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Agroeconomic Value of Jerusalem Artichoke *Helianthus tuberosus* Cultivars

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ABSTRACT

Jerusalem artichoke - *Helianthus tuberosus,* belonging to the Asteraceae family is a crop with multiple uses. The goal of this study was to evaluate some agro biological peculiarities and the quality indices of aerial phytomass and tubers from the local cultivars ‘Maria’ and ‘Solar’ of *Helianthus tuberosus.* It was found that the studied cultivars of Jerusalem artichoke, at the mowing time, reached a plant height of 215-290 cm, the phytomass yield was 5.29-8.45 kg/m^2 green mass or 1.84-1.92 kg/m^2 dry matter with 7.7-11.6% crude protein, RFV=124-135, 10.44-10.66 MJ/kg metabolizable energy and 6.46-6.67 MJ/kg net energy for lactation. The fermentation and quality indices of prepared silages were: pH=3.95-4.17, 41.3-50.9 g/kg lactic acid, 8.7-18.6 g/kg acetic acid, butyric acid was not detected, 9.7-14.5% crude protein, RFV=118-120, 10.17-10.35 MJ/kg metabolizable energy and 6.19-6.37 net energy for lactation. The tuber productivity varied from 2.67 kg/m^2 to 3.91 kg/m^2, with 32.74-33.71% dry matter. The biochemical composition of the dry matter of tubers: 9.94-10.24% crude protein, 0.71% crude fat, 4.77-8.12% crude cellulose, 55.30-58.29% inulin, 5.12-8.02 % ash, 0.09-0.16% calcium and 0.30-0.32% phosphorus with 11.45-12.12 MJ/kg metabolizable energy.

The Jerusalem artichoke phytomass from local cultivars can be used for anaerobic digestion in biogas plants with biochemical methane potential of 298-316 liters/kg organic matter. The stems of the studied cultivars quickly shed leaves and dehydrate in the autumn-winter period; they can be chopped, milled and used as feedstock for the production cellulosic ethanol and solid bio fuel.

The obtained results indicate the possibility of using the local Jerusalem artichoke cultivars ‘Maria’ and ‘Solar’ for the creation of plantations as a source of fodder and as feedstock to obtain different products, including renewable bioenergy.

Keywords: biochemical composition, biochemical methane potential, cultivars ‘Maria’ and ‘Solar’, forage quality of green mass and silage, *Helianthus tuberosus*, productivity, tubers.

INTRODUCTION

The genus *Helianthus* L. of *Asteraceae* fam. includes 71 species of annual and perennial plants, native to North and South America. The popular annual species *Helianthus annuus* L. and the perennial *Helianthus tuberosus* L. are cultivated as food crops for humans, as forage for cattle and poultry, as energy biomass and as ornamental plants, and other species are involved as valuable gene pool in breeding programs aimed at developing resistance to various biotic and abiotic factors. They are also used as ornamental plants and as raw materials in biorefineries and bioenergy production (Fiserova et al., 2006; Johansson et al., 2015; Liu et al., 2015; Anton et al., 2018; Cabral et al., 2018; Adams et al., 2019; Mehmood et al., 2019; Rossini et al., 2019; Wróbel et al., 2019; Wang et al., 2020; Liava et al., 2021; Ţîţei and Roşca, 2021; Kintl et al., 2022).

Jerusalem artichoke or topinambur, *Helianthus tuberosus* L., fam. *Asteraceae*, is a C_4 carbon fixation herbaceous perennial plant, native to North America. The stem is erect, cylindrical, woody at the base, slightly furrowed longitudinally, stiff-hairy, green with anthocyanin shades, covered with a layer of bluish-gray wax, 1.5-5.0 m tall, branched at the top, with 50-70 leaves. The leaves are dark green, on the lower part of the stem - opposite, and at the top - alternate; they are petiolate with a medium-sized ovate leaf blade, with a roughly toothed margin. The inflorescences are solitary flower heads produced at the top of the branches, of 4-6 cm in diameter when fully open. The flowering stage starts at the end of August-September.

