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THE TECHNOLOGICAL ITINERARY, SYSTEM OF MACHINES FOR THE CULTIVATION OF JERUSALEM ARTICHOKE *HELIANTHUS TUBEROSUS* AND ITS USE AS FODDER AND ENERGY BIOMASS

Victor ŢÎŢEI[1], Mihai GADIBADI[1,2], Natalia CÎRLIG[1], Alexei ABABII[1,2], Ana GUŢU[1]

[1] "Alexandru Ciubotaru" National Botanical Garden (Institute), 18 Padurii Street, Chişinău, Republic of Moldova, Phone: +37322550443, Fax: +37322550443, Emails: vic.titei@gmail.com, m.gadibadi@uasm.md, nataliacirlig86@gmail.com, ababiialexei@gmail.com, anaiuliagutu@mail.ru
[2]State Agrarian University of Moldova, 56 Mirceşti str., Chişinău, Republic of Moldova, Phone: +37322312232, Fax: +37322312232, Emails: m.gadibadi@uasm.md, ababiialexei@gmail.com

Corresponding author: vic.titei@gmail.com

Abstract

The technological itinerary and the system of machines and equipment used for the cultivation of Jerusalem artichoke, Helianthus tuberosus L., and possibilities to use on the cv. Solar as fodder and energy biomass are presented in this article. We found to planting and harvest Jerusalem artichoke tubers, the same agricultural machinery and equipment will be used as for potatoes crop, and to harvest aerial biomass – agricultural machinery and equipment for harvesting corn and other silage crops. The Jerusalem artichoke energy biomass can be processed into solid fuel with the available briquetting/pelletizing machines, the net calorific value of solid biofuel was 17.7 MJ/kg and the ash content – below 2.2 %. It has been determined that the prepared silage contained 240-290 g/kg DM, 9.7-13.5 % CP, 8.90-12.96 % CA, 55.9-62.3 % NDF, 31.0-45.8 % ADF, 4.8-6.3 % ADL, 11.25-12.43 MJ/kg DE, 9.23-10.21 MJ/kg ME and 5.96-7.02 MJ/kg NEl. The biochemical methane potential of Jerusalem artichoke silage substrate 4,000-6,000 m^3/ha. The lignocellulosic substrate of Jerusalem artichoke dry stems contained 276 g/kg cellulose, 176 g/kg hemicellulose, 98.04 g/kg hexoses sugars and 45.4 g/kg pentoses sugars, the theoretical bioethanol yield from stems was 598 l/kg. Helianthus tuberosus cv. Solar may serve as an alternative crop for producing silage and as a sustainable source of feedstock for renewable energy production.

Key words: *biochemical composition, biomethane potential, Helianthus tuberosus cv. Solar, physical and mechanical properties, silage fodder value*

INTRODUCTION

Recently, the value of some neglected and underutilized plant species has been reassessed and researchers concluded that they can be successfully cultivated for different purposes.
Jerusalem artichoke, *Helianthus tuberosus* L. (synonym *H. esculentus* Warsz., *H. serotinus* Tausch, *H. tomentosus* Michx), fam. Asteraceae, native to North America, is a C_4, herbaceous, perennial plant. 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. 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 [38].

Jerusalem artichoke, *Helianthus tuberosus* contains large amounts of organic polyacids, including citric acid, malic acid, succinic acid and fumaric acid. Together with vitamin C, these substances can act as antioxidants. Jerusalem artichoke also contains high amounts of pectin (about 11% of dry matter). Pectins are high molecular weight carbohydrates contained mostly in the cell membrane and intercellular tissue of some plants. Pectins possess absorbent, astringent and thickening properties. They may offer several potential health benefits, such as: lowering the cholesterol level, improving metabolic processes, normalizing bowel movements and improving the peripheral circulation. The tubers of Jerusalem artichoke are used for the preparation of salads, including for the prevention and correction of blood sugar in diabetes mellitus; green mass is used in folk medicine, for example, for the prevention of joint diseases (arthrosis, bursitis, arthritis, etc.), as well as herbal baths to relieve fatigue, increase immunity and improve the overall health in the winter-spring period. Currently, this species is researched in various universities and research centres. More than 200 Jerusalem artichoke cultivars have been created and patented worldwide, the cultivated area exceeds 2.5 million ha, tubers are used in food, medicine, biorefineries, and the aerial biomass – as fodder, raw material for obtaining renewable energy, biochemicals and building materials [1, 9, 11, 14, 16, 17, 18, 19, 21, 23, 26, 27, 33, 34, 35, 36, 37, 39, 40, 41, 43, 44]. The Jerusalem artichoke tubers are composed of 72.09-78.23 % water, 17.10-19.47 % carbohydrates, inclusive 12.08 -13.39 % inulin, 10.56-13.49 mg/100g fresh mass vitamin C and 1-2 % protein [7]. Jerusalem artichoke tuber flour has a high content of essential amino acids such as histidine, isoleucine, methionine, phenylalanine and valine, the replacement of wheat flour with 5% Jerusalem artichoke tuber flour, to obtain a product rich in micro and macronutrients with better organoleptic properties and a longer shelf life, which positively influences human health [5].

