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BIOLOGICAL FEATURES AND BIOMASS QUALITY OF SOME *Helianthus* SPECIES UNDER THE CONDITIONS OF THE REPUBLIC OF MOLDOVA

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Abstract

The genus Helianthus Asteraceae family comprising 71 species of annual and perennial plants, most of them native to North America and Central America. The species Helianthus annuus, Helianthus mollis, Helianthus strumosus Helianthus tuberosus, which grow in the "Alexandru Ciubotaru" National Botanical Garden (Institute), Chisinau, Republic of Moldova served as research subjects. It was found that the researched species had different growth and development rates, which affected the accumulation of biomass and nutrients. The harvested green mass of the studied Helianthus species contained 78-121 g/kg CP, 67-103 g/kg ash, 251-382 g/kg CF, 288-404 g/kg ADF, 456-604 g/kg NDF, 41-71 g/kg ADL, 40- 186 g/kg TSS, 239-332g/kg Cel, 164-209 g/kg HC with nutritive and energy value 415-681 g/kg DDM, 376-679 g/kg DOM, RFV = 89-135, 11.43-13.03 MJ/kg DE, 9.38-10.66 MJ/kg ME and 5.40-6.72 MJ/kg NEl. The biochemical methane potential of green mass substrates varied from 282 to 333 l/kg VS. The dehydrated stems of studied Helianthus species contained 474-511 g/kg cellulose, 237-263 g/kg hemicellulose and 102-121 g/kg acid detergent lignin with estimated theoretical ethanol potential 523-559 L/tone. The energy biomass from Helianthus species is characterized by 46.30-47.04% C, 5.19-5.58% H, 0.25-0.48% N, 0.05-0.06% S, 0.03-0.04% Cl, 1.56-3.18% ash with calorific value 18.05-18.65 MJ/kg GCV and 16.93-17.45 MJ/kg NCV.

Key words*: biochemical composition, biochemical methane potential, biological features, calorific, value Helianthus species, nutritive value, theoretical ethanol potential.*

INTRODUCTION

Within the past decade, increased attention has been paid to the need for development and diversification of the uses of traditional crops and to the domestication of new plant species to meet new demands for food, forage, fibres, fuel, pharmaceuticals, chemicals and other important raw materials, which could stimulate economic growth.

Asteraceae is one of the two largest families of flowering plants, thus "The Plant List" mentions approximately 27.773 species, belonging to 1.765 plant genera. Some of these species are of particular interest due to their biological peculiarities, productivity and tolerance to biotic and abiotic factors. Among them, there is the genus *Helianthus* with 71 species of annual and perennial plants, native to North and South America. The popular annual species *Helianthus annuus* and the perennial *Helianthus tuberosus* are cultivated in temperate regions and some tropical regions as food crops for humans, forage for cattle and poultry, energy biomass and as ornamental plants (Johansson et al., 2015; Cabral et al., 2018; Wróbel et al., 2018; Wang et al., 2020; Liava et al., 2021; Ţîţei& Roşca, 2021).

Sunflower, *Helianthus annuus* is one of the most important cultivated oilseed and melliferous crops in our region. Sunflower is one of the important energy plants the above-ground biomass of which could be used as substrate for producing biogas. The sunflower dry biomass varied from 8.05 to 11.69 t/ha (Ion et al., 2015; Băşa et al., 2018). Sunflowers can grow in certain environments where corn, another silage crop, grows poorly, and sunflowers have a comparable nutrient content. Sunflowers have been used as silage, a type of livestock feed, for decades (Ray, 1919).

During the past decades, the narrow genetic base of cultivated sunflower has been broadened by the infusion of genes from wild relatives, which have provided a continuous source of agronomic traits for crop breeding. Researchers have identified genes that provide resistance to several pathogens, such as *Puccinia helianthi*, *Plasmopara halstedii, Orobanche cumana*, *Sclerotinia* head rot, *Sclerotinia* stalk rot, and resistance to insects such as *Homoeosoma electellum* from the wild *Helianthus* species and successfully transferred them into cultivated sunflower. Wild *Helianthus* species are an important reservoir of useful genes for sunflower, *Helianthus annuus*, breeding programs aimed at providing resistance to various abiotic factors. *Helianthus paradoxus* might be a suitable genetic resource for improving the salt tolerance of sunflower, and *Helianthus pauciflorus* for influencing its cytoplasmic male sterility (Balogh, 2008; Seiler et al., 2017; Anton et al., 2018

Among them, the cultivated sunflower - *Helianthus annuus* and Jerusalem artichoke - *Helianthus tuberosus* and several ornamental plant species *Helianthus argophyllus, Helianthus debilis*, *Helianthus decapetalus*, *Helianthus maximiliani*, *Helianthus mollis Helianthus petiolaris*, *Helianthus salicifolius* etc. are of practical importance, having also industrial uses (Seiler, 2007; Adams et al., 2019; Rost, 2021; Blinkov et al., 2022; Peni et al., 2022). Some of the *Helianthus* species are invasive or dangerous weeds (Balogh, 2008); in the Republic of Moldova, *Helianthus decapetalus*, *Helianthus tuberosus* and *Helianthus tuberosus* var. *subcanescens* have been mentioned (Mârza, 2010).

