE* 'GIGANT' AND *SILPHIUM PERFOLIATUM* 'VITAL' GROWN UNDER THE CONDITIONS OF THE REPUBLIC OF MOLDOVA
/
EVALUAREA CALITĂȚII BIOMASEI DIN CULTURILE ENERGETICE DE POLYGONUM SACHALINENSE 'GIGANT' ȘI SILPHIUM PERFOLIATUM 'VITAL' CULTIVATE ÎN CONDIȚIILE REPUBLICII MOLDOVA

Victor ȚÎȚEI
"Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, Chisinau/ Republic of Moldova;
*Tel.: 37367192266, *E-mail: vic.titei@gmail.com*
DOI: https://doi.org/10.35633/inmateh-77-112

Keywords: *biomass, energy crops, quality indices, Polygonum sachalinense 'Gigant', Silphium perfoliatum 'Vital'*

ABSTRACT
Replacing fossil fuels with renewable energy alternatives has become a major global challenge of the 21st century and a key element of sustainable development. Phytomass has considerable potential as a source of energy and value-added products within the circular economy. This study aimed to evaluate the quality indices of fresh whole-plant biomass harvested during the flowering period and dry stem biomass collected in early spring from the perennial energy crops cup plant (Silphium perfoliatum 'Vital') and giant knotweed (Polygonum sachalinense 'Gigant') cultivated in the experimental plots of the National Botanical Garden, Chișinău. The fresh biomass contained 289-375 g/kg DM, with 10.8-11.7% CP, 6.0-8.3% ADL, 31.6-39.3% Cel, 21.3-23.9% HC, and 8.4-11.1% ash, while the biomethane yield ranged from 270 to 310 L/kg VS. The dry stem biomass collected in early spring contained 522-563 g/kg Cel, 234-248 g/kg HC, 110-128 g/kg ADL, and 2.61-4.24% ash, with an estimated theoretical ethanol yield of 558-578 L/t VS. Densified biomass fuels, including briquettes and pellets, exhibited a high calorific value. The local cultivars of perennial energy crops Silphium perfoliatum 'Vital' and Polygonum sachalinense 'Gigant' represent versatile and promising raw materials for renewable energy production in the Republic of Moldova.

REZUMAT
Înlocuirea combustibililor fosili cu surse alternative de energie regenerabilă a devenit o problemă globală majoră în secolul XXI și o cheie spre dezvoltarea durabilă. Fitomasa are un potențial înalt pentru a fi utilizată drept sursă de energie și produse cu valoare adăugată în economia circulară. Scopul prezentului studiu a constat în evaluarea indicilor calitativi a plantelor recoltate în perioada de înflorire și a biomasei tulpinilor uscate colectate primăvara devreme de la culturile energetice perene silfia Silphium perfoliatum 'Vital' și hrișca de Sahalin Polygonum sachalinense 'Gigant', cultivate pe terenul experimental al Grădinei Botanice Naționale din Chişinău. S-a determinat că substratul din plantele proaspăt recoltate conține 289-375 g/kg masă uscată cu o concentrație de 10.8-11.7% proteină brută, 6.0-8.3% lignină detergent acid, 31.6-39.3% celuloză, 21.3-23.9% hemiceluloză, 8.4-11.1% cenușă și potențialul biochimic de biometan variază de la 270 până la 310 l/kg materie organică uscată. S-a stabili că biomasa de tulpini uscate colectată în primele zile a primăverii conținea 522-563 g/kg celuloză, 234-248 g/kg hemiceluloză, 110-128 g/kg lignină detergent acid, 2.61-4.24% cenușă iar potențialul teoretic de etanol fiind de 558-578 L/t materie organică uscată. Combustibillii densificați în formă de brichete și peleți, posedă o valoare calorică înaltă. Soiurile locale de plante energetice perene 'Silphium perfoliatum 'Vital' și Polygonum sachalinense 'Gigant' reprezintă o materie primă versatilă și promițătoare pentru producerea energiei regenerabile în Republica Moldova.

INTRODUCTION
The increase in population has an impact on increasing food and energy demand. Concerns regarding fluctuating petroleum and natural gas prices, greenhouse gas emissions and the need for energy independence represent a driving force pushing research towards alternate sources.

Replacing fossil fuels with renewable energy alternatives has become a major global issue of the 21th century and a key to sustainable development. Biomass continues to be the most important type of renewable energy source (RES), used as feedstock for solid, liquid and gaseous biofuels, for the production of electricity, heating and transport fuel. In energy terms, biomass provides the major share (75%) of the energy component (~60%) of the EU's renewable energy mix. These trends are expected to continue under The European Green Deal proposed by the current European Commission. There are various types of biomass, including forest biomass, agricultural residues, energy crops and waste biomass (*Andersen et al., 2021; El Bassam, 2010; NECPs, 2019*).

The Republic of Moldova imports nearly 95 % petroleum and natural gas, its energy security depending entirely on external suppliers. Therefore, the issue of biomass as a renewable energy source is still relevant. The use of the gene pool of local and introduced plant species as feedstock for renewable energy production is a new direction of research initiated in 2009 at the "Alexandru Ciubotaru" National Botanical Garden (Institute). As a result of the research conducted, a collection of plants with energy biomass potential was established, consisting of 117 taxa from 17 families, including annual and perennial, herbaceous and woody species. These taxa can contribute to the utilization of marginal lands and low-quality soils, including eroded and salinized areas, among others (*Țîței, 2020; Țîței and Roșca, 2021)*.

High potential lies in perennial herbaceous species for energy biomass production from the botanical families *Asteraceae* and *Polygonaceae*, which have been on rise in recent years (*Daraduda, 2024; El Bassam, 2010; Rakhmetov, 2018; Roman et al., 2016; Von Cossel et al., 2021)*.