In the Catalogue of Plant Cultivars of the Republic of Moldova, there are 3 registered cultivars of Jerusalem artichoke: ‘Solar’, ‘AMIC 1’ and ‘AMIC 2’ [4].

While conducting this research, we aimed at identifying the most optimal techniques and equipment for the cultivation of Jerusalem artichoke, *Helianthus tuberosus* L., to make it possible to use its biomass as a source of fodder and fuel.

MATERIALS AND METHODS

The cultivar ‘Solar’ of Jerusalem artichoke *Helianthus tuberosus* L. was created in the National Botanical Garden (Institute) and registered in 2014 in the Catalogue of Plant Varieties [4] and patented in 2016, by the State Agency on Intellectual Property (AGEPI) of the Republic of Moldova, patent no. 209/31.05.2016 [3]. The plants that have been cultivated in the experimental plot of the “Alexandru Ciubotaru” National Botanical Garden (Institute), Chişinău, served as research subjects.

The technological itinerary was elaborated on the basis of the analysis of the specialized literature, and the technical means necessary for its realization were determined on the basis of the bibliographic sources and the range agricultural machines and equipment available on the market [1, 2, 12, 17, 19, 20, 21, 25, 28, 29, 30, 31, 40, 42, 47]. Scientific research was also carried out in the Agricultural Machinery Laboratory of the Faculty of Agricultural Engineering and Auto Transport, State Agrarian University of Moldova.

Fresh mass samples were taken for evaluation at the beginning of the flowering stage. Whole plants were cut to pieces with the stationary feed shredder, and the fractional composition of the obtained shredded mass was determined by using the vibratory sieve shaker (sieve diameter – 400 mm; opening diameter – 31.5 mm, 16 mm, 8 mm, 3.15 mm). The silage was prepared from shredded mass by compaction in airtight containers. The silage produced by this method was dehydrated in a forced ventilation oven, at 60 °C, for further chemical analyses. After that, we used a laboratory ball mill to grind finely the biological material. The amounts of crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) and crude ash (CA) were determined by near infrared spectroscopy (NIRS) in a PERTEN DA 7200 NIR analysis system, at the Research-Development Institute for Grasslands Brasov, Romania. We applied standard equations to calculate the concentration of hemicellulose (HC) and cellulose (Cel), as well as metabolizable energy (ME), digestible energy (DE) and net energy for lactation (NEl). The estimation of the biogas production potential and the specific methane yield was based on the chemical compounds identified in the cell walls, sulphur-containing lignin and hemicellulose [6]. The dried stalks of *H. tuberosus* were harvested in January and shredded, then, the obtained mass was ground in a hammer mill (diameter of sieve openings: 10 mm and 6 mm). The fractional composition of the shredded and ground mass was determined using the vibratory sieve shaker (sieve diameter of 200 mm and different size of openings). The Jerusalem artichoke pellets and briquettes were manufactured and evaluated using the equipment of the “Solid Biofuels” Laboratory of the State Agrarian University of Moldova and the State Enterprise "Mecagro" Institute of Agricultural Technology.