Ashy sunflower, *Helianthus mollis* Lam., is a perennial herbaceous plant, with erect, hirsute to villous stems, up to 1.5 m tall, spreading by means of underground rhizomes. Leaves are sessile. The plant is greyish-white, the stem and the involucral bracts are densely covered in whitish down. Flower heads develop singly from the upper stems, with each flower having 15-30 showy petal-like yellow ray florets surrounding a central disk of tiny darker yellow disk florets. The achenes are wedge-shaped to egg-shaped, dark brown or brown-mottled, tipped by 2 scales with pointed tips, enclosing small seed. The root system is fibrous and rhizomatous. This plant tends to form dense colonies. *Helianthus mollis* grows on prairies, roadsides, dry open woods, rocky glades, fields, and thickets. Ashy sunflower has been used for various purposes, such as restoration of degraded lands, feeding the livestock and wildlife and as ornamental plant. Dairy cattle, beef cattle and sheep could consume *Helianthus mollis* when grazing in a new pasture with native plants or farmers could intentionally grow it and store the plant matter in silos (Ray, 1919; Taylor, 2021; Rost, 2021).

Woodland sunflower, *Helianthus strumosus* L. is native to eastern North America, is a rhizomatous perennial plant, stems erect, hairless or has sparse, long hairs downwards from the inflorescences, often glaucous, growing up to two meters tall. Leaves are up to 10 cm long and cuneate to subcordate in shape. The composite flower heads can be up to 9 cm at the peduncle. The ray florets are dark yellow, and disc florets - orange-brown in the centre. Achenes have an elongated rounded base and a truncated top with two relatively long, weakly attached awns, and are 4 to 5.5 mm long. Rhizomes are normally well developed, thin or a little thick, may sometimes be tuberous. *Helianthus strumosus* is frequently found in dry forests, but also in completely open habitats, on watersides, roadsides and prairies (Balogh, 2008).

The mobilization and study of some *Helianthus* plant species as forage and energy crops may be necessary.

The main goal of this research was to evaluate some biological features, the quality of green mass and dry stem biomass of the species: *Heliathus annuus, Helianthus mollis, Helianthus strumosus* and *Helianthus tuberosus* grown under the climatic conditions of the Republic Moldova.

MATERIALS AND METHODS

The Asteraceae species: *Heliathus annuus, Helianthus mollis, Helianthus strumosus* and *Helianthus tuberosus* cultivar 'Maria', which grow in the "Alexandru Ciubotaru" National Botanical Garden (Institute), Chisinau, Republic of Moldova served as research subjects. The green mass was mowed in early flowering stage. The leaf/stem ratio was determined by separating the leaves, buds and flowers from the stem, weighing them separately and establishing the ratios for these quantities (leaves/stems). The harvested green mass was chopped with a stationary forage chopping unit. The dry matter content was detected by drying samples up to constant weight at 105°C. For biochemical analyses, the plant samples were dried in a forced air oven at 60°C, milled in a beater mill equipped with a sieve with diameter of openings of 1 mm and some assessments of the main biochemical parameters: crude protein (CP), ash, acid detergent fibre (ADF), neutral detergent fibre (NDF), acid detergent lignin (ADL), total soluble sugars (TSS), digestible dry matter (DDM), digestible organic matter (DOM) have been determined by the method of near infrared spectroscopy (NIRS) using PERTEN DA 7200. The concentration of hemicellulose (HC), cellulose (Cel), digestible energy (DE), metabolizable energy (ME), net energy for lactation (NEl) and relative feed value (RFV) were calculated according to standard procedures. The carbon content of the substrates was obtained using an empirical equation reported by Badger et al. (1979). The biochemical methane potential was calculated according to the equations of Dandikas et al. (2015).

The *Helianthus annuus* stems, after seed removal, were collected at the end of September, but *Helianthus mollis, Helianthus strumosus* and *Helianthus tuberosus* stems were collected in March. The harvested stems were chopped and disintegrated in a knife mill with a sieve with the mesh size of 1 mm. To perform the analyses, the biomass samples were dried in an oven at 85°C. After that, the total carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) amounts were determined by dry combustion in a Vario Macro CHNS analyser. The content of ash was determined at 550°C in a muffle furnace HT40AL according to SM EN ISO 18122; the automatic calorimeter LAGET MS10A with accessories was used to determine the calorific value, according to SM EN ISO 18125. The content of cell walls was evaluated using the near infrared spectroscopy (NIRS) technique PERTEN DA 7200. Theoretical Ethanol Potential (TEP) was calculated according to the equations of Goff et al. (2010) based on the conversion of hexose and pentose sugars.