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The involucral bracts are imbricate, ovate-lanceolate, acute to acuminate, and with stiff hairs on margins. The ray florets are ligulate, 3-4 cm long, sterile, with a yellow petal. The disc florets are tubular, hermaphrodite, consisting of a yellowish-white calyx and a yellow gamopetalous corolla with 5 teeth. The androecium consists of 5 stamens with fused anthers, and the gynoecium has a unilocular inner ovary and a style ending in a bifid stigma. Jerusalem artichoke bears fruit depending on the weather conditions. The fruit is an achene, 5-6 mm long and 1.8–2.1 mm wide, light gray. The weight of 1,000 fruits is 5.3–6.4 g. In the underground part of the stem, at the end of May, the development of stolons starts and by thickening their terminal part; tubers of different shape, colour, size and weight are produced. On the surface of the tuber, ring-shaped nodes of the stolon are noticeable. On each ring, two opposite buds develop and then give rise to new plants. The weight of medium-sized tubers is 43-65 g. Jerusalem artichoke is a frost-tolerant species, the tubers in the soil can overwinter under a layer of snow at temperatures as low as -30°C. In spring, the plants resume growth at a soil temperature of 7-10°C, an intensive growth is observed in spring at air temperatures of 18-26°C. Young plants can be affected by spring frosts of -5°C. In summer, they can withstand temperatures above 35°C. Jerusalem artichoke is a mesoxerophilic plant, on one hand, due to the vigorous and deep root system, and on the other hand, due to the fact that during the growing season it covers the soil well. It prefers meadow soil, which is sandy-clayey, loose and rich in humus and calcium. It tolerates less clayey and swampy soils. It propagates by tubers (Țîței and Roșca, 2021).

Helianthus tuberosus is a late summer-autumn bloomer, attractive to various insect visitors - honey bees, wasps, flies and butterflies. The total sugar yield varied from 25.4 to 47.4 kg/ ha and pollen yield - from 57.8 to 212.7 kg/ ha (Denisow et al., 2019).

In the “Alexandru Ciubotaru” National Botanical Garden (Institute), over the last 70 years, it has been accumulated a collection of over 70 taxa of *Helianthus tuberosus* mobilized from different areas of the world. They differ in the duration of the growing season, plant habitus, shape and color of tubers, and serve as material for plant breeding, the most promising forms being selected in order to create new cultivars. Currently, in the Catalogue of Plant Varieties of the Republic of Moldova, there are four cultivars.

The goal of this study was to evaluate some agro biological peculiarities and the quality indices of aerial phytomass and tubers from the local cultivars *‘Maria’* and *‘Solar’* of *Helianthus tuberosus*.

MATERIAL AND METHODS

The local cultivars *‘Solar’* and *‘Maria’* of Jerusalem artichoke, *Helianthus tuberosus*, created at the “Alexandru Ciubotaru” National Botanical Garden (Institute) of Moldova State University, registered in 2014 (no. 0733131) and 2023 (no. 0734840), in the Catalogue of Plant Varieties and patented by the State Agency on Intellectual Property of the Republic of Moldova, patents no. 205/31.05.2016 and no. 402/28.02.2023, served as research subjects, and the traditional forage crop hybrid *‘Porumbeni 374’* of corn, *Zea mays* and the hybrid ‘SAȘM-4’ of sorghum - Sudan grass, *Sorghum bicolor* x *Sorghum sudanense*, were used as controls. The experimental design was a randomized complete block design with four replications, and the experimental plots measured 50 m^2. The Jerusalem artichoke tubers were planted in the first days of April with a scheme of 70 cm x 35 cm. The green mass samples of Jerusalem artichoke cultivars were collected during the stage of formation of flower heads, but the samples of corn and sorghum - Sudan grass green mass - in the wax stage of grains. The leaf/stem ratio was determined by separating leaves and flower heads from the stem, weighing them separately and establishing the ratios for these quantities. The dry matter content was detected by drying samples up to constant weight at 105°C. Silage was produced from harvested whole plants, cut into small pieces and compressed in glass containers. The organoleptic assessment and the determination of the content of organic acids in the silage were done in accordance with the Moldavian standard SM 108. For biochemical analyses, the fresh mass and fermented fodder samples were dehydrated in an oven with forced ventilation at a temperature of 60°C, at the end of the fixation, the biological material was finely ground in a laboratory ball mill. The quality of the biomass was evaluated by analyzing such indices as: crude protein (CP), crude fiber (CF), crude ash (CA), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL) which have been determined by near infrared spectroscopy (NIRS) technique PERTEN DA 7200 of the Research and Development Institute for Grassland Braşov, Romania. The concentration of hemicellulose (HC), cellulose (Cel), digestible dry matter (DDM), digestible energy (DE), the metabolizable energy (ME), the net energy for lactation (NEl) and the relative feed value (RFV) were calculated according to standard procedures. The carbon content of the substrates was determined according to Badger et al. (1979), the biochemical methane potential - according to Dandikas et al. (2015). The tubers and dry stems were collected in March. The nutrient content of tubers were carried out in the Laboratory of Nutrition and Forage Technology of the Scientific-Practical Institute of Biotechnology in Animal Husbandry and Veterinary Medicine Maximovca, in accordance with the methodological indications: crude protein (CP) - by Kjeldahl method; crude fat (EE) - by Soxhlet method, crude cellulose (CF) - by Van Soest method; ash - in muffle furnace at 550°C, nitrogen-free extract (NFE) was mathematically appreciated; calcium (Ca) concentration of the samples was determined by using atomic absorption spectrometry method, phosphorus (P) concentration - by spectrophotometric method. The harvested dry 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 analyzer, according to standard protocols at the State Agrarian University of Moldova. 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 in dry stems 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 biological peculiarities of growth and development, several differences between the studied Jerusalem artichoke cultivars were identified. The seedlings of the *'Solar'* cultivar emerged at the soil surface in 20 days after planting, the leaves were dark green with numerous hairs, while the seedlings of the *'Maria'* cultivar emerged 5 days later, the leaves had delicate structure and were light green-yellow. The growth and development rates of *'Solar'* cultivar were faster. We observed that *'Maria'* cultivar produced more shoots. Some agrobiological peculiarities and productivity of the local cultivars of Jerusalem artichoke are presented in Table 1. At the cutting time, the plant height varied from 215 cm in *'Maria'* cultivar to 290 cm in *'Solar'* cultivar. The dry matter content varied from 21.78% in *'Maria'* cultivar to 36.23% in *'Solar'* cultivar, the leaf share in the harvested mass varied from 35.6% *'Solar'* cultivar to 35.6% *'Maria'* cultivar. The green mass productivity reaches 8.45 kg/m^2 in *'Maria'* cultivar; however, because of the low content of dry matter in the green mass, the yield was only 1.84 kg/m^2 dry matter.