Sakhalin knotweed, or giant knotweed, *Polygonum sachalinense* F. Schmidt (syn. *Fallopia sachalinensis* Ronse Decr., *Reynoutria sachalinensis* Nakai, *Tiniaria sachalinensis* Janch., *Pleuropterus sachalinensis* Moldenke), family *Polygonaceae* Juss., is widespread in the wild flora of eastern Russia, northern Japan, and China. It is a herbaceous perennial plant characterized by an erect, hollow stem with 10-18 internodes, branched in the upper part and green to brown in colour. The leaves are arranged alternately along the stem; they are simple, petiolate, with an entire leaf blade. The leaves are dark green, broadly ovate, measuring 20-38 cm in length and 15-20 cm in width, with an acuminate apex, slightly wavy margins, and pinnate-reticulate venation. Long multicellular hairs are present on the veins on the underside of the leaves. The flowers are small, actinomorphic, and hermaphroditic, rarely unisexual, with a simple creamy-white perianth and 6-8 stamens; the filaments are proximally flattened and glabrous. The styles are fused at the base, and the stigmas are fringed. Flowers are arranged in panicle inflorescences. The fruit is a trigonous, brown, oval achene, measuring 2.8-4.5 mm in length and 1.1-1.8 mm in width, with a smooth, glossy surface. The thousand-seed weight averages 1.2-1.6 g. The underground organs consist of a main root and creeping rhizomes bearing thin adventitious roots. The potential productivity reaches up to 100 t/ha of fresh biomass and 20-25 t/ha of dry biomass. The species is an important source of pollen and nectar for bees, producing 30-70 kg/ha of honey *(Țîței and Roșca, 2021)*. Giant knotweed was introduced to Europe in the second half of the 19th century and was used as a forage crop during the 20th century due to its tolerance to soil and climatic conditions and its stable productivity, providing livestock feed from spring until the onset of negative temperatures in autumn. The species is also a natural source of biologically active compounds *(Ivanova and Țîței, 2014)*. Stilbene compounds (resveratrol and its glycosidic derivatives), as well as flavonoids, phenylpropanoids, and their glycosides, have been isolated from various plant organs *(Fan et al., 2010)*.

A promising introduced species from the *Asteraceae* family is the cup plant, *Silphium perfoliatum* L., which occurs naturally in eastern and central North America. In the second half of the 18th century, *Silphium perfoliatum* was introduced to Western Europe as an ornamental plant, and during the 20th and 21st centuries it has been cultivated as a forage and energy biomass crop in various regions of the world. Cup plant (*Silphium perfoliatum*) is a perennial, herbaceous, polycarpic species characterized by an erect, quadrangular, pubescent stem, branched in the upper part, reaching a height of 250-370 cm and a basal diameter of 2-4 cm. The leaves are light green and cordate, measuring 25-35 cm in length and 16-22 cm in width, and are arranged oppositely along the stem. The lower leaves are petiolate, whereas the upper leaves are broadly winged and fused around the stem, forming a cup-like structure that enables efficient utilization of moisture and sunlight. The inflorescence consists of 20-30 yellow capitula, each 3-5 cm in diameter, and the flowering period lasts 51-60 days. Owing to its prolonged flowering period, this species has a high melliferous potential, producing 150-220 kg/ha of honey. The fruit is a brown-grey winged achene, with a thousand-seed weight of 22-24 g, and seed yield ranges from 290 to 450 kg/ha. Cup plant develops a deep taproot system, reaching depths of up to 3.5 m *(Țîței and Roșca, 2021)*.

Currently, the species *Polygonum sachalinense* and *Silphium perfoliatum* are studied in various scientific centres and universities and are implemented as agricultural crops with multiple uses in different regions of the world (*Auerswald et. al.,* 2025; *Bury et. al.,* 2020; *Cîrlig, 2019; Costea et. al., 2025*; *Daraduda, 2024; Cumplido-Marin et. al., 2020; Gazoulis, 2025; Höller, 2022; Ivanova et. al., 2015; Klimek et. al., 2016; Kowalska et. al., 2020, 2022; Mueller et. al., 2020; Ruf & Emmerling, 2022; Stolarski et al. 2014, 2023; Sumalan et. al., 2023; Peni et. al., 2020, 2022; Ţîţei, 2014, 2020; Wu et. al., 2020*).

The aim of the study was to evaluate the quality indices of fresh whole-plant biomass for biomethane production, as well as dry stem biomass as raw material for the production cellulosic bioethanol and solid densified biomass fuels, briquettes and pellets, obtained from the perennial energy crops, *Silphium perfoliatum* 'Vital' and *Polygonum sachalinense* 'Gigant'.

MATERIALS AND METHODS

The local cultivars of perennial energy crops developed at the "Alexandru Ciubotaru" National Botanical Garden (Institute) MSU, registered in the Catalogue of Plant Varieties in 2012* and patented by the AGEPI- State Agency on Intellectual Property (BOPI, 2016)** of the Republic of Moldova: cultivar 'Gigant' of giant knotweed *Polygonum sachalinense* and cultivar 'Vital' of cup plant *Silphium perfoliatum* cultivated in the experimental plot of the National Botanical Garden Chişinău, N 46°58′25.7″ latitude and E 28°52′57.8″ longitude, served as the research material.

Fig. 1 - 'Gigant' *Polygonum sachalinense*

Fig. 2 - 'Vital' *Silphium perfoliatum*

Whole plants of *Polygonum sachalinense* 'Gigant' and *Silphium perfoliatum* 'Vital', in the seventh year of growth, were manually harvested during the flowering period in August. Subsequently, the whole plants were chopped using a stationary forage chopper to a particle size of 12-25 mm. The dry matter (DM) or total solids (TS) content was determined by drying samples to constant weight at 105 °C. For biochemical analyses, samples were oven-dried at 60 °C, ground to <1 mm, and homogenized. The biochemical composition of the phytomass was evaluated by determining crude protein (CP), crude ash (CA), acid detergent fibre (ADF), neutral detergent fibre (NDF), and acid detergent lignin (ADL). These parameters were measured using near-infrared spectroscopy (NIRS) with a PERTEN DA 7200 analyser at the Research and Development Institute for Grassland, Brașov, Romania. Additional parameters were calculated as follows: cellulose content was estimated as ADF minus ADL, and hemicellulose content as NDF minus ADF. The carbon (C) content of the biomass was calculated using the empirical equation proposed by *Badger et al. (1979)*. The biochemical methane potential (BMP) was estimated according to the method described by *Dandikas et al. (2015)*.