RESULTS AND DISCUSSIONS

While researching the characteristics of growth and development, several differences between the studied *Heliathus* species were identified. It has been found that the seedlings of *Helianthus annuus* emerged at the soil surface in 12 days after sowing, the stems developed intensively by the middle of May, the flower heads started developing at the beginning of July, the full flowering stage occurred at the middle of July and seed ripening – in August. *Helianthus mollis* plants, in the first year of life, went through all the ontogenetic stages, but the flowering stage occurred very late and the plants did not produce viable seeds. In the second year, *H. mollis* plants came out of dormancy at the beginning of April, the intensive stem development was recorded at the middle of May, the flower heads developed in the middle of June and bloomed in August, and the seed ripening stage lasted from the end of August until the middle of September.

Helianthus strumosus, as well as some other perennial Asteraceae species, in the first year of growth, formed a rosette and the stalk with erect growth reached 50-55 cm in height. In the second year and the in further years of vegetation, in the middle of April, when the air temperature exceeded 10°C, the regrowth of *Helianthus strumosus* plants started from generative buds. From the end of May, the growth and development of the plants intensified, and by the middle of July the shoots were 135-155 cm tall. In the middle of September, shoots developed and passed into the generative phase, and in the first days of October, the plants bloomed, but produced few seeds and most of them did not germinate. *Helianthus strumosus* has the ability to propagate easily from small rhizome fragments, going through all the ontogenetic phases in the year when it is planted. It was found that the number of the stems per plant varied from 5 to 23.

In our previous articles, we mentioned the agro-biological features of the species *Helianthus tuberosus*. According to the results of our research on plants of *Helianthus tuberosus* 'Maria', the tubers were planted in the first days of April, and after 25 days the seedlings emerged at the soil surface. In the middle of May, the initiation of stem development was observed, and in mid-June - the formation of stolons. In the following period - July-September, growth and development intensified and the plants exceeded 250 cm in height. At the end of September, the development of flower heads was observed, and in October, the full flowering stage occurred, but the plants did not produce viable seeds.

Plant height, stem thickness and leaf/stem ratio have significant impact on the yield, but also affect the quality of the phytomass. Results regarding some biological peculiarities and the structure of the harvested phytomass of the studied *Helianthus* species are presented in Table 1. At the time of harvesting, plant height varied from 162 cm (*Helianthus strumosus*) to 215 cm (*Helianthus tuberosus*), the leaf share of the fodder from 34.0% (*Helianthus strumosus*) to 53.9% (*Helianthus mollis*).

Anton et al. (2018) reported that in the collection of wild *Helianthus* species from NARDI Fundulea, Romania, in the flowering stage, *Helianthus mollis* plants reached 165 cm in height, *Helianthus strumosus* - 250 cm and *Helianthus tuberosus* - 140-290 cm.

The biochemical composition, nutritive and energy value of the green mass from the studied *Helianthus* species are presented in Table 2. Analysing the results of the biochemical composition of green mass, we found that the dry matter of the studied species contained 78-121 g/kg CP, 67-103 g/kg ash, 251-382 g/kg CF, 288-404 g/kg ADF, 456-604 g/kg NDF, 41-71 g/kg ADL, 40-186 g/kg TSS, 239-332g/kg Cel and 164-209 g/kg HC. The nutritive and energy value of the harvested natural fodder was: 415-681 g/kg DDM, 376-679 g/kg DOM, RFV = 89-135, 11.43-13.03 MJ/kg DE, 9.38-10.66 MJ/kg ME and 5.40-6.72 MJ/kg NEl. *Helianthus mollis* fodder is characterized by higher concentration of protein and lower – of lignin. *Helianthus tuberosus* and *Helianthus mollis* do not differ essentially in the content of ash, neutral and acid detergent fibres, cellulose and energy concentration. *Helianthus strumosus* had lower concentration of protein, total soluble sugars and higher concentration of structural carbohydrates, which had a negative effect on digestibility, relative feed value and net energy for lactation.

