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Varietal Characteristics of Jerusalem Artichoke as a High Nutritional Value Crop for Herbivorous Animal Husbandry

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Abstract: Jerusalem artichoke (*Helianthus tuberosus* L.) is considered to be one of the most promising multipurpose bioenergetic crops. The goal of this study was to carry out laboratory and field research regarding the tops and tubers of 16 Jerusalem artichoke (JA) cultivars grown on sod-podzolic sandy loam soils, taking into account varietal characteristics in order to point out advances in JA potential as alternative feedstock in herbivorous animal husbandry. The height of JA plants produced was from 147 to 280 cm. Having formed by the beginning of September, the size of the assimilating leaf apparatus surface was 0.41 to 2.31 m^2/plant. In early September, the productivity of JA green mass amounted to 23.6 to 86.0 t/ha for late-maturing cultivars on average; correspondingly, this was 13.0 to 25.4 t/ha for early-maturing cultivars. At the end of October, the "late" cultivars produced 28.2 to 86.9 t/ha of green mass; on the contrary, the herbage of the "early" ones mostly withered and even dried up. The highest gross yield of tubers in early September was obtained from cultivars Diyeticheskiy (43.5 t/ha) and Nadezhda (40.8 t/ha). The average yield of early-maturing cultivars was 13.4 . . . 43.5 t/ha; as for "late" ones, it was reported to be 6.0 . . . 35.9 t/ha. In the third ten-day period of October, tubers of all cultivars gained weight significantly: the average yield of early-maturing cultivar tubers increased up to 33.1 . . . 51.1 t/ha, whereas the average tuber yields of "late" cultivars were 14.4 . . . 43.9 t/ha. On average, the distribution of dry matter content in JA was 28.8 to 29.8% in aboveground biomass and in tubers, 23.8 to 24.0%. According to the chemical composition, cellulose (10.9 to 13.1%) and sugars (4.0 to 4.2%) could be noted to predominate in the green mass, but tubers were high in sugars (16.9 to 17.6%). The analyses on the trace elements (Ca, Fe, Mg, Mn, Si and Zn) showed that crop green mass contained more Mg (45 to 72 mg/100 g) and Mn (44 to 65 mg/100 g), but for JA tubers, late-maturing cultivars were rich in Si (27.2 to 79.0 mg/100 g) and early-maturing cultivars were mainly high in Zn (32.8 to 46.5 mg/100 g). The highest total coefficient of energy efficiency was displayed by the following cultivars: Novost VIRa (3.09); Tadzhikskiy (2.78); Spindle (2.68); Korenevskiy (2.43); Interes (2.10); and Skorospelka (1.98). In this respect, Jerusalem artichoke certainly has potential as a forage crop that can reach high yields with low external inputs. The data obtained may be useful for farmers who want to adapt and produce this useful and essential crop for the sustainability of feed production.

Keywords: Jerusalem artichoke; green mass; tubers; feed value; chemical composition; macro- and microelements

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1. Introduction

One of the main objectives of the state program for agriculture development is the increase in worldwide forage production. Fodder production is sure to be a fundamental branch of agriculture. The analyses of the scientific and technical state of feed production and animal husbandry in recent years and the prospects for the development of these industries in a market economy have shown that breakthrough innovative solutions are urgently needed for successful progress to be made in animal husbandry, fish farming, and keeping domestic animals. In the long term, Jerusalem artichoke should become a strategic point for further forage production development in the country, along with grain. The herbage of Jerusalem artichoke must be used for the production of inexpensive, high-quality feed, both for large and personal subsidiary plots [1–3].

Topic relevance: Jerusalem artichoke (*Helianthus tuberosus* L.) is considered to be one of the most appreciable bioenergetic agricultural crops for general-purpose application, since it is a source of inulin, fructose and pectin [4,5]. JA green mass is characterized by a high content of carbohydrate complex (fructose, glucose, sucrose, fructosides, etc.).

The plant dry mass contains up to 17% protein with a balanced amino acid composition. The introduction of inulin and bioethanol process waste from Jerusalem artichoke into feed composition may provide an increase in the economic efficiency of animal husbandry and guarantee the ecological safety of animal products [6,7].

Since the beginning of the twentieth century, Jerusalem artichoke has been known in India, Afghanistan and Egypt. As a valuable fodder, food and medicinal crop, it has been grown in the USA, Canada, Australia, Japan and some other countries [8–10]. Currently, the area under use for Jerusalem artichoke growth is globally about 2.5 million hectares; in France, for example, it is almost equal to the area under use for potato growth. Despite a shortage of arable land, China has intensively been developing its JA production. Jerusalem artichoke is grown as a vegetable crop in many countries, e.g., Italy, Spain and Germany. It is imported in small quantities to Russia as a vegetable crop [11–13].