Fig. 3 - 'Gigant' *Polygonum sachalinense*

Fig. 4 - 'Vital' *Silphium perfoliatum*

The dry stems of *Polygonum sachalinense* 'Gigant' and *Silphium perfoliatum* 'Vital' were manually harvested in early March. The harvested stems were chopped into chaff using a stationary chopping unit. For pellet production, the chopped biomass was milled in a beater mill (SV7) equipped with a 4 mm sieve, whereas for briquette production a 10 mm mesh sieve was used. Biomass densification, including briquetting and pelleting, was carried out using *Briklis BrikStar 50* and *MLG 200* equipment at the Laboratory of Biosolid Fuel, Technical University of Moldova. The quality indices of dry stem biomass, briquettes, and pellets were determined according to *Marian (2016)*. The cell wall fractions were determined using near-infrared spectroscopy (NIRS). The theoretical ethanol potential (TEP) was calculated based on the equations proposed by *Goff et al. (2010)*, considering the conversion of cellulose and hemicellulose into hexose (H) and pentose (P) sugars.

RESULTS AND DISCUSSIONS

Analysis of selected agrobiological traits of the tested perennial energy crops, *Polygonum sachalinense* cultivar 'Gigant' and *Silphium perfoliatum* cultivar 'Vital', during the seventh vegetation season, showed that vegetation onset was uniform in mid-March. The appearance of generative shoots in *Polygonum sachalinense* 'Gigant' was observed in the first part of April, whereas in *Silphium perfoliatum* 'Vital' it occurred at the end of April. The tested perennial energy crops also differed in their growth and developmental rhythms. The onset of the flowering stage in *Silphium perfoliatum* 'Vital' was recorded in the first part of July, while in *Polygonum sachalinense* 'Gigant' it occurred in the first half of August. During the flowering stage, the shoots of *Silphium perfoliatum* 'Vital' reached heights of 240-289 cm, whereas those of *Polygonum sachalinense* 'Gigant' reached 365-383 cm.

Among the options for valorising phytomass as biofuel, biogas production is of particular importance, as it can partially replace natural gas for the generation of electricity and heat, as well as serve as a transport fuel. Biogas is obtained through anaerobic digestion in biogas reactors under controlled temperature regimes, using specific microbial consortia. This process results in the production of biogas, mainly composed of methane and carbon dioxide, and a residual digestate rich in macro- and micronutrients, which is widely used as an organic fertilizer in ecological agriculture. The biochemical composition of the phytomass from the tested energy crops and their biochemical methane potential are summarized in Table 1. The fresh phytomass of the tested energy crops contained 289-375 g/kg dry matter, with 10.8-11.7% crude protein, 6.0-8.3% acid detergent lignin, 31.6-39.3% cellulose, and 21.3-23.9% hemicellulose. The fresh phytomass of Polygonum *sachalinense* 'Gigant' exhibited a higher dry matter content compared to that of *Silphium perfoliatum* 'Vital'. In contrast, the fresh phytomass of *Silphium perfoliatum* 'Vital' was characterized by a significantly higher crude protein content and a lower proportion of cell wall components than that of *Polygonum sachalinense* 'Gigant'. Furthermore, the ash content was higher in the fresh phytomass of *Polygonum sachalinense* 'Gigant'.

It is well known that the carbon-to-nitrogen (C/N) ratio is a key factor influencing the efficiency of anaerobic digestion in biogas reactors and the biomethane production potential. C/N ratios higher than 30:1 are considered unsuitable for optimal anaerobic digestion, while ratios lower than 10:1 may be inhibitory due to low pH, poor buffering capacity, and high ammonia concentrations in the substrate. The C/N ratios of the investigated fresh phytomass from the tested energy crops did not differ substantially, ranging from 27.18 to 28.61, and thus met the requirements for optimal anaerobic digestion. As mentioned above, the fresh phytomass of *Polygonum sachalinense* 'Gigant' contained higher cellulose and acid detergent lignin contents and lower hemicellulose content compared to *Silphium perfoliatum* 'Vital', a factor that may influence the activity of methanogenic microorganisms. The biochemical methane potential of the investigated fresh phytomass varied considerably, ranging from 270 to 310 L/kg organic matter or 240 to 284 L/kg dry matter. The BMP of fresh phytomass from *Silphium perfoliatum* 'Vital' was significantly higher than that of *Polygonum sachalinense* 'Gigant'.

Data on the biomethane production potential of substrates derived from *Polygonum sachalinense* and *Silphium perfoliatum* are available in the specialized literature. According to *Haag et al. (2015)*, the specific methane yield of cup plant substrate measured in a continuous test was 227 L/kg organic matter, whereas in a batch test it reached 251 L/kg organic matter. *Höller (2022)* reported that the studied accessions of *Silphium perfoliatum* achieved dry matter yields of 13.6-17.2 t/ha, with 38.73-42.75% ADF, 5.81-6.56% acid detergent lignin, and 8.86-9.40% ash, while the specific methane yield ranged from 258.4 to 273.0 L/kg organic matter, corresponding to 3697-4634 m^3/ha of methane. *Lehtomäki (2006)* found that giant knotweed biomass harvested during the flowering period contained 303 g/kg dry matter, 283 g/kg organic matter, 1.2% nitrogen, 47.2% carbon, and 28.0% lignin, with a methane yield of 270 L/kg organic matter. *Peni et al. (2022)* reported that methane production differed significantly depending on the type of *Silphium perfoliatum* substrate, ranging from 193.59 to 243.61 L/kg organic matter.