The estimation of the theoretical potential of bioethanol production (TEP) from Jerusalem artichoke stems (L/kg) was performed according to the equations of the National Energy Research Laboratory (NREL) (Golden, CO) adjusted by Goff et al. [8], as presented below.

$$TEP = [H + P] \times 4.17 \quad (1)$$

where:

$$H = [\%\ Cel + (\%\ HC \times 0.07)] \times 172.82 \quad (2)$$

where:
H - hexose sugars (H)
Cel- cellulose content
HC- hemicellulose content

$$P = [\%\ HC \times 0.93] \times 176.87 \quad (3)$$

where:
P - pentose sugars
HC- hemicellulose content.

The equation indicated above shows that cellulose (Cel) and hemicellulose (HC) are converted into hexoses (H) and pentoses (P).

The amount of cellulose was estimated via subtraction of the values obtained for ADL from the concentration of ADF. The amounts of hemicelluloses were estimated via subtraction of the ADF from the NDF values obtained for each sample.

RESULTS AND DISCUSSIONS

According to the classical agricultural technologies, Jerusalem artichoke should be grown outside the crop rotation system. It can be grown on a land previously cultivated with wheat, corn, sorghum, vetch, peas or soya; but the lands on which sunflower and rapeseed have been cultivated should be avoided because of their common diseases (*Sclerotinia sclerotiorum*). The soil preparation and cultivation techniques are similar to those required by the potato cultivation technology. It is necessary to plough the soil at 25-30 cm depth, to incorporate manure, mineral fertilizers and to loosen the soil. Thus, proper conditions will be created for the development of the root system and the storage of needed water reserves. The soil shall be harrowed several times until autumn and twice in spring, with the disc harrow or the cultivator, to loosen it before planting. The optimal depth for planting the tubers is 4-10 cm, and the distance between rows should be 70 cm. The recommended plant density is 25-40 thousand plants/ha. Weed must be removed when necessary throughout the growing season. The growing season ends with the harvest of the aerial biomass and tubers. Several specialists have mentioned that when creating industrial plantations of Jerusalem artichoke to produce tubers for food, pharmaceutical and biochemical needs, the planting scheme needs to be adjusted to fit the equipment that is going to be used for harvesting and transporting aerial biomass, so that it will not cause any significant soil compaction or tuber damage. The technological elements and the necessary agricultural machinery for the cultivation of *Helianthus tuberosus* were studied by many researchers, such as Kosaric et al. [15], Barloy [2], Soltner [28], Zimin [47], Abdel Maksoud et al. [1], Kalinin [12], Manokhina [19, 20], Starovoytov et al., [29, 30, 31], Mikheev et al. [21], Rossini et al. [26], Liava et al. [17]. Thus, Zimin [47] mentioned that the most difficult and time-consuming technological operation is the harvesting of tubers. He concluded that potato harvesters, weighing more than 7 tons, are not suitable for the conventional technology, because 45% of the tubers are thrown away in the field along with the roots, and recommended using the digger-loader KP-2, weighing 1,800 kg, designed by VISKHOM to re-equip the machine KCT-1.4. Romanyuk et al. [25] proposed the planting scheme 132x35 + 35 + 35x30 cm; they recommended the feed harvesting combine KBK 8060 "PALESSE FS 8060" for harvesting the aerial biomass, and for transporting it – the PS-60 semi-trailer attached to a BELARUS 1221 tractor. Vlăduţ et al. [42] presented 12 types of machines to harvest Jerusalem artichoke aerial biomass and tubers in small, medium and large areas.

Particle size distribution of chopped green mass influenced the costs of transport and particle size reduction has been reported as one of the major effects of silage quality. It was established that when passing through the feed shredder, the harvested whole plants contained 38-43 % leaf, a moderate amount of humidity and fine fibres, which affected the homogeneity of the shredded mass. It was determined that the Jerusalem artichoke shredded green mass contained 16.0 % particles larger than 16.0 mm, 38.6 % particles of 8.0-16.0 mm, 43.0 % particles of 3.15-8.0 mm and 11.9 % particles smaller than 3.15 mm.

When the containers with silage from Jerusalem artichoke were opened, there was no gas and liquid leakage, the colour of the silage was dark green and it had a specific aroma of pickled vegetables, with active acidity pH = 3.9-4.30 (Photo. 1).

Photo 1. Jerusalem artichoke ‘Solar’ silage
Source: Own photo.