Jerusalem artichoke is cultivated on an area of only about 3 thousand hectares in Russia, mainly in the regions of Nizhny Novgorod, Lipetsk, Tver, Ryazan, Tula, Ulyanovsk, Kostroma, Volgograd, Omsk, Bryansk, Moscow, Saratov, Yaroslavl, as well as, in the Republic of Chuvashia, the Krasnodar and Stavropol regions [7,8].

There are more than 200 Jerusalem artichoke species, most of them being herbaceous like sunflowers, some being semi-shrubs, and very few being real shrubs up to 5–7 m in height [4]. E.I. Stroeva, an individual entrepreneur, the head of a farm in the Kameshkovskiy district, the Vladimir region, is sure that Jerusalem artichoke is a very unpretentious plant [14,15] (Figure 1).

Figure 1. Areas planted with artichoke at the farm household headed by E.I. Stroeva, an individual entrepreneur (village Serebrovo, Kameshkovskiy district, Vladimir region).

World experience in the cultivation of Jerusalem artichoke has shown that the plant does best in areas with a temperate climate [16–18]. It does well on different soils, excluding acidic, saline and waterlogged soils. It thrives even on nutrient-poor soils. The plant has a high reproduction rate and good frost and drought resistance. It easily tolerates spring frosts and autumn cold snaps [16,17,19]. Thus, it is vital to choose a cultivar suitable both for soil and climatic conditions. Otherwise, a cultivar that is not adapted to local environments will result in poor-quality production and low plant productivity [20–22], as the geographical location of the area for JA cultivation is crucial to ensure maximum yield [23–25]. However, in the majority of cases, attention has been drawn mainly to the physiological aspects of this species, while agronomical practices are still not well developed.

Since Jerusalem artichoke is a short-day crop, the productivity of a cultivar depends on its photoperiodic sensitivity and adaptive ability to local growing conditions. In this regard, the photosynthetic activity of cultivars is very different and it also depends on the degree of their short-day duration, as well as on the ecological and geographical conditions of cultivation [26]. The total leaf area of plants is an indicator of the photosynthetic activity and productivity of each cultivar [25,27,28].

The aboveground mass of Jerusalem artichoke can be applied for livestock feeding in the form of green top dressing, hay or in silage [15,20,29]. Possessing the ability to regrow after grazing, Jerusalem artichoke can also be used as a pasture crop. Herbage in its nutritional value is not inferior and even surpasses other fodder crops [3,30,31]. The yield of herbage and digestible protein from Jerusalem artichoke per 1 hectare is 2–4 times higher than that of other forage plants. Silage from Jerusalem artichoke herbage is second only to corn silage in nutritional value; it surpasses sunflower silage in taste. It is readily eaten by cattle, pigs, sheep, goats and rabbits. The digestible protein content is 1.2% per 100 kg of JA herbage silage, 0.8% for sunflower silage and 0.6% for corn silage, respectively. [4,32,33]. The value of Jerusalem artichoke as a fodder, vegetable, industrial and medicinal crop is determined, first of all, by the chemical composition of the plant [6,34,35]. Herbage serves as a source of potassium, magnesium, calcium, etc. [4,30,36]. Jerusalem artichoke tubers and aboveground mass contain a large amount of dietary fiber, protein, amino acids, including essential ones, vitamins, vital macro- and microelements, as well as organic and fatty acids. In terms of the content of magnesium, iron, silicon, zinc, as well as vitamins B and C, Jerusalem artichoke surpasses potatoes, carrots and beets [3,37,38].

In feeding Jerusalem artichoke tubers and green mass to animals, it was revealed that there is a significant attraction for all classes of animals to this crop as a forage (herbage and tubers), and its preference over other forages was also revealed [1,39,40].

JA tubers are considered to be appropriate succulent feeds, so they are widely used in cattle rations [35]. Moreover, being a good source of easily hydrolysable carbohydrates, mainly sugars, they provide animals with energy. Having been fed with a Jerusalem artichoke tuber additive diet for 5–6 days, cows were reported to increase milk yield by 4–5 kg/day, and young animals significantly gained weight when JA tubers were given as a succulent feed for them [37]. In addition, Jerusalem artichoke is considered to be one of the best feeds for pigs and suckling pigs under the age of 60 days [40]. Additionally, it is necessary to point out the high nutritive value of JA herbage as well [8].