Some authors have mentioned various findings about the productivity of this species. Kerckhoffs et al. (2011) found the dry matter yield was 15.3 t/ha. Adamović et al. (2014) mentioned that the *Helianthus* *tuberosus* green mass yield achieved 75 t/ha with 22.38% DM content. Bogucka and Jankowski (2022) reported that, in August, the aerial biomass yield of Jerusalem artichoke was 89.46-96.33 t/ha fresh mass or 27.36-31.58 t/ha dry matter.

Table 1. Some agrobiological peculiarities and productivity of the local cultivars of Jerusalem artichoke

Cultivars	Plant height, cm	Stem, g		Leaf + flowers, g		Total weight of a shoot, g		Yield, kg/m^2		Content of leaves and flowers in fodder, %
		green mass	dry matter	green mass	dry matter	green mass	dry matter	Green mass	dry matter	
Solar	290	409.2	156.3	269.7	87.1	678.9	243.4	5.30	1.92	35.6
Maria	215	386.4	82.3	232.6	52.6	619.0	134.9	8.45	1.84	39.0

Table 2. The biochemical composition and the fodder value of the green mass

Indices	*Helianthus tuberosus*		*Sorghum bicolor* x *Sorghum sudanense* SASM 4	*Zea mays* Porumbeni 374
	Solar	Maria		
Crude protein, g/kg DM	77	116	73	84
Crude fibre, g/kg DM	297	251	415	248
Minerals, g/kg DM	81	103	77	52
Acid detergent fibre, g/kg DM	311	292	424	271
Neutral detergent fibre, g/kg DM	485	456	692	474
Acid detergent lignin, g/kg DM	60	53	45	48
Cellulose, g/kg DM	251	239	379	223
Hemicellulose, g/kg DM	174	164	268	203
Digestible dry matter, g/kg DM	647	662	559	678
Relative feed value	124	135	75	133
Digestible energy, MJ/ kg	12.72	12.98	11.14	13.28
Metabolizable energy, MJ/ kg	10.44	10.66	9.15	10.90
Net energy for lactation, MJ/ kg	6.45	6.67	5.16	6.91

Table 3. The biochemical composition and the fodder value of the silage

Indices	*Helianthus tuberosus*		*Sorghum bicolor* x *Sorghum sudanense* SASM 4	*Zea mays* Porumbeni 374
	Solar	Maria		
pH index	4.17	3.95	4.06	3.77
Organic acids, g/kg DM	69.5	50.0	26.7	48.6
Free acetic acid, g/kg DM	8.9	3.9	3.3	5.1
Free butyric acid, g/kg DM	0.0	0	0	0
Free lactic acid, g/kg DM	10.4	12.1	7.9	17.0
Fixed acetic acid, g/kg DM	9.7	4.8	3.6	5.2
Fixed butyric acid, g/kg DM	0.0	0	0	0.2
Fixed lactic acid, g/kg DM	40.5	29.1	11.9	21.1
Total acetic acid, g/kg DM	18.6	8.7	6.9	10.3
Total butyric acid, g/kg DM	0.0	0	0	0.2
Total lactic acid, g/kg DM	50.9	41.3	19.8	38.1
Acetic acid, % of organic acids	27	17	26	21
Butyric acid, % of organic acids	0	0	0	0.41
Lactic acid, % of organic acids	73	83	74	78
Crude protein, g/kg DM	97	145	61	80
Crude fibre, g/kg DM	308	299	397	245
Minerals, g/kg DM	103	127	84	59
Acid detergent fibre, g/kg DM	334	318	403	258
Neutral detergent fibre, g/kg DM	526	496	670	469
Acid detergent lignin, g/kg DM	50	33	39	37
Cellulose, g/kg DM	334	285	364	221
Hemicellulose, g/kg DM	192	178	267	211
Digestible dry matter, g/kg DM	629	641	575	688
Relative feed value	118	120	80	136
Digestible energy, MJ/ kg	12.39	12.61	11.42	13.45
Metabolizable energy, MJ/ kg	10.17	10.35	9.26	11.04
Net energy for lactation, MJ/ kg	6.19	6.37	5.40	7.06