Table 1. Some biological peculiarities and the structure of the harvested mass from the studied *Helianthus* species

Plant species	Plant height, cm	Stem, g		Leaf + flower head, g		Total weight of a shoot, g		The leaf share of the fodder, %
		green mass	dry matter	green mass	dry matter	green mass	dry matter	
Helianthus annuus	170	511.2	66.7	230.0	36.0	741.2	102.7	35.1
Helianthus mollis	154	38.1	13.6	60.6	15.9	98.7	29.5	53.9
Helianthus strumosus	162	51.5	17.3	29.2	8.9	80.7	26.2	34.0
Helianthus tuberosus	215	386.4	82.3	232.6	52.6	619.0	134.9	39.0

Table 2. The biochemical composition and the nutritive value of the green mass from the studied *Helianthus* species

	Helianthus annuus	*Helianthus strumosus*	*Helianthus mollis*	*Helianthus tuberosus*
Crude protein, g/kg DM	90	78	121	115
Crude fibre, g/kg DM	358	382	255	251
Minerals, g/kg DM	67	84	100	103
Acid detergent fibre, g/kg DM	367	404	288	292
Neutral detergent fibre, g/kg DM	576	604	460	456
Acid detergent lignin, g/kg DM	49	71	44	53
Total soluble sugars, g/kg DM	145	40	163	186
Cellulose, g/kg DM	318	332	244	239
Hemicellulose, g/kg DM	209	201	172	164
Digestible dry matter, g/kg DM	531	415	622	681
Digestible organic matter, g/kg DM	510	376	579	679
Relative feed value	97	89	134	135
Digestible energy, MJ/ kg	11.92	11.43	13.03	12.98
Metabolizable energy, MJ/ kg	9.79	9.38	10.70	10.66
Net energy for lactation, MJ/ kg	5.81	5.40	6.72	6.67

Literature sources indicate considerable variation in the chemical composition and nutritional value of *Helianthus* plant species. According to Medvedev & Smetannikova (1981), the chemical composition of green mass from early-blooming sunflower cultivars was 7% CP, 32.4% CF, and 8.6% ash, but from late-blooming sunflower cultivars- 12.4% CP, 26.2% CF and 11.5% ash. Seiler et al. (1991) remarked that *Helianthus annuus* contained 13.1-20.4% CP, 3.3-2.0-2.1% EE and 17.9-19.5% ash; *Helianthus decapetalus* - 4.7% CP, 1.5 % EE and 15.5% ash; *Helianthus mollis* - 5.3% CP, 1.5 % EE and 18.6% ash; *Helianthus strumosus* - 7.1% CP, 2.0 % EE and 10.4% ash; *Helianthus tuberosus* - 3.8% CP, 1.0 % EE and 8.5% ash. Seiler (1993) mentioned that *in vitro* digestibility of dry matter of the Jerusalem artichoke cultivars varied from 542 to 715 g/kg in whole plants in the flowering stage. According to Cosgrove et al. (2000), the Jerusalem artichoke tops contained 270 g/kg dry matter, 5% crude protein and 67% total digestible nutrients. Mello et al. (2006) mentioned that the dry matter content and the nutritional quality of sunflower whole plant forage, as influenced by sowing dates and peculiarities of different hybrids, was 328-347 g/kg DM, 90.8-93.0 % OM, 8.7-14.8 % CP, 39.5-52.5 % NDF, 36.3-48.8 % ADF, 9.0-9.7 % ADL. For comparison, Seiler (2007) remarked that *Helianthus grosseserratus* had a protein concentration of 201 g/kg, *Helianthus arizonensis* of 184 g/kg, *Helianthus simulans* of 181 g/kg, *Helianthus petiolaris* subsp. *fallax* of 173 g/ kg, and *Helianthus neglectus* of 162 g/kg. Kerckhoffs et al. (2011) revealed that the dry matter content and the biomass composition of *Helianthus annuus* plants was: 360 g/kg DM, 11.8% CP, 8.1% EE, 3.5% sugars, 0.4% starch, 20.5% cellulose, 10.2% hemicellulose, 24.9% CF, 36.9% NDF, 26.7% ADF, 6.2% lignin, 12.2% ash, but *Helianthus tuberosus* plants contained 282 g/kg DM, 4.7% CP, 0.7% EE, 5.0% sugars, 0.3% starch, 27.7% cellulose, 12.6% hemicellulose, 32.3% CF, 48.0% NDF, 35.5%ADF, 7.8% lignin, 8.8% ash. Teleuţă&Ţîţei (2013) found that green mass of the cultivar "Solar" of *Helianthus tuberosus* harvested during the formation of flower buds, contained 255 g/kg of dry matter and its chemical composition was: 9.32% of raw protein, 1.93% of raw fat, 21.29% of raw cellulose, 8.75% of minerals, 58.71% of nitrogen free extract. Heuze et al. (2015a; 2015b) remarked that the average feed value of Jerusalem artichoke fresh mass was: 32.3% DM, 15.3% CP, 2.2% EE, 15.1% CF, 40.6% NDF, 34.5% ADF, 11.5% lignin, 14.4% ash, 63% DOM, 16.8 MJ/kg GE, 10.1 MJ/kg DE and 8.2 MJ/kg ME, but sunflower fresh mass – 15.8% DM, 13.0% CP, 2.2% EE, 25.0% CF, 39.6% NDF, 35.9% ADF, 9.7% lignin, 13.1% ash, 64.4% DOM, 17.7 MJ/kg GE, 11.0 MJ/kg DE and 8.9 MJ/kg ME. Silva et al. (2016) revealed that the chemical composition of sunflower plants was 12.5% CP, 16.13% EE, 11.78% ash, 40.16% NDF, 31.27% ADF; corn plants contained 8.31% CP, 2.09% EE, 8.45% ash, 58.24% NDF, 32.50% ADF; sorghum plants - 5.57% CP, 1.74% EE, 4.63% ash, 63.73% NDF, 38.14% ADF. Ersahince & Kara (2017) have found that the chemical composition of Jerusalem artichoke green mass harvested in early flowering stage was 7.37% protein, 1.70% fats, 40.15% NFC, 39.03% aNDFom, 31.7% ADFom, 6.78% ADL. Adams et al. (2019) revealed that the crude protein content varied in sunflower species, between the following values: 14.6-20.1% CP in *Helianthus grosseserratus*, 15.9% CP in *Helianthus angustifolius*, 10.8-15.3% CP in *Helianthus maximiliani*, 12.9% CP in *Helianthus strumosus*, 12.1% CP in *Helianthus tuberosus*, 9.3% CP in *Helianthus tuberosus x annuus*, 8.6-8.7% CP in *Helianthus annuus*, 6.6-8.9% CP in *Helianthus mollis* and 2.6% CP in *Helianthus divaricatus.* Farzinmehr et al. (2020) evaluated the effect of the maturity stage and harvesting frequency of Jerusalem artichoke forage, and depending on the stage of maturity, it contained 146-247 g/kg DM, 9.25-14.5% CP, 1.43-1.87% fats, 34.0-46.7% NDF, 25.5-34.7% ADF, 5.96-11.0% ADL, 5.65-12.1% WSC, 29.9-35.5% NFC, 11.8-16.4% ash, 58.1-69.1% OMD, 7.69-9.37 MJ/kg ME. Pınar et al. (2021) revealed that Jerusalem artichoke green mass could provide a good source of nutrients for ruminants: 5.82-13.36% CP, 0.65-2.42% EE, 0.95-1.67% condensed tannins, 31.67-45.71% ADF, 38.77-53.27% NDF, 9.89-16.85% ash, 1.6-4.5% Ca, 0.5-2.9%P, 2.0-3.3% K, 0.3-0.7% Mg, 43.30-60.20% OMD, 5.82-8.52 MJ/kg ME, 2.65-4.93