Animals fed from a very early age with feeds made from Jerusalem artichoke are, on average, three times healthier than those who are not and do not need antibiotics. Jerusalem artichoke increases milk yield by 20–25%, with its fat and protein content being improved as well. Jerusalem artichoke is likely to raise chicken egg production by 10% and dramatically improve egg taste. However, on the other hand, when feeding animals with Jerusalem artichoke, it is necessary to keep in mind the usual precautions of transferring animals to new feed, i.e., first, include a little Jerusalem artichoke in the feeding ration, and then increase the dose step by step. Recommended rates for adding Jerusalem artichoke silage to the daily diet are: for cattle—up to 25–45 kg; sheep and goats—up to 3–5 kg; pigs of all ages—up to 3–8 kg; horses—up to 8 kg; rabbits, nutria—up to 0.25 kg; poultry—up to 0.04–0.25 kg [4,31].

On the one hand, Jerusalem artichoke herbage is high in dry matter content, amino acids and carbohydrates; on the other hand, it is low in fiber; therefore, it can be considered as a source of high-energy feed exceeding legumes and corn in the feeding value [32]. Due to the high dry matter content (22–32%), the JA green mass feed value is equal to corn. To improve the quality of dairy products, it is recommended to use JA herbage as energy feed for up to 30% of cows' summer diets. It may increase the content of calcium by 4.2%, phosphorus by 7.6% and slightly increase protein content in raw milk [41]. JA green mass, as well as raw washed tubers, may be used as food for domestic rabbits [31].

JA green mass should be used for the production of economical, high-quality feeds, both for sizable enterprises and personal subsidiary farms [1–3].

Animals have been noted to readily consume both JA green mass and root crops (Figure 2).

Figure 2. Artichoke green mass as a kickshaw (the farm household headed by E.I. Stroeva, an individual entrepreneur (village Serebrovo, Kameshkovskiy district, Vladimir region)).

The purpose of the work was to conduct lab and on-farm research regarding the herbage and tubers of 16 JA cultivars with different maturation periods, grown on sod-podzolic sandy loam soils, and to highlight their advantages for feed production, considering their varietal characteristics, that is, to carry out phenological observations; to measure the biometric, morphological and chemical parameters of different JA cultivars; to inspect diseases and pests on Jerusalem artichoke plants; to determine the performance of JA green mass and tubers; and to calculate the energy efficiency of crop cultivation.

2. Methodology

2.1. Trial Field Soils

To find out if JA can be cultivated in soils in the Moscow Region, the research was carried out at the "Korenevo" Experimental Center test site in 2014–2016.

The Moscow Region is a constituent entity of the Russian Federation and belongs to the Central Federal District. The middle part of the territory of Russia, including the Central and Central Black Earth regions, the Middle Volga region, western Siberia, the Urals and mountainous regions, despite the wide variety of soil composition and fertility and the amount and uniformity of precipitation, is generally characterized by a relatively moderate background of infectious load and can be considered as a fairly fortunate region for organizing the individual production of high-quality Jerusalem artichoke for seeds and forage.

The research results were obtained on the basis of laboratory–field experiments, carried out on soils typical for the non-Chernozem zone of the Russian Federation in terms of their agrophysical and agrochemical properties.

The soils of the field trial site used to evaluate JA cultivars on the experimental base "Korenevo" were characterized as sod-slightly podzolic sandy loam with high exchangeable (pH_{KCl} = 4.4–4.9) and hydrolytic acidity (Hg = 3.3–4.8 meq/100 g of soil); low amounts of absorbed bases and saturation degrees (S = 1.5–3.9 meq/100 g of soil; V = 31.0–46.8%); high contents of mobile (available) phosphorus (267–354 mg/kg of soil) and below-average content of exchangeable potassium (95–136 mg/kg of soil); low humus content (1.6–1.9% humus); and easily hydrolysable nitrogen—64–76 Mg/100 g of soil.

2.2. Agrometeorological Conditions for Conducting Research

Agrometeorological conditions during the growing seasons of 2014–2016 were generally satisfactory for Jerusalem artichoke growth, development and productivity. The average air temperature in 2014 was 12.4 °C (in 2015—12.5 °C and in 2016—12.4 °C), with a norm of 11.4 °C. Total precipitation during the growing season in 2014 was 300.2 mm; in 2015 it was 425 mm, and it was 642.3 mm in 2016 at the rate of 410.1 mm.