The nutrient content of the dry matter from the green mass is an important indicator in feed quality evaluation. The biochemical composition and the fodder value of the green mass from the studied Jerusalem artichoke cultivars are presented in Table 2. We found that the dry matter nutrient and feed energy values of green mass were: 77-116 g/kg CP, 81-135g/kg ash, 251-297 g/kg CF, 292-311 g/kg ADF, 456-485 g/kg NDF, 53-60 g/kg ADL, 239-251 g/kg Cel, 164-174 g/kg HC, 64.7-66.2% DMD, RFV=124-135, 12.72-12.98 MJ/kg DE, 10.44-10.66 MJ/kg ME, 6.46-6.67 MJ/kg NEl. By comparing the quality indices, we found that the green forage of *'Maria'* cultivar is characterized by higher concentration of protein and minerals, and lower concentration of structural carbohydrates and lignin than in the forage of *'Solar'* cultivar, which had a positive impact on the nutritive value, metabolizable energy and net energy for lactation. The green forage from studied Jerusalem artichoke cultivars have lower content of cellulose and hemicellulose, but higher - of crude protein, lignin and minerals, as compared with sorghum - Sudan grass fodder. The dry matter of *‘Maria’* cultivar contained high amount of crude protein, minerals, acid detergent lignin, and low level of neutral detergent fiber and hemicellulose as compared with de traditional forage crop - the corn hybrid *‘Porumbeni 374’*, while the indices of relative feed value do not differ essentially.

Different results regarding the biochemical composition and the nutritive value of the harvested green mass from *Helianthus tuberosus* plants. 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, and 0.9% starch. Karsli and Bingöl (2009) mentioned that Jerusalem artichoke herbage contained 394 g/kg dry matter with 87.54% OM, 10.43% CP, 36.67% NDF, 24.66% ADF, 59.15% IOMD, 2.14 Mcal/kg ME. Kerckhoffs et al. (2011) reported that *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. Heuzé et al. (2015), revealed that the aerial part of the *Helianthus tuberosus* had 323 g/kg dry matter with 15.3% CP, 15.3% CF, 40.6% NDF, 34.5% ADF, 2.2% EE, 11.5% lignin, 14.4% ash, 63.0% OMD, 10.1 MJ/kg DE, 8.2 MJ/kg ME and 5.0-6.0 MJ/kg NEl, for ruminants. Ersahince and Kara (2017) reported that the green forage harvested in early flowering stage contained 7.37% CP 1.70% EE, 40.15% NFC, 39.03% aNDFom, 31.7% ADFom, 6.78% ADL, 6.62 MJ/kg ME for horses and 7.96 MJ/kg ME for ruminants. Taherabadi and Kafilzadeh (2022) reported that Jerusalem artichoke harvested at inflorescence emergence stage contained 281 g/kg dry matter with 89.09% OM, 9.63% CP, 41.03% NDF, 34.61% ADF, 22.34% WSC. Farzinmehr et al. (2020) mentioned that in dependence on the stage of maturity and harvesting frequency of Jerusalem artichoke forage contained 146-247 g/kg DM with 9.25-14.5% CP, 1.43-1.87% EE, 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) found that the studied genotypes of Jerusalem artichoke contained: 5.82-13.36% CP, 0.65-2.42% EE, 0.95-1.67% CT, 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) reported that the nutrient composition of Jerusalem artichoke herbage from early cultivars was 2.8% CP, 3.3% EE, 4.2% sugars, 10.9% Cel and 7.6% others nutrients, but in late cultivars - 3.1% CP, 3.5% EE, 4.0% sugars, 13.1% Cel and 6.1% others nutrients, respectively.

For a balanced feeding all year-round, fermented forage is an important component of livestock diets. The results regarding the fermentation characteristics and nutrient content of prepared Jerusalem artichoke silages are shown in Table 3. The fermentation silage indices were pH=3.95-4.17, 41.3-50.9 g/kg lactic acid, 8.7-18.6 g/kg acetic acid, butyric acid was not detected. The nutrient content and energy supply of the ensiled feed from the studied Jerusalem artichoke cultivars reached 97-145 g/kg CP, 103-127 g/kg ash, 299-308 g/kg CF, 318-344 g/kg ADF, 496-526 g/kg NDF, 33-50 g/kg ADL, 285-334 g/kg Cel, 178-192 g/kg HC with 62.9-64.1% DMD, RFV=118-120, 12.39-12.61 MJ/kg DE, 10.17-10.35 MJ/kg ME, 6.19-6.37 MJ/kg NEl. During the process of ensiling of Jerusalem artichoke plants, we observed an increase in the content of crude protein, cellulose and hemicellulose, and a significant reduction of the acid detergent lignin content. As compared with the harvested green mass, the digestibility indices and the feed energy value of the prepared silages is lower. The silage prepared from *'Maria'* cultivar is of very high quality. Jerusalem artichoke silage differs from corn silage in a higher concentration of structural carbohydrates, and from sorghum x Sudan grass silage - in an optimal content of structural carbohydrates, high level of digestibility, metabolizable energy and net energy for lactation.