In our previous studies *(Ţîţei, 2014, 2020, 2023; Ţîţei and Roşca, 2021)*, it was established that the biochemical methane production potential of substrates derived from *Polygonum sachalinense* ranged from 250 to 340 L/kg organic matter, while those from *Silphium perfoliatum* ranged from 280 to 330 L/kg organic matter. *von Cossel et al. (2021)* reported that *Silphium perfoliatum* substrate contained 44.6% acid detergent fibre, 52.0% neutral detergent fibre, 6.7% acid detergent lignin, 37.9% cellulose, 7.4% hemicellulose, and 9.2% ash, with a specific methane yield of 264.7 L/kg organic matter. *Witaszek et al. (2022)* observed that untreated lignocellulosic biomass of *Silphium perfoliatum* contained 665.6 g/kg dry matter, 82.53% organic matter, 21.62% lignin, 30.96% cellulose, and 22.6% hemicellulose, resulting in a methane yield of 204 L/kg organic matter. In contrast, treated biomass exhibited 725.9-903.4 g/kg dry matter, 83.47-87.74% organic matter, 19.71-23.68% lignin, 21.07-30.49% cellulose, and 18.41-20.56% hemicellulose, with methane yields increasing to 244-255 L/kg organic matter.

Table 1

Quality indices of fresh phytomass substrates and biomethane production potential of the studied energy crops

Index	*Polygonum sachalinense* 'Gigant'	*Silphium perfoliatum* 'Vital'
Nitrogen, [g/kg DM]	17.28	18.72
Crude protein, [g/kg DM]	108.00	117.00
Ash, [g/kg DM]	110.00	84.00
Organic matter, [g/kg DM]	890.00	916.00
Carbon, [g/kg DM]	494.44	508.89
Carbon/ Nitrogen ratio	28.61	27.18
Acid detergent fibre, [g/kg DM]	476.00	376.00
Neutral detergent fibre, [g/kg DM]	689.00	615.00
Acid detergent lignin, [g/kg DM]	83.00	60.00
Cellulose, [g/kg DM]	393.00	316.00
Hemicellulose, [g/kg DM]	213.00	239.00
Biomethane potential, [L/kg ODM]	270	310
Biomethane potential, [L/kg DM]	240	284

The studied perennial energy crops, *Polygonum sachalinense* 'Gigant' and *Silphium perfoliatum* 'Vital', differed in the rhythm of stem dehydration and defoliation during the autumn-winter period. At the end of the growing season, following the establishment of temperatures below 0 °C in November, the stems of *Polygonum sachalinense* were completely defoliated, whereas the leaves of *Silphium perfoliatum* were retained for a longer period. Consequently, at harvest time, in the first days of March, leaves accounted for approximately 15% of the total biomass of *Silphium perfoliatum*. Under field conditions, the rate of stem dehydration was faster in *Silphium perfoliatum* 'Vital' than in *Polygonum sachalinense* 'Gigant'. During winter, the stems of both studied perennial energy crops proved to be structurally resistant, were not easily flattened, and could be harvested and utilized for the production of liquid and solid biofuels. Plant height, stem thickness, leaf-to-stem ratio, dry matter content, and biochemical composition have a significant influence on energy yield and on the selection of appropriate technologies for liquid and solid biofuel production. It is well known that, due to its irregular shape, heterogeneous particle size, and low bulk density, phytomass is difficult to handle, transport, store, and utilize in its original form. Densification of phytomass into durable compacts, such as pellets and briquettes, represents an effective solution to these limitations. The quality indices of dry stem biomass and solid densified fuels obtained from the studied energy crops are presented in Table 2. The moisture content of the stems of the tested energy crops ranged from 9.49% in *Polygonum sachalinense* 'Gigant' to 10.64% in *Silphium perfoliatum* 'Vital', while the ash content varied from 2.61% in *Polygonum sachalinense* 'Gigant' to 4.24% in *Silphium perfoliatum* 'Vital'. The bulk density of chopped and milled biomass as well as the net calorific value of both raw biomass and solid fuels derived from *Polygonum sachalinense* 'Gigant' were higher compared with those obtained from *Silphium perfoliatum* 'Vital'. This difference is likely related to the morphological structure of *Silphium perfoliatum* 'Vital' plants, which is characterized by a higher proportion of leaves and pith tissues in the total biomass.

The cell wall composition of phytomass, in addition to productivity, determines the energy yield potential of second- and third-generation conversion technologies. Second-generation bioethanol produced from phytomass is attracting increasing attention as an alternative transport fuel and represents an area of intensive research interest *(Premjet et al., 2013)*.

Cellulosic ethanol production utilizes the structural polysaccharides of the plant cell wall, namely cellulose and hemicellulose, as sugar sources for microbial fermentation. Cellulose is composed exclusively of linked six-carbon glucose monomers, whereas hemicellulose consists primarily of the five-carbon sugar xylose, along with significant proportions of glucose and smaller amounts of other five- and six-carbon sugars *(Vermerris et al., 2007)*. The contents of cellulose, hemicellulose, and lignin depend on the type of energy crop and the harvesting period. Effective conversion of lignocellulosic biomass requires prior depolymerization of these polysaccharides into fermentable monosaccharides.

The results regarding the biochemical composition and theoretical ethanol potential of dehydrated stem substrates from the studied energy crops are presented in Table 3. The cell wall composition of the dehydrated stem substrates ranged between 522-563 g/kg cellulose, 234-248 g/kg hemicellulose, and 110-128 g/kg acid detergent lignin. The estimated theoretical ethanol yield derived from cell wall carbohydrates averaged 558.8-578.1 L/t. The dehydrated stem substrate of *Polygonum sachalinense* 'Gigant' was characterized by a higher cellulose content, lower hemicellulose content, and consequently a higher theoretical ethanol potential compared to the substrate of *Silphium perfoliatum* 'Vital'.