MJ/kg NEL. Manokhina et al. (2022) found that the chemical composition of Jerusalem artichoke green mass from early leaf wilting cultivars was 2.8% CP, 3.3% fats, 4.2% sugars, 10.9% cellulose 7.6% others nutrients, but in cultivars with late leaf wilting respectively - 3.1% CP, 3.5% fats, 4.0% sugars, 13.1% cellulose 6.1% others nutrients.

Biogas is produced by microorganisms, such as methanogens and sulphate-reducing bacteria, performing anaerobic respiration inside a bioreactor, primarily consisting of methane, carbon dioxide and hydrogen sulphide, is an environmentally-friendly, renewable energy source. 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 biochemical potential biomethane are illustrated in Table 3. We found that the carbon content in the studied substrates ranged from 491.7 g/kg DM to 518.3 g/kg DM, and the nitrogen content from 12.5 g/kg DM to 19.4 g/kg DM, the C/N ratio varied from 25 to 41, respectively. The optimal C/N = 25-27 was found in *Helianthus mollis* and *Helianthus tuberosus* substrates. Essential differences were observed between the hemicellulose and lignin contents, which played an important role in biomethane yield. A high yield of biomethane can be provided by the *Helianthus mollis* substrate (333 l/kg VS), but the *Helianthus strumosus* substrate has low potential because of the very high content of lignin (282 l/kg VS). The biochemical methane potential of green mass substrates from *Helianthus annuus* and *Helianthus tuberosus* reached 317-320 l/kg VS.

Table 3. Biochemical composition and biomethane production potential of substrates from the studied *Heliathus* species

Indices	*Heliathus annuus*	*Helianthus strumosus*	*Helianthus mollis*	*Helianthus tuberosus*
Minerals, g/kg DM	67	84	100	103
Nitrogen, g/kg DM	14.4	12.5	19.4	18.4
Carbon, g/kg DM	518.3	508.9	500.0	491.7
Ratio carbon/nitrogen	36	41	25	27
Hemicellulose, g/kg DM	209	201	172	164
Acid detergent lignin, g/kg DM	49	71	44	53
Biomethane potential, L/kg VS	320	282	333	317