In various publications, researchers have presented different results regarding the biochemical composition and the nutritive value of the ensiled mass from Jerusalem artichoke. Thus, Heiermann et al. (2009) remarked that the ensiled mass from Jerusalem artichoke had pH=4.1 and 268 g/kg DM with 91.0% OM, 9.8% CP, 1.2% EE, 35.1% CF, 18.8% sugar, 1.7% starch, but ensiled maize hybrids - pH=3.7-3.8 and 251-370 g/kg DM with 95.0-96.5% OM, 8.8-10.2% CP, 2.0-8.7% EE, 23.7-32.4% CF, 2.0-8.7% sugar, 25.1-33.0% starch. Karsli and Bingöl (2009) mentioned that Jerusalem artichoke silage was characterized by pH=4.54, 4.30% lactic acid, 2.14% acetic acid, 330.5 g/kg DM, 85.74% OM, 9.38% CP, 42.53% NDF, 30.12% ADF, 51.71% IOMD, 1.87 Mcal/kg ME. Adamović et al. (2014) found the Jerusalem artichoke silages have pH=4.07-4.20, 26.93-33.68% DM, inclusive 2.00-2.29% CP, 0.19-0.35% EE, 6.35-6.88% CF, 15.46-23.21% NFE with 1.47-1.71 MJ/kg silage NEl. Herrmann et al. (2016) mentioned that Jerusalem artichoke silage contained 282 g/kg DM with pH=3.9, 7.2% lactic acid, 1.6% acetic acid, 89.7% OM, 9.8% CP, 1.9% EE, 49.6% NFE, 44.1% NDF, 39.6% ADF, 11.7% ADL; maize silage contained 302 g/kg DM with pH=3.7, 5.1% lactic acid, 1.6% acetic acid, 95.8% OM, 7.8% CP, 2.6% EE, 64.7% NFE, 41.2% NDF, 24.0% ADF, 2.9% ADL; the silage from the Sudan grass hybrid contained 233 g/kg DM with pH=3.8, 6.7% lactic acid, 1.9% acetic acid, 94.0% OM, 8.9% CP, 1.4% EE, 52.2% NFE, 58.0% NDF, 36.6% ADF, 5.5% ADL. Dubljevic et al. (2020) found that *Helianthus tuberosus* pure silage contained 115.4 g/kg DM, 4.70% lactic acid, 2.51% acetic acid, 0.19% butyric acid, 10.12% CP, 2.77% EE, 21.26% CF, 49.62% NFE, 16.25% ash. Wang et al. (2020) remarked that Jerusalem artichoke silage contained 258 g/kg DM, 12.4% CP, 1.6% EE, 31.7% ADF, 43.9% NDF, 7.5% ADL, 5.9% ash, 11.9 MJ/kg DE, 9.20 MJ/kg ME, but corn silage 351 g/kg DM, 8.8% CP, 3.2% EE, 28.1% ADF, 45.0% NDF, 2.6% ADL, 4.3% ash, 12.5 MJ/kg DE, 9.75 MJ/kg ME. Kintl et al. (2022) found that monosilage from *Helianthus tuberosus* contained 306 g/kg DM, 5.1% CP, 2.9% EE, 19.8% CF, 27.8% ADF, 33.2% NDF, 8.1% ADL, 9.2% starch; *Zea mays* silage - 336 g/kg DM, 9.3% CP, 4.4% EE, 16.8% CF, 21.1% ADF, 43.8% NDF, 2.3% ADL, 16.1% starch, but mixture silages - 315-334 g/kg DM, 7.3-8.3% CP, 3.4-3.5% EE, 17.7-19.1% CF, 23.9-26.3% ADF, 36.8-41.6% NDF, 3.5-7.4% ADL, 10.1-15.3% starch.