Table 2

Quality indices of dry stem biomass and solid densified biomass fuels obtained from the studied energy crops

Index	*Polygonum sachalinense* 'Gigant'	*Silphium perfoliatum* 'Vital'
Moisture content of chopped biomass, [%]	9.49	10.64
Bulk density of chopped chaff, [kg/m^3]	76.40	58.80
Bulk density of milled biomass for briquettes, [kg/m^3]	175.60	122.80
Bulk density of milled biomass for pellets, [kg/m^3]	178.40	142.80
Ash content of biomass, [%]	2.61	4.24
Volatile matter, [%]	80.09	76.40
Gross calorific value of biomass, [MJ/kg]	18.82	18.54
Net calorific value of biomass, [MJ/kg]	17.48	17.21
Bulk density of briquettes, [kg/m^3]	618.57	533.20
Bulk density of pellets, [kg/m^3]	708.40	555.00
Net calorific value of briquettes, [MJ/kg]	15.37	15.03
Net calorific value of pellets, [MJ/kg]	15.27	15.11

Table 3

Biochemical composition and theoretical ethanol potential of the substrates from the studied energy crops

Index	*Polygonum sachalinense* 'Gigant'	*Silphium perfoliatum* 'Vital'
Acid detergent fibre, [g/kg DM]	691.00	632.00
Neutral detergent fibre, [g/kg DM]	925.00	880.00
Acid detergent lignin, [g/kg DM]	128.00	110.00
Cellulose, [g/kg DM]	563.00	522.00
Hemicellulose, [g/kg DM]	234.00	248.00
Ash content of biomass, [g/kg DM]	26.10	42.40
Theoretical ethanol potential from hexose sugars, [L/t ODM]	417.54	388.69
Theoretical ethanol potential from pentose sugars, [L/t ODM]	160.51	170.11
Theoretical ethanol potential of biomass, [L/t ODM]	578.05	558.80

Numerous studies have reported data on the quality indices of dry stem biomass and densified biomass fuels derived from the energy crops *Polygonum sachalinense* and *Silphium perfoliatum*. According to *Bury et al.* (2020), *Silphium perfoliatum* biomass contained 3.10-4.08% ash, 33.7-34.5% carbon, 1.37-1.62% nitrogen, 0.06-0.07% phosphorus, 0.08-0.09% potassium, and 0.05-0.09% sulphur, with a higher calorific value of 16.26-16.95 MJ/kg. *Gramauskas et al. (2023)* reported that the density of giant knotweed pellets (moisture content 5–8%) reached 1227.47 kg/m^3, while that of briquettes was 615.60 kg/m^3, with an ash content of 4.28% and a calorific value of 17.73 MJ/kg. *Papamatthaiakis et al. (2021)* showed that pellets produced from *Fallopia sachalinensis* var. 'Igniscum' exhibited a bulk density of 677.71 kg/m^3, ash content of 1.5%, mechanical durability of 92.86%, and an energy content of 19.97 MJ/kg at a moisture content of 5%. Furthermore, *Peni et al. (2022b)* reported that *Silphium perfoliatum* biomass contained 8.47% ash, 24.47%

cellulose, 14.80% hemicellulose, 8.29% lignin, 18.51% fixed carbon, and 73.02% volatile matter, with a higher heating value of 17.73 MJ/kg.

Premjet et al. (2013) presented the results of an investigation of 75 plant species for bioenergy and bioethanol production and reported that ash content varied from 2.6 to 17.5%, lignin from 4.6 to 20.4%, cellulose from 18.8 to 56.0%, and hemicellulose from 3.3 to 34.2%. The lower calorific value ranged from 12.5 to 18.5 MJ/kg, while the bioethanol yield varied between 239.2 and 584.4 L/t. *Ruf and Emmerling (2022)* reported that harvest residues (stubbles) from cup plant contained 10.5% hemicellulose, 20.6-31.6% cellulose, and 8.2-11.7% lignin, whereas residues from silage maize contained 16.6-20.0% hemicellulose, 24.2-41.3% cellulose, and 10.1-11.2% lignin. *Stolarski et al. (2014)* found that giant knotweed stalks harvested in March contained 2.70% ash and had a gross calorific value of 18.90 MJ/kg, while cup plant stalks contained 3.04% ash and exhibited a gross calorific value of 18.70 MJ/kg. *Streikus et al. (2017)* reported that pellets produced from giant knotweed biomass contained 4.3% ash, had a bulk density of 509.9 kg/m³, a specific density of 1227.3 kg/m³, and a net calorific value of 18.96 MJ/kg.

Šurić et al. (2022) reported that *Silphium perfoliatum* biomass contained 5.86% ash, 15.49% coke, 9.28% fixed carbon, and 74.45% volatile matter, with a higher heating value of 15.46 MJ/kg and a lower heating value of 14.54 MJ/kg. In previous studies *(Ţîţei, 2020, 2023; Ţîţei and Roșca, 2021)*, it was found that dry stem biomass of *Polygonum sachalinense* contained 45.18% carbon, 5.44% hydrogen, 0.28% nitrogen, 0.07% sulphur, 2.38-2.51% ash, 25.6% hemicellulose, 51.1% cellulose, and 12.2% acid detergent lignin, with a higher calorific value of 19.0-19.3 MJ/kg. In contrast, stem biomass of *Silphium perfoliatum* contained 45.02% carbon, 5.96% hydrogen, 0.21% nitrogen, 0.03% sulphur, 3.03–3.83% ash, 29.2% hemicellulose, 56.2% cellulose, and 11.4% acid detergent lignin, with a higher calorific value of 17.8-18.3 MJ/kg. *Tóth (2022)* reported that the lignocellulosic composition and calorific value of *Silphium perfoliatum* biomass ranged between 31.3-48.94% acid detergent fibre, 7.21-12.54% acid detergent lignin, 24.11-37.30% cellulose, 2.33-5.75% hemicellulose, and 34.94-54.69% neutral detergent fibre, with a higher heating value of 15.21-16.79 MJ/kg.