Several literature sources describe the biochemical composition and biomethane potential of substrates from *Helianthus* species. In Finland, Lehtomäki (2006) determined that the methane potential of *Helianthus tuberosus* tops was 300-430 l/kg VS. Amon et al. (2007) reported that the specific methane yield of substrates from two sunflower cultivars in the course of the growing season significantly decreased from 454 to 190 L/kg VS. Mursec et al. (2009) reported that the highest biomethane production was achieved by the sunflower substrate 283 L/kg VS, followed by the sorghum 188 L/kg VS and maize substrate 187 L/kg VS, amaranth substrate 225 L/kg VS and the Jerusalem artichoke substrate 115 L/kg VS. Heiermann et al. (2009) found that the fresh mass of Jerusalem artichoke contained 234 g/kg DM, 86.9% OM, 16.8% CP, 0.6% EE, 24.9% CF, 26.9% sugar, C/H=16.8, methane yield 220 L/kg. Alaru et al. (2011) reported that the sunflower substrates contained 5.18-7.29% HC, 27.99-34.06% Cel, 7.72-8.28% lignin, with methane yield 280-290 L/kg VS, but Jerusalem artichoke substrates contained 5.48% HC, 20.95% Cel, 5.05% lignin, with methane yield 325 L/kg VS. Kerckhoffs et al. (2011) revealed that the specific yield in biomass feedstock from maize was 304-310 L/kg VS, from sorghum 293-303 L/kg VS, but from sunflower 255 L/kg VS. Seppälä (2013) found that the specific methane yield of Jerusalem artichoke was 340 L/kg VS, but in sunflower substrate 380 L/kg VS. Kikas et al. (206 remarked that the methane yield of Jerusalem artichoke substrate was 325 L/kg TS. Sotnar et al. (2015) reported that the average specific biogas production from the aerial parts of Jerusalem artichoke was 484 L/kg; the methane content was 53.26% on average, corresponding to 249 L/kg. Opurum et al. (2021) remarked that the feedstock from fresh leaves and stalks of sunflower contained 909 g/kg total solids, 761 g/kg volatile solids, 21.5% CP, 2.1% fats, 28.6% CF, 3.4% nitrogen, 39.4% organic carbon, C/N = 11.5, but the livestock manure feedstock contained 905 g/kg total solids, 598 g/kg volatile solids, 9.1% CP, 2.9% fats, 30.3% CF, 1.5% nitrogen, 54.3% organic carbon, C/N= 37, the biogas yield of sunflower only substrate was 130 L/kg VS and sunflower with 50% livestock manure - 460 L/kg VS. Oleszek & Matyka (2018) reported that the theoretical methane yield of sunflower was 484 L/kg VS and the experimental methane yield 160 L/kg VS. Spyridonidis et al. (2019) remarked that the methane yields of stalk and head residues were 112.2 and 183.0 L/kg TS, but after alkaline pre-treatment the methane yields were 150.7 and 196.4 L/kg TS. A study conducted in Poland by Peni et al. (2022) showed that the biogas yield from *Helianthus salicifolius* averaged between 269.29 L/kg VS for raw biomass and 286.6 L/kg VS for silage. Zhurka et al. (2020) reported that the highest methane production, 268.35 L/kg VS, was achieved from the pre-treated sunflower head residues.

During the first decades of the 21th century, there has been an enormous interest in the production and usage of liquid biofuels (biodiesel or bioethanol) as promising substitutes for fossil fuels. Bioethanol is an attractive alternative fuel because it is a renewable resource and it is oxygenated, providing thus potential for reducing emissions in engines. Second generation bioethanol produced from lignocellulosic plant biomass is attracting attention as an alternative energy source and it is currently a topic of great interest for researchers around the world. The hydrolysis of lignocellulosic biomass to monomeric sugars is necessary before microorganisms can metabolize them. Analysing the cell wall composition of dehydrated stems of studied *Helianthus* species, Table 4, we could mention that the concentrations of structural carbohydrates in *Helianthus annuus* and *Helianthus tuberosus* substrates are much higher in comparison with *Helianthus strumosus* substrate. The *Helianthus annuus* substrate had high content of cellulose, hemicellulose and optimal content of acid detergent lignin as compared with *Helianthus tuberosus* substrate. The estimated theoretical ethanol yield from cell wall carbohydrates averaged 559 L/t in *Helianthus annuus* substrate, 543 L/t in *Helianthus tuberosus* substrate as compared with 523 L/t in *Helianthus strumosus* substrate.