Jerusalem artichoke tubers can be harvested and used in late autumn to winter. They can be eaten raw or cooked and are also known as a folk remedy for diabetes. Besides, the tubers can be used as fodder for ruminants, pigs, rabbits. The productivity and the biochemical composition of tubers of the local cultivars of Jerusalem artichoke are shown in Table 4. The tuber productivity varied from 2.67 kg/m^2 to 3.91 kg/m^2, with 32.74-33.71% dry matter content. The biochemical composition of the dry matter of tubers was: 9.94-10.24% CP, 0.71% EE, 4.77-8.12% CF, 72.90-79.46% NFE, 3.53-4.86% starch, 55.30-58.29% inulin, 5.12-8.02% ash, 0.09-0.16% Ca and 0.30-0.32% P with 11.45-12.12 MJ/kg ME. We would like to mention that *'Maria'* cultivar is characterized by high yield of tubers. The concentration of crude protein and crude fats does not differ, but the nitrogen free extract content is higher in the tubers of *'Solar'* cultivar. It was found that the levels of crude fibers, inulin, starch and ash were significantly higher in the tubers of *'Maria'* cultivar.

Several studies have evaluated the *Helianthus tuberosus* tuber productivity and its nutrient content. According to Gunnarsson et al. (2014), the main chemical compounds of tuber dry matter were: 79.1-83.3% inulin, 4.3-5.1% free sugar and 6.6-8.8% protein. Heuzé et al. (2015) reported that fresh tubers contained 323 g/kg dry matter with 7.4% CP, 5.1% CF, 9.0% NDF, 5.7% ADF, 1.1% EE, 0.8% lignin, 5.9% ash, 86.1% OMD, 17.1 MJ/kg GE, 11.8-12.5 MJ/kg ME for ruminants. Gîncu et al. (2017) found that topinambur powder contained 9.5-9.9% CP, 0.5 % EE, 2.8-3.5% CF, 69.5-70.0% soluble carbohydrates, 20.45-39.2 % inulin and 12.2-13.5% pectin. Catană et al. (2018) reported that the powder obtained from Jerusalem artichoke tubers is characterized by 51.60-57.45% inulin-type fructans, 6.85-8.27% CF, 8.75-9.26% CP, 1.12-1.55% EE and 3.49-

4.48% ash. Farzinmehr et al. (2020) mentioned that the tuber yield reached 28.99 t/ha fresh material or 7.36 t/ha dry matter. Dima et al. (2021) found that the yield of fresh tubers of the studied cultivars was 22.87-70.77 t/ha with 21.77-27.91% DM, including 12.08-13.39% inulin. Isticioaia et al. (2021) revealed that tuber yield of studied varieties of Jerusalem artichoke varied from 5.8 t/ha to 47.1 t/ha fresh mass, the tuber dry matter chemical composition were 11.52-19.58% proteins, 0.24-0.39% lipids, 3.13-3.87 % ash, 3.00-3.67% crude fiber and 48.35-56.15% inulin. Taherabadi and Kafilzadeh (2022) reported that tuber productivity in the variant with no aerial part cut was 63.3 t/ha or 14.8 t/ha dry matter, the chemical composition of tuber dry matter: 948 g/kg OM, 57.7 g/kg ADF, 95.8 g/kg NDF, 44.6 g/kg HC and 653.7 g/kg WSC. Manokhina et al. (2022) mentioned that the tuber yield varied from 14.4 to 51.1 t/ha, the tuber nutrient concentration was 2.9-3.3% CP, 0.1-0.2% EE, 16.9-17.6% sugars, 1.9-2.5% Cel and 1.1-1.3% others nutrients.

Increasing the share of the renewable energy is extremely important in replacing oil, coal, natural gas and reducing greenhouse gas emissions. Methanization of agricultural waste, residues and energy crops is part of circular economy. The results regarding the quality indices of substrates for biomethane production from the studied Jerusalem artichoke cultivars are presented in Table 5. In the investigated green mass substrates, the carbon nitrogen ratio (C/N), constituted 26.3-41.4, but in the ensiled mass substrates C/N=20.9-32.11. The substrates from *'Maria'* cultivar are characterized by carbon to nitrogen ratio that met the established standards and by low concentration of acid detergent lignin, and the biochemical methane potential is higher as compared with corn silage substrate.