Wiatrowska et al. (2022) reported that the chemical composition and energy value of *Reynoutria sachalinensis (Polygonum sachalinense)* dry biomass included 20.09% pentosans, 29.57% cellulose, 29.80% hemicellulose, 19.17% lignin, 21.16% soluble fraction, and 5.77% ash, with a gross calorific value of 19.927 MJ/kg, a net calorific value of 18.405 MJ/kg, and an ethanol yield of 104.6 g/kg. For *Reynoutria japonica*, the corresponding values were 15.98% pentosans, 31.94% cellulose, 20.87% hemicellulose, 20.18% lignin, 16.14% soluble fraction, and 9.49% ash, with 18.485 MJ/kg gross and 16.965 MJ/kg net calorific values, and an ethanol yield of 48 g/kg. In the case of *Reynoutria × bohemica*, biomass contained 20.51% pentosans, 31.71% cellulose, 34.48% hemicellulose, 19.41% lignin, 19.72% soluble fraction, and 6.58% ash, with 19.210 MJ/kg gross and 17.683 MJ/kg net calorific values, and an ethanol yield of 48 g/kg. Finally, *Witaszek et al. (2022)* reported that lignocellulosic biomass of *Silphium perfoliatum* with a moisture content of 7.17% exhibited a heat of combustion of 15.78 MJ/kg and a calorific value of 14.08 MJ/kg.

CONCLUSIONS

The local cultivars *Polygonum sachalinense* 'Gigant' and Silphium perfoliatum 'Vital' are suitable for the establishment of industrial biomass energy plantations. Their cultivation and phytomass harvesting do not require sophisticated machinery, unlike short-rotation woody crops, and can be performed using conventional agricultural equipment for fodder crops. Low ash and moisture contents enhance fuel combustibility, while high bulk density facilitates transportation, and a high pelletizing yield improves the efficiency of the pellet production process.

The phytomass of *Polygonum sachalinense* 'Gigant' and *Silphium perfoliatum* 'Vital' can be utilized as fresh whole-plant biomass for biomethane production, while dehydrated stems can serve as raw material for the production of solid densified biomass fuels and cellulosic ethanol.

The biochemical methane potential was significantly higher in the phytomass substrate of *Silphium perfoliatum* 'Vital'. In contrast, the stem substrate of *Polygonum sachalinense* 'Gigant' was characterized by lower ash content, higher net calorific value, greater bulk density, and a higher ethanol potential.

ACKNOWLEDGEMENTS

The study has been carried out in the framework of the project: 20.80009.5107.02 "*Mobilization of Plant Genetic Resources, Plant Breeding and as Forage, Melliferous and Energy Crop in Bioeconomy*" and the subprogramme 01.01.02 *"Identification of Valuable Forms of Plant Resources with Multiple Uses for the Circular Economy"*

REFERENCES

[1] Andersen S.P., Allen B., Domingo G.C. (2021). Biomass in the EU Green Deal: Towards consensus on the use of biomass for EU bioenergy. Policy report, Institute for European Environmental Policy (IEEP). *https://ieep.eu/uploads/articles/attachments/a14e272d-c8a7-48ab-89bc-31141693c4f6/Biomass%20in%20the%20EU%20Green%20Deal.pdf?v=63804370211*

[2] Auerswald K., Oberneder A., Wiesmeier M., Ebertseder F., & Fritz M. (2025). Erosion impact of cup plant (*Silphium perfoliatum* L.) stands established with and without nurse crop. *Soil Use and Management,* 41, e70047. *https://doi.org/10.1111/sum.70047*

[3] Badger C.M., Bogue M.J., & Stewart D.J., (1979). Biogas production from crops and organic wastes. *New Zealand Journal of Science*, 22 (1), 11-20.

[4] Bury M., Możdżer E., Kitczak T., Siwek H., & Włodarczyk M. (2020). Yields, caloric value and chemical properties of cup plant *Silphium perfoliatum* L. biomass, depending on the method of establishing the plantation. *Agronomy*, 10(6), 851; *https://doi.org/10.3390/agronomy10060851*

[5] Cîrlig N. (2019). *Biology of the species Reynoutria sachalinensis (F.Schmidt) Nakai (Polygonaceae Juss.) under the conditions of the Republic of Moldova (Biologia speciei Reynoutria sachalinensis (F.Schmidt) Nakai (Polygonaceae Juss.) în condiţiile Republicii Moldova).* PhD dissertation, “Alexandru Ciubotaru” National Botanical Garden (Institute), Chisinau/Republic of Moldova. *http://www.cnaa.md/files/theses/2019/55518/natalia_cirlig_thesis.pdf*

[6] Costea M., Danci M., Sumalan R. (2025). Developing an "in vitro" propagation protocol for Silphium perfoliatum. *Journal of Horticulture, Forestry and Biotechnology,* 29(2), 1-9.

[7] 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*, 10, 67. *https://doi.org/10.3390/agronomy10070928.*

[8] Daraduda N. (2024). *Exploiting the biomass of energy crops for producing densified solid biofuels* PhD thesis in engineering sciences *(Valorificarea biomasei culturilor energetice pentru producerea biocombustibililor solizi densificaţi).* PhD dissertation, Technical University of Moldova, Chisinau/Republic of Moldova. *https://anacec.md/files/Daraduda-teza.pdf*

[9] El Bassam, N. (2010). *Handbook of bioenergy crops: a complete reference to species, development and applications.* ISBN 978-1-84407-854-7 Earthscan, London, UK. *https://nishat2013.files.wordpress.com/2013/11/handbook-of-bioenergy-crops.pdf*

[10] European Commission. National Energy and Climate Plans (NECPs) (2019). *https://ec.europa.eu/info/energy-climate-change-environment/overall-targets/national-energy-and-climate-plans-necps_en*