The silage prepared from Jerusalem artichoke ‘Solar’ shredded mass contained 240-290 g/kg dry matter. The biochemical composition and fodder value of silage dry matter were 4.5-5.7 % lactic acid, 1.2-1.4 % acetic acid, 9.7-13.5 % CP, 8.90-12.96 % ash, 4.7-6.5 g/kg Ca and 2.8-3.1 g/kg P, 55.9-62.3 % NDF, 31.0-45.8 % ADF, 4.8-6.3 % ADL, 11.25-

12.43 MJ/kg DE, 9.23-10.21 MJ/kg ME and 5.96-7.02 MJ/kg NEl. The esteemed biochemical methane potential of Jerusalem artichoke silage substrates was 4,000-6,000 m^3/ha. According to Karsli et al. [13] the quality indices of Jerusalem artichoke silage were: pH=4.54-4.81, 2.12-4.30% lactic acid, 2.12-4.30% acetic acid, 0.29-0.41% propionic acid, 0.82-1.14% ammonia-N levels, 29.99-33.28% DM, 85.41-85.79% OM, 8.58-9.59% CP, 35.58-42.53% NDF, 23.94-30.12% ADF, 51.71-54.67% IOMD, 1.87-2.012 Mcal/kg ME. Wang et al. [44] reported that Jerusalem artichoke silage contained 258 g/kg DM, 12.4 % CP, 1.6% EE, 31.7 % ADF, 43.9 % NDF, 7.5% ADL, 11.9 MJ/kg DE, 9.20 MJ/kg ME. Herrmann et al. [10] studied the nutrient and fibre composition of crop silages in Germany and remarked that the Jerusalem artichoke silage contained 14.3-41.3% dry matter and 87.2-92.2% organic matter, pH 3.6-4.3, 5.1-9.6% lactic acid, 0.4-2.1% acetic acid, 4.6-15.0% protein, 0.9-3.3% fat, 37.6-49.9% NDF, 34.7-45.8% ADF, 8.3-17.7% ADL, C/N=18-57, biochemical methane potential 198.9-236.1 L/kg OM. Zhang et al. [46] analysing literature data reported the BMP yields of Jerusalem artichoke substrates varied from 252 to 370 l/kg VS.

In autumn, when temperatures below 0°C are recorded, the rates of dehydration and defoliation of the stems accelerate, and in January, the stems are completely defoliated, and the moisture content does not exceed 15%. It was determined that the shredded mass of dried Jerusalem artichoke stems contained 15.7% particles larger than 8.0 mm, 65.4 % particles of 3.15-8.0 mm, 15.1 % particles of 1.00-3.15 mm and 4.3 % smaller than 1.00 mm. Among the fundamental physical properties of solid biofuel (briquettes, pellets) which were observed belong the density, durability, moisture content and calorific value. It was found that the ground Jerusalem artichoke biomass had a bulk density of 165-190 kg/m^3, and the briquettes had a bulk density of 435 kg/m^3 and a specific density of 872 kg/m^3; the pellets had a bulk density of 552 kg/m^3 and a specific density of 880 kg/m^3 (Photo 2). The net calorific value of solid biofuels was 17.7 MJ/kg and the ash content – below 2.2 %.

There are different results reported in research studies conducted by other authors. In Poland, Kowalczyk-Jusko et al. [16] stated that the calorific value of biomass of the examined varieties of Jerusalem artichoke varied within narrow limits 16.10- 16.30 MJ/kg, while the ash content was 5.4- 5.6%; Stolarski et al. [32] mentioned that the ash content of *Helianthus tuberosus* stalks, from November to April, decreased from 5.26% to 3.02%, but the gross calorific value grew insignificantly from 18.45 to 18.59 MJ/kg dry matter. Urbanovičová et al. [41] mentioned that produced Jerusalem artichoke briquettes contained 11% water, 3.40% ashes, 3.07 g/kg nitrogen, 0.70 g/kg phosphorus, 1.93 g/kg potassium, 0.71 g/kg sulfur, 0.71 g/kg chlorine, 14.41 g/kg lignin, reached density 940 kg/m^3, 92 % durability and 16 MJ/kg calorific value. Zapalowska & Bashutska [45] noted that Jerusalem artichoke pellets were characterized by 6.81% moisture content, 2.04% ash content, 18.85 MJ/kg energy value and 1,024.57 Newton resistance to crushing.