Several literature sources describe the biomethane potential of substrates from *Helianthus tuberosus*. According to Lehtomäki (2006) the methane potential of aerial mass was 300-430 l/kg VS. Heiermann et al. (2009) found that the Jerusalem artichoke fresh mass substrate had C/N=16.8 and 220 L/kg methane yield, the ensiled mass substrate C/N=16.8 and 252 L/kg methane yield, the tubers substrate C/N=19.6 and 374 L/kg methane yield, but the ensiled maize substrate C/N=28.8-33.2 and 468-477 L/kg methane yield. Mursec et al. (2009) reported that biomethane production was 115 L/kg VS. Heiermann et al. (2009) revealed 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 with C/N=16.8 and methane yield 220 l/kg, but silage mass had pH=4.1; 268 g/kg DM, 91.0% OM, 9.8% CP, 1.2% EE, 35.1% CF, 18.1% sugar with C/N=29.8 and methane yield 252 l/kg. Alaru et al. (2011) reported that Jerusalem artichoke substrate had 5.48% HC, 20.95% Cel, 5.05% lignin and methane yield 325 l/kg TS, but energy sunflower substrates - 5.18-7.29% HC, 27.39-34.06% Cel, 7.72-8.81% lignin and 284-295 L/kg TS, respectively. Seppälä (2013) revealed that the specific methane yield of Jerusalem artichoke substrate was 340 L/kg VS, but in sunflower substrate - 380 L/kg VS. Kikas et al. (2016) found that the Jerusalem artichoke substrate contained 314.8 g/kg DM with 5.48 % HC, 20.95% Cel, 5.70% lighin, 5.15% ash and the methane yield was 325 L/kg TS. Sotnar et al. (2015) mentioned that the methane yield of the substrate from aerial parts of Jerusalem artichoke was 249 L/kg. Herrmann et al. (2016) mentioned that *Helianthus tuberosus* silage substrate had C/N=31 and biochemical methane potential 218.9 l/kg, *Zea mays* silage substrate - C/N=37 and biochemical methane potential 328.2 l/kg, *Sorghum bicolor x Sorghum sudanense* silage substrate - C/N=31 and biochemical methane potential 288.9 l/kg. Ruf and Emmerling (2018) mentioned that the whole-plant substrate from Jerusalem artichoke had 252-301 l/kg methane and from maize 0.282-0.347 l/kg methane. Zhang et al. (2021) showed that the methane yield of Jerusalem artichoke substrates in long retention batch tests were 252-370 l/kg, but in short retention batch tests 301-309 l/kg. Kintl et al. (2022) found that the methane yield of the ensiled substrate from Jerusalem artichoke was 274 l/kg, corn silage - 352 l/kg and mixed silage - 261-302 l/kg.

Table 4. The productivity and the biochemical composition of tubers of the local cultivars of Jerusalem artichoke

Indices	Cultivars	
	Solar	Maria
Fresh mass yield, t/ha	26.72	36.12
Dry matter yield, t/ha	9.01	12.81
Crude protein, g/kg DM	99.4	102.4
Crude fibres, g/kg DM	47.7	81.2
Crude fats, % DM	7.1	7.1
Nitrogen free extract, % DM	794.6	729.0
Inulin, g/kg DM	553.0	582.9
Starch, g/kg DM	35.3	48.6
Ash, g/kg DM	51.2	80.2
Calcium, g/kg DM	0.9	1.6
Phosphorus, g/kg DM	3.2	3.0
Metabolizable energy, MJ/kg DM	12.17	11.45

Table 5. Biochemical biomethane production potential of substrates

Indices	*Helianthus tuberosus*				*Sorghum bicolor* x *Sorghum sudanense* SASM 4		*Zea mays* Porumbeni 374	
	Solar		Maria					
	fresh mass	silage	fresh mass	silage	fresh mass	silage	fresh mass	silage
Organic dry matter, g/kg	919	897	897	873	923	916	948	941
Minerals, g/kg DM	81	103	103	127	77	84	52	59
Crude protein, g/kg DM	77	97	116	145	73	61	84	80
Nitrogen, g/kg DM	12.32	15.52	18.56	23.20	11.68	9.76	13.44	12.80
Carbon, g/kg DM	511	498	498	485	513	509	527	523
Ratio carbon/nitrogen	41.4	32.11	26.83	20.90	43.9	52.1	39.2	40.8
Cellulose, g/kg DM	251	284	239	285	379	364	223	221
Hemicellulose, g/kg DM	174	192	164	178	268	267	203	211
Acid detergent lignin, g/kg DM	60	50	53	33	45	39	48	37
Biomethane potential, L/kg DM	273	287	286	311	300	305	302	317
Biomethane potential, L/kg ODM	297	320	322	356	325	333	319	336

Table 6. Some quality indices of dry stem biomass from studied cultivars of Jerusalem artichoke, *Helianthus tuberosus*

Indices	*Helianthus tuberosus* cultivars	
	Solar	Maria
Carbon	46.96	47.11
Hydrogen	5.42	5.51
Nitrogen	0.29	0.31
Sulphur	0.05	0.05
Chlorine	0.03	0.04
Ash content of biomass, %	2.19	1.03
Gross calorific value, MJ/kg	18.60	18.83
Net calorific value, MJ/kg	17.41	17.62
Acid detergent fibre, g/kg	648	652
Neutral detergent fibre, g/kg	875	888
Acid detergent lignin, g/kg	99	101
Cellulose, g/kg	549	551
Hemicellulose, g/kg	227	236
Theoretical ethanol potential, L/tone	563	571

Lignocellulosic plant biomass is a promising renewable and safe resource for the production of various types of biofuels, and currently its utilization is a topic of great interest to researchers worldwide. The investigated cultivars differ in the rate of dehydration and defoliation in the autumn-winter period. It was found that, at the harvest time, the dry stem biomass yield of *‘Solar’* cultivar was 1.63 kg/m^2, while - of *‘Maria’* cultivar - 1.29 kg/m^2.