[11] Fan P., Terrier L., Hay A. E., Marston A., & Hostettmann K. (2010). Antioxidant and enzyme inhibition activities and chemical profiles of *Polygonum sachalinensis* F. Schmidt ex Maxim (Polygonaceae). *Fitoterapia*, 81(2), 124-131. *DOI: 10.1016/j.fitote.2009.08.019*

[12] Gazoulis I., Pyliou K., Kokkini M., Danaskos M., Kanatas P., & Travlos I. (2025). Cup plant (*Silphium perfoliatum*): Agronomy, Uses, and Potential Role for Land Restoration. *Land*, 14(6), 1307. *https://doi.org/10.3390/land14061307*

[13] Goff B. M., Moore K. J., Fales L., & Heaton A. (2010). Double-cropping sorghum for biomass. *Agronomy Journal*, 102(6), 1586-1592. *DOI: 10.2134/agronj2010.0209*

[14] Gramauskas G., Jasinskas A., Kleiza V., Mieldažys R., Blažauskas E., & Souček J. (2023). Evaluation of invasive herbaceous plants utilization for the production of pressed biofuel. *Processes*, *11*(7), 2097. *https://doi.org/10.3390/pr11072097*

[15] Haag N.L., Nägele H.J., Reiss K., Biertümpfel A., & Oechsner H. (2015). Methane formation potential of cup plant (*Silphium perfoliatum*). *Biomass Bioenergy*, 75, 126–133. *DOI: 10.1016/j.biombioe.2015.02.012*

[16] Höller M.G. (2022). *Phenotypic analysis of different Silphium perfoliatum L. accessions and evaluation as a renewable resource for material use*. PhD dissertation, Universitäts-und Landesbibliothek, Bonn/ Germany. *https://bonndoc.ulb.uni-bonn.de/xmlui/handle/20.500.11811/10441*

[17] Ivanova R., & Ţîţei V. (2014). Biological characteristics and accumulation of polyphenolics in *Polygonum sachalinense* introduced in the flora of the Republic of Moldova. *Oltenia. Studii şi comunicări. Ştiinţele Naturii*, 30(1), 53-56. *https://biozoojournals.ro/oscsn/cont/30_1/09_Ivanova_pp53-56.pdf*

[18] Ivanova T., Muntean A., Titei V., Havrland B., & Kolarikova M. (2015). Energy crops utilization as an alternative agricultural production. *Agronomy Research*, 13(2), 311-317. https://agronomy.emu.ee/vol132/AgronomyResearch_vol_13_number_2.pdf

[19] Kowalska G., Pankiewicz U., & Kowalski R. (2020). Evaluation of chemical composition of some *Silphium* L. species as alternative raw materials. *Agriculture*, 10, 132. doi:10.3390/agriculture10040132

[20] Kowalska G., Baj T., Kowalski R., & Hanif M.A. (2022). Characteristics of selected *Silphium* species as alternative plants for cultivation and industry with particular emphasis on research conducted in Poland: A Review. *Sustainability*, 14, 5092 https://doi.org/10.3390/su14095092

[21] Lehtomäki A. (2006). *Biogas production from energy crops and crop residues*. University of Jyväskylä ISBN 951-39-2559-5, Jyväskylä/ Finland. 91.

[22] Marian G. (2016). *Solid biofuels, production and properties (Biocombustibilii solizi, producere şi proprietăţi)*. Chişinău: S. n., ISBN 978-9975-87-166-2, Chisinau/Republic of Moldova. 172. https://www.undp.org/sites/g/files/zskgke326/files/2024-07/biocombustibili_solizi.pdf

[23] Mueller A.L., Berger C.A., Schittenhelm S., Stever-Schoo B., & Dauber J. (2020). Water availability affects nectar sugar production and insect visitation of the cup plant *Silphium perfo*liatum L. (Asteraceae). *Journal of Agronomy and Crop Science*, 206, 529–537. https://doi.org/10.1111/jac.12406

[24] Papamatthaiakis N., Laine A., Haapala A., Ikonen R., Kuittinen S., Pappinen A., Kolström, M., & Mola-Yudego B. (2021). New energy crop alternatives for Northern Europe: yield, chemical and physical properties of Giant knotweed (*Fallopia sachalinensis* var. 'Igniscum') and Virginia mallow (*Sida hermaphrodita*). *Fuel*, 304, 121349. 10.1016/j.fuel.2021.121349.

[25] Peni, D., Debowski M., & Stolarski M.J. (2022a). Influence of the fertilization method on the *Silphium perfoliatum* biomass composition and methane fermentation efficiency. *Energies* 15, 927. https://doi.org/10.3390/en15030927

[26] 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.

[27] Peni, D., Stolarski M.J., & Debowski M. (2022b). Green biomass quality of perennial herbaceous crops depending on the species, type and level of fertilization. *Industrial Crops and Products, 184, 115026* https://doi.org/10.1016/j.indcrop.2022.115026

[28] Premjet S., Pumira B., & Premjet D. (2013). Determining the potential of inedible weed biomass for bio-energy and ethanol production. *BioResourses,* 8(1), 701-716. DOI: 10.15376/biores.8.1.701-716

[29] Rakhmetov D. (2018). *Non-traditional plant species for bioenergetics (*Нетрадиционные виды растений для биоэнергентики). ISBN 978-80-552-1855-7, University of Agriculture in Nitra, Nitra/ Slovak. 103. https://doi.org/10.15414/2018.fe-9788055218557

[30] Roman Gh. V., Ion V., Epure L.I., & Băşă A. Gh. (2016). *Biomass. Alternative Energy Source (Biomasa. Sursă alternativă de energie),* Universitară Publishing House, ISBN 978-606-28-0506-7, DOI: 10.5682/978-606-28-0506-7, Bucharest /Romania, 432.