Bioethanol fuel is a renewable energy source, which is a potential alternative to some fossil fuels. Bioethanol is mainly produced by sugar fermentation. The potential of second generation bioethanol produced from lignocellulosic biomass as an alternative energy source has been studied in many research centres around the world. Lignocellulosic biomass contains primarily polymeric sugars, such as cellulose and hemicellulose, lignin and minerals, in smaller amounts (ash). The amounts of these components vary significantly depending on the plant species, type of biomass and harvesting time. [9, 17, 18, 22, 24, 26, 43].

Analyzing the cell wall composition, we could mention that the lignocellulosic substrate of Jerusalem artichoke stems (Photo 3) contained 276 g/kg cellulose, 176 g/kg hemicellulose, 98.04 g/kg hexoses and 45.4 g/kg pentoses, the theoretical bioethanol yield from stems was 598 l/kg, for comparison, 556 l/kg can be obtained from corn stems.

A

B

Photo 2. Solid biofuel from Jerusalem artichoke 'Solar'
A – briquettes; B – pellets
Source: Own photo.

Photo 3. Lignocellulosic biomass substrate of Jerusalem artichoke 'Solar' for bioethanol fuel
Source: Own photo.

Several literature sources describe the biochemical composition of Jerusalem artichoke stem. Gunnarsson et al. [9] determined the Jerusalem artichoke stem harvested in December contained 16.5-29.5% cellulose, 9.3-14.6 % hemicellulose, 16.3-20.7% lignin and 1.1-2.9 % protein, 2.1-3.8 % lipids, 10.1-12.7 % extractives and 2.9-7.9 % ash. Prusov et al. [23] remarked that cellulose yield from the stem was: cortex 51.1%, pith 65.2% with the α-cellulose content 96–98%. Wang et al. [43] reported that Jerusalem artichoke stalks contained 320 g/kg lignin, 405 g/kg cellulose, 19.6 g/kg hemicellulose, after NaOH pretreatment the lignin content decreased by 13.1%-13.4%, hemicellulose content decreased by 87.8%-96.9% and cellulose content increased by 56.5%-60.2%.

Liu et al. [18] found that cellulose content of Jerusalem artichoke stem range from 23.3% to 33.4%, hemicellulose content - from 5.9% to 15.1% and lignin from 4.7 to 12% respectively.

The ethanol potential yield from cellulose and hemicellulose in aboveground biomass were 1,821 to 5,930 L/ha, contributing 29.8-66.4% of the total ethanol yield.

CONCLUSIONS

The technological itinerary for cultivating Jerusalem artichoke plants includes soil preparation, weed and pest control during the growing season, aerial mass harvesting, tuber harvesting and storage.

To planting and harvest Jerusalem artichoke tubers, the same agricultural machinery and equipment will be used as for potatoes crop, and to harvest aerial biomass – agricultural machinery and equipment for harvesting corn and other silage crops.

The Jerusalem artichoke energy biomass can be processed in solid fuel with the available briquetting/pelletizing machines.

The prepared silage had pH index 3.90-4.30 and contained 240-290 g/kg DM, 4.5-5.7 % lactic acid, 1.2-1.4 % acetic acid, 9.7-13.5 % CP, 8.90-12.96 % CA, 4.7-6.5 g/kg Ca and 2.8-3.1 g/kg P, 55.9-62.3 % NDF, 31.0-45.8 % ADF, 4.8-6.3 % ADL, 11.25-12.43 MJ/kg DE, 9.23-10.21 MJ/kg ME and 5.96-7.02 MJ/kg NEl. These characteristics indicate a good quality of feed for ruminants.

The biochemical methane potential of Jerusalem artichoke silage substrates was 4,000-6,000 m^3/ha.

The lignocellulosic substrate of Jerusalem artichoke dry stems contained 276 g/kg cellulose, 176 g/kg hemicellulose, 98.04 g/kg hexoses sugars and 45.4 g/kg pentoses sugars, the theoretical bioethanol yield from stems was 598 l/kg.

Helianthus tuberosus cv. Solar may serve as alternative silage crops and sustainable feedstock for renewable energy production.

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