Some authors mentioned various findings about the quality of lignocellulosic substrates from *Helianthus* species. Wróblewska et al. (2009) reported that the *Helianthus tuberosus* stalks have an average content of 40.95% Seifert cellulose, 22.65% pentosans, 20.48% Klason lignin and 35.46% soluble substances. Gunnarsson et al. (2014) determined the chemical components of the Jerusalem artichoke aerial mass: 15.7-24.8% cellulose, 11.2-12.4% hemicellulose, 16.6- 19.0% lignin, 1.6-1.8% protein, 3.2-3.8% lipids, 10.9-12.2% extractives, 12.3-14.5% uronic acid and 5.8-12.2% ash. Kikas et al. (2016) reported that the quality of sunflower plant was characterized by the following indices 5.18% HC, 34.06% Cel, 7.72% Lig, 9.78% ash, 49 g/m^2 potential ethanol yield, 33.08% hydrolysis efficiency and 66.36% fermentation efficiency, but - of Jerusalem artichoke harvested in September and October - 4.50-5.48% HC, 20.95-25.99% Cel, 5.05-5.70% Lig, 4.56-5.15% ash, 38-40 g/m^2 potential ethanol yield, 74.70-77.88% hydrolysis efficiency and 38.14-44.19% fermentation efficiency, respectively. Liu et al. (2015) found that, in Jerusalem artichoke stems, the concentration of cellulose was 284-481g/kg, hemicellulose 55-1751 g/kg, lignin 47-1201 g/kg, the ethanol potential yield from cellulose and hemicellulose in aboveground biomass varied from 1821 to 5.930 L/ha. Mathias et al. (2015) remarked that sunflower stem bark contained 48% cellulose and 14% lignin, but sunflower stem pith 31.5% cellulose and 2.5% lignin. Barbash et al. (2016) noted that chemical composition of sunflower stalks was: 67.32% holocellulose, 41.83% cellulose, 24.36% pentosans, 20.12% Klason lignin and 3.07% ash. Fiserova et al. (2006) reported that the Jerusalem artichoke stalks contained 28.5% alpha-cellulose, 23.1% hemicelluloses, 14.8% lignin, 33.9% extractives, 3.1% ash. Prusov et al. (2019) remarked that Jerusalem artichoke stem cortex contained 51.1% alpha-cellulose, 16.3% hemicelluloses, 12.5% lignin, 1.8% ash, but

Jerusalem artichoke stem pith 67.7% alpha-cellulose, 4.6% hemicelluloses, 7.6% lignin, 1.3% ash. Gholami-Yangije et al. (2019) reported that sunflower stalks contained 2.26% CP, 85.09 % NDF, 72.72 % ADF and 15.25 % ADL. Rossini et al. (2019) noted that Jerusalem artichoke ethanol yield from tubers ranges from 1500 to 11000 L/ha and from aerial biomass - 2835 to 11230 L/ha. Ţîţei et al. (2021) revealed that dry stems of *Helianthus tuberosus* 'Solar' contained 276 g/kg cellulose, 176 g/kg hemicellulose, 98.04 g/kg hexose sugars and 45.4 g/kg pentose sugars, the theoretical bioethanol yield from stems 598 l/kg.

Table 4. The cell wall composition and theoretical ethanol potential of substrates from the studied *Heliathus* species

Indices	*Helianthus annuus*	*Helianthus strumosus*	*Helianthus tuberosus*
Acid detergent fibre, g/kg	614	576	632
Neutral detergent fibre, g/kg	877	823	869
Acid detergent lignin, g/kg	107	102	121
Cellulose, g/kg	507	474	511
Hemicellulose, g/kg	263	247	237
Hexose sugars, g/kg	90.80	84.90	91.18
Pentose sugars, g/kg	43.21	40.63	38.98
Theoretical ethanol potential, L/tone	559	523	543

Table 5. The elemental composition, ash content and calorific value of stem biomass from studied the *Heliathus* species

Indices	*Helianthus annuus*	*Helianthus strumosus*	*Helianthus tuberosus*
Carbon	46.30	46.44	47.04
Hydrogen	5.21	5.19	5.58
Nitrogen	0.48	0.25	0.29
Sulphur	0.06	0.05	0.05
Chlorine	0.04	0.04	0.03
Ash content of biomass, %	3.18	2.68	1.56
Gross calorific value, MJ/kg	18.05	18.35	18.65
Net calorific value, MJ/kg	16.93	17.21	17.45

The chemical composition of dry biomass is a key factor that affects the calorific value and the technologies to be implemented for the production of solid biofuels. The elemental composition of 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). 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 higher net calorific value. 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 elemental composition, ash content and calorific value of stem biomass from the studied *Helianthus* species is presented in Table 5. We found that the studied stem biomass was characterized by 46.30-47.04% C, 5.19-5.58% H, 0.25-0.48% N, 0.05-0.06% S, 0.03-0.04% Cl, 1.56-3.18% ash, 18.05-18.65 MJ/kg GCV and 16.93-17.45 MJ/kg NCV. The higher content of carbon and hydrogen, and the lower content of nitrogen, sulphur and chlorine in *Helianthus tuberosus* stems had positive impact on calorific value as compared with *Helianthus annuus* biomass. According to Unal & Alibas (2006) the sunflower stalks contained 10.5 % moisture, 68.0% volatile matters, 7.0% ash, 48.2% carbon, 24.4 % fixed carbon, 5. 7% hydrogen, 1.1% nitrogen, 0.1% sulphur, 18.65 MJ/kg HHV and 17.19 MJ/kg LHV, but wheat straw 12.8 % moisture, 73.8% volatile matters, 6.2% ash, 44.8% carbon, 20.0 % fixed carbon, 5.4% hydrogen, 0.6% nitrogen, 0.2% sulphur, 17.88. MJ/kg HHV and 16.23 MJ/kg LHV, respectively. Wróblewska et al. (2009)