[31] Ruf T., & Emmerling C. (2022). Biomass partitioning and nutrient fluxes in *Silphium perfoliatum* and silage maize cropping systems. *Nutrient Cycling in Agroecosystems*, 124, 389–405. https://doi.org/10.1007/s10705-022-10242-0

[32] Siwek H., Włodarczyk M., Możdżer E., Bury M., & Kitczak T. (2019). Chemical composition and biogas formation potential of *Sida hermaphrodita* and *Silphium perfoliatum*. *Applied Sciences*, 9, 4016. doi:10.3390/app9194016

[33] Stolarski M.J., Krzyżaniak M., & Olba-Zięty E. (2024). Energy efficiency of *Silphium perfoliatum* and *Helianthus salicifolius* biomass production. *Energy*, 307, 132592. DOI: 10.1016/j.energy.2024.132592

[34] Stolarski M.J., Krzyzaniak M., Snieg M., Slominska E., Piórkowski M., & Filipkowski R. (2014): Thermophysical and chemical properties of perennial energy crops depending on harvest period. *International Agrophysics*, 28, 201-211. doi: 10.2478/intag-2014-0009

[35] Streikus D., Jasinskas A., Domeika R., Čekanauskas S., Pedišius N., Vonžodas T., & Annuk A. (2017). Evaluation of Giant Knotweed and Miscanthus as perspective energy plants and assessment of produced biofuel quality indicators. In *International scientific conference Rural Development,* 448-452. DOI: 10.15544/RD.2017.004

[36] Sumalan R.L., Nescu V., Berbecea A., Sumalan R.M., Crisan M., Negrea P., & Ciulca S. (2023). The impact of heavy metal accumulation on some physiological parameters in *Silphium perfoliatum* L. plants grown in hydroponic systems. *Plants*, *12*(8), 1718. https://doi.org/10.3390/plants12081718

[37] Šurić J., Šic Žlabur J., Peter A., Brandić I., Voća S., Dujmović M., Leto J., & Voća N. (2022). Energy vs. nutritional potential of virginia mallow (*Sida hermaphrodita* L.) and cup plant (*Silphium perfoliatum* L.). *Plants*, 11, 2906. *https://doi.org/10.3390/plants112129 06*

[38] Ţîţei V. (2014). Biological peculiarities of cup plant (*Silphium perfoliatum* L.) and utilization possibilities in the Republic of Moldova. *Lucrări Ştiinţifice*, seria *Agronomie*, 57 (1), 289-293. *https://www.uaiasi.ro/revagrois/PDF/2014-1/paper/2014-57(1)_55-en.pdf*

[39] Ţîţei V. (2020). 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 de biomasă energetică: realizări și perspective*). *Journal of Bot*any, 2 (21), 92-105. *DOI: https://doi.org/10.52240/1857-2367.2020.2(21).9*

[40] Ţîţei V. (2023). The mobilization of energy crop resources in Moldova. *Romanian Agricultural Research*, 40, 646-654. *https://www.incda-fundulea.ro/rar/nr40/rar40.3.pdf*

[41] Ţîţei 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 potenţial de biomasă energetică: Ghid practic pentru producătorii agricoli)*. Chişinău: S. n., ISBN 978-9975-87-778-7 Chisinau/Republic of Moldova. 80.

[42] Tóth S. (2023). Ligno-cellulose quality and calorific value of green phytomass of *Silphium perfoliatum* L. cultivated on marginal soils under conditions of moderate continental climate of Central Europe. *Journal of Central European Agriculture*, 24(2), 391-402 *DOI: /10.5513/JCEA01/24.2.3707*

[43] Vermerris W., Saballos A., Ejeta G., Mosier N.S., Ladisch M.R., & Carpita N.C. (2007). Molecular breeding to enhance ethanol production from corn and sorghum stover. *Crop Science*, *47*, S-142*. DOI: 10.2135/cropsci2007.04.0013IPBS*

[44] Von Cossel M. (2019). *Agricultural diversification of biogas crop cultivation.* PhD dissertation, University of Hohenheim, Stuttgart/Germany. *https://opus.unihohenheim.de/volltexte/2019/1600/.*

[45] Von Cossel M., Pereira L.A., & Lewandowski I. (2021). Deciphering substrate-specific methane yields of perennial herbaceous wild plant species. *Agronomy* 11, 451. https://doi.org/10.3390/agronomy11030451

[46] Wiatrowska B. M., Wawro A., Gieparda W., & Waliszewska B. (2022). Bioethanol production potential and other biomass energy properties of invasive *Reynoutria, Solidago*, and *Spiraea* plants. *Forests*, *13*(10), 1582. *https://doi.org/10.3390/f13101582*

[47] Witaszek K., Herkowiak M., Pilarska A.A., & Czekała W. (2022). Methods of handling the cup plant (*Silphium perfoliatum* L.) for Energy Production. Energies, 15, 1897. *https://doi.org/10.3390/en15051897*

[48] Wöhl L., Kemmann B., Ruf T., Emmerling C., Well R., & Schrader S. (2025). Earthworm-controlled CO_2, N_2O and N_2 emissions from a silt loam soil amended with senescent litter of two energy crops (*Silphium perfoliatum* and *Zea mays*). *Plant and Soil*, 1-23. *10.1007/s11104-025-07696-w*.

[49] Wu H., Shang H., Guo Y., Zhang H., & Wu H. (2020). Comparison of different extraction methods of polysaccharides from cup plant (*Silphium perfoliatum* L.). *Process Biochemistry*, 90, 241–248*. DOI: 10.1016/j.procbio.2019.11.003*

[50] ****The Catalog of Plant Varieties of Republic of Moldova. (Catalogul soiurilor de plante pentru anul 2024)* Chisinau/Republic of Moldova. *https://cstsp.md/uploads/files/Catalog%202024.pdf*

[51] ****The Official Bulletin of Intellectual Property (BOPI) Republic of Moldova (Buletin Oficial de Proprietate Intelectuală)* (2016). Chisinau/Republic of Moldova. *http://agepi.gov.md/ro/bopi/9-2016*