The chemical composition of dry biomass is a key factor that affects the calorific value of solid biofuels, also and the technologies to be implemented for the production of solid and liquid biofuels. The quality indices of dry stem biomass from the cultivars of Jerusalem artichoke studied by us is presented in Table 5. We found that the studied stem biomass was characterized by higher content of carbon and hydrogen, the optimal content of nitrogen, sulphur, chlorine and low ash concentration. The biomass of *‘Maria’* cultivar has higher calorific value. The potential of energy production as a solid fuel accounts for 227 GJ/ ha from *‘Maria’* cultivar and 284 GJ/ha from *‘Solar’* cultivar.

Analyzing the cell wall composition of stems of the studied cultivars we found that the substrate from *‘Maria’* cultivar contains higher amounts of cellulose, hemicellulose and acid detergent lignin. The estimated theoretical ethanol potential from stem cell wall carbohydrates averaged 571 L/t in the substrate from *‘Maria’* cultivar and 563 L/t in the substrate from *‘Solar’* cultivar, but the annual yield varied from 7400 L/ha (*‘Maria’* cultivar) to 9200 L/ha (*‘Solar’* cultivar). According to Fiserova et al. (2006) the Jerusalem artichoke stalks contained 28.5% alpha-cellulose, 23.1% hemicelluloses, 14.8% lignin, 33.9% extractives, 3.1% ash. Stolarski et al. (2014) reported that the harvested *Helianthus tuberosus* aerial mass contained 17.93-63.49% moisture, 3.02-5.26% ash, 44.83-46.98% C, 5.11-5.79% H, 0.032-0.050% S, 18.25-18.66 MJ/kg HHV and 5.20-14.78 MJ/kg LHV. Gunnarsson et al. (2014) determined the Jerusalem artichoke aerial mass contained: 15.7-24.8% Cel, 11.2-12.4% HC, 16.6-19.0% Lig, 1.6-1.8% CP, 3.2-3.8% EE, 10.9-12.2% extractives, 12.3-14.5% uronic acid and 5.8-12.2% ash. Liu et al. (2015) found that the aboveground biomass contained 28.4-48% Cel, 5.5-17.1% HC, 4.7-12.01% Lig and the ethanol potential yield varied from 1821 to 5.930 L/ha. Kikas et al. (2016) reported that the quality indices of Jerusalem artichoke biomass were 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. Szostek et al. (2018) mentioned that Jerusalem artichoke biomass had 15.41-16.02 MJ/kg HHV or 14.19-14.72 MJ/kg LHV. Prusov et al. (2019) found that *Helianthus tuberosus* stem cortex contained 51.1% alpha-cellulose, 16.3% hemicelluloses, 12.5% lignin, 1.8% ash, but 704 Jerusalem artichoke stem pith 67.7% alphacellulose, 4.6% hemicelluloses, 7.6% lignin, 1.3% ash. Rossini et al. (2019) noted that Jerusalem artichoke ethanol yield from tubers ranged from 1500 to 11000 L/ha and from aerial biomass - from 2835 to 11230 L/ha. In our previous research, Țîței et al. (2019), we found that the Jerusalem artichoke milled chaffs contained 2.12% ash and 19.1 MJ/kg HHV. Mehmood et al. (2019) reported that Jerusalem artichoke biomass contained 43.56-43.62% C, 5.35-5.40% H, 47.48-47.58% O, 0.49-0.51% N, 0.10% S, 8.85% ash, 17.48% fixed carbon with 18.76 MJ/kg HHV. Kurhak et al. (2021) found that the yield of *Helianthus tuberosus* first-year dry biomass was 16.2 t/ha with 17.4 MJ/kg LHV. Dalmış (2023) mentioned that, in *Helianthus tuberosus* fiber, there was 62.65% cellulose, 17.36% hemicellulose, 18.49% lignin and 1.5% others.

CONCLUSIONS

The local cultivars of Jerusalem artichoke *‘Maria’* and *‘Solar’* provide high productivity of green fodder with optimal nutrient content and feed energy values.

The tuber productivity varied from 2.67 kg/m^2 in *‘Solar’* cultivar to 3.91 kg/m^2 - *‘Maria’* cultivar.

The Jerusalem artichoke phytomass can be used for anaerobic digestion in biogas plants as green mass substrate or silage substrate with biochemical methane potential of 298-316 liters/kg organic matter.

The stems of the studied cultivars quickly shed leaves and dehydrate in the autumn-winter period; they can be chopped, milled and used as feedstock for the production of cellulosic ethanol and solid bio fuel.

The obtained results indicate that the local Jerusalem artichoke cultivar *'Maria'* is optimal to be cultivated for tubers and the cultivar *'Solar'* - to obtain energy biomass for the production of solid biofuel and cellulosic ethanol.

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