found that *Helianthus tuberosus* biomass contained 45.9% C, 6.1% H, 0.3% N, 2.5% ash and had 16.653 MJ/kg calorific value, in dry and ash-free state. Hăbăşescu & Cerempei (2012) mentioned that sunflower stem biomass had 3.78 % ash, 0.08%S, 14.76 MJ/kg LHV, maize stems 5.14 % ash, 0.09%S and 14.2 MJ/kg LHV, and wheat straw 6.25 % ash, 0.15 % S and 14.36 MJ/kg LHV, respectively. Kowalczyk-Juśko et al. (2012) reported that Jerusalem artichoke biomass contained 5.4-5.6% ash and had 16.10-16.30 MJ/kg calorific value. Teleuţă & Ţîţei (2013) determined that Jerusalem artichoke stems collected at the end of December had 15% humidity, the bulk density of the crumbled stems was 288 kg/m^3 and the specific density of the briquettes reached 720 kg/m^3 with gross calorific value 18.7 MJ/kg. Huang (2014) mentioned that the briquettes from sunflower stems were characterized by a calorific value of 4300 kcal/kg (18.0 MJ/kg) and 4.3% ash, wheat straw briquettes 4100 kcal/kg (17.1 MJ/kg) and 8.00 % ash, as compared with wood chips – 4785 kcal/kg (20.0 MJ/kg) and 1.2 % ash content. Stolarski et al. (2014) found that *Helianthus tuberosus* harvested in April contained 17.934% moisture, 3.87% ash, 46.60% carbon, 5.68% hydrogen, 0.032% sulphur, 18.75 MJ/kg HHV and 13.35 MJ/kg LHV. Maj (2015) mentioned that the heat of combustion of tested Jerusalem artichoke plant biomass was 14.22-14.85 MJ/kg, but Virginia mallow biomass was 16.92-17.55 MJ/kg. Mathias et al. (2015) reported that the heat capacity value of sunflower stem bark was 14 MJ/kg and sunflower stem pith – 13 MJ/kg. Szostek et al. (2018) found that the aboveground *Helianthus tuberosus* biomass contained 5.35-6.18% ash, 15.41-16.02 MJ/kg HHV and 14.19-14.72 MJ/kg LHV. Pavlenco (2018) found that sunflower whole plant contained 55.0% DM, 42.50% C, 5.10% H, 1.11% N, 0.11% S, 11.80% ash, 16.9 MJ/kg GCV and 15.8 MJ/kg NCV. Zapalowska & Bashutska (2017) noted that Jerusalem artichoke pellets were characterized by 6.81% moisture, 2.04% ash, 18.85 MJ/kg HHV. Țîței et al. (2019) reported that the Jerusalem artichoke milled chaffs contained 2.12% ash and 19.1 MJ/kg HHV, but pellets 2.10% ash and 17.7 MJ/kg LHV.

CONCLUSIONS

The harvested green mass of the studied *Helianthus* species contains 78-121 g/kg CP, 67-103 g/kg ash, 251-382 g/kg CF, 288-404 g/kg ADF, 456-604 g/kg NDF, 41-71 g/kg ADL, 40-186 g/kg TSS, 239-332 g/kg Cel, 164-209 g/kg HC with nutritive and energy value 415-681 g/kg DDM, 376-679 g/kg DOM, RFV = 89-135, 11.43-13.03 MJ/kg DE, 9.38-10.66 MJ/kg ME and 5.40-6.72 MJ/kg NEl.

The biochemical methane potential of green mass substrates varies from 282 to 333 l/kg VS.

The dehydrated stems of the studied *Helianthus* species contain 474-511 g/kg cellulose, 237-263 g/kg hemicellulose and 102-121 g/kg acid detergent lignin with estimated theoretical ethanol yield 523-559 L/ton.

The dehydrated stem mass of the studied *Helianthus* species is characterized by the following indices: 46.30-47.04% C, 5.19-5.58% H, 0.25-0.48% N, 0.05-0.06% S, 0.03-0.04% Cl, 1.56-3.18% ash, 18.05-18.65 MJ/kg GCV and 16.93-17.45 MJ/kg NCV.

Helianthus mollis has high potential as fodder for livestock and as substrate for biogas stations, and *Helianthus strumosus* - for the production of solid biofuels.

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