Weather conditions are commonly characterized by the hydrothermal coefficient according to Selyaninov (HTC), the value of which is closely related to the yield level. HTC is determined by dividing the precipitation amount for the calculated period by the value of effective temperatures (>10 °C), reduced by 10 times over the same period. A decrease in yield is observed at HTC = 0.8 or less during the tuberization period. When HTC is more than 3.0, yield decreases are caused by moisture excess [42]. The HTC in 2014 was 0.97 (dry), in 2015 it was 1.61 (wet), and in 2016 it was 2.03 (very wet).

2.3. Research Conditions

The research objects were 16 Jerusalem artichoke cultivars [43]:

- Early-maturing—Skorospelka (Russian Federation (RF));
- Mid–early—Vylgortskiy (RF);
- Mid-season—Dieticheskiy (RF), Kaluzhskiy (RF), Korenevskiy (RF), Nadezhda (RF), Nakhodka (RF), Podmoskovniy (RF), Sireniki (RB), Blank Brekos (France) and Violet de Rense (France);
- Late-maturing—Interes (RF), Interes 21 (RF), Novost VIRa (RF), Tadzhikskiy Krasniy (USSR) and Spindle (Germany).

The following operations were carried out in the studies:

(1) Disking of green manure crops (vetch + oats) in 2 tracks using an aggregate with a disc harrow in the first ten days of August of the previous year;
(2) Autumn under-winter plowing (first ten-day period of October)—using a unit with a reversible plow without a skimmer to a depth of 18–20 cm;
(3) Spring continuous cultivation with harrowing (second–third ten-day period of April)—using a unit with a continuous cultivator with tooth harrows attached;
(4) Ridge formation using a row cultivator with fertilizer dispensers;
(5) Seed preparation—the calibration and selection of healthy tubers was conducted;
(6) Seed tubers of 25–40 mm in transverse diameter were planted on the test plot using a planting unit (Figure 3) and tubers were manually placed to a depth of 8–10 cm. Variable-size planting cups and their inserts ensured planting with any fraction of planting material.

Figure 3. General view of a planting unit.

The field test scheme consisted of the following aspects:

- Repeatability of the experiment—4 times;
- Planting density—25 thousand pcs./ha (75 × 53 cm);

- Recording plot area—20.0 m^2.

The planting dates were April 27–30.

Mineral fertilizers in the form of azofoska ($N_{60}P_{60}K_{60}$) were applied locally in May with two belts using a row cultivator with fertilizer dispensers. The ribbons were about 4 cm wide and were placed 4–5 cm in each direction from the center of the rest-balk and 3–4 cm below the row of tubers. Planting management included one pre-emergence and one post-emergence inter-row cultivation with hilling using a row cultivator in May–June. Weed control protective measures on stands were carried out with a boom sprayer and herbicides (the 1st treatment—Zenkor 600 g/ha + Titus 30 g/ha + Trend 200 mL/ha) in May.

2.4. Methodology of Field Experiments, Observations, Analyses and Reports

The field experiment was established, and records and observations were carried out in accordance with the requirements of the field experiment methodology [44], the Program and methodology for Jerusalem artichoke varieties assessment in test nurseries [45].

The evaluation of soil agrochemical parameters was fulfilled during the soil field survey, meeting the requirements of the Methodology for the soil samples selection on elementary field areas for differentiated use of fertilizers. The agrochemical characteristics of the soil before fertilization were: humus according to Tyurin (Russian National Standard GOST 26213-91); P_2O_5 and K_2O—according to Kirsanov (GOST 26207-91); pH (salt) potentiometrically (GOST 26483-85); hydrolytic acidity—according to Kappen, modified by ZINAO (GOST 26212-91).

Phenological observations were carried out according to the method of the State Sortset. For each cultivar, the number of days from planting to the emergence of shoots and the onset of budding, flowering and complete wilting of the green mass were taken into account [46].

The biometric parameters (plant height and leaf area) were assessed during the flowering phase of cultivars with early wilting of the aboveground plant parts [47].

The visual infestation registration of JA plants was completed. The evaluation of viral and bacterial diseases and pests was carried out on the basis of the visual examination of plants in the plot.

The calculation of fungal, bacterial and viral diseases in the field was carried out according to the method used when testing Jerusalem artichoke, similar to that used when testing potato via the sample method [44,48]. This was carried out in the following periods: the first survey was conducted when the plants reached a height up to 100 cm (July), the second survey—in the early flowering phase, and for mid–early cultivars (third ten-day period of August–first ten-day period of September), and the third one—in the budding–flowering phase of late-maturing cultivars (the third ten-day period of October).

Disease analyses were carried out by examining each plant in the sample (for rust, powdery mildew, cercospora, ascochitosis, bacterial spots and septoria) according to the number of affected plants on a scale: 9 points—no symptoms of damage; 8 points—the lesion can be from 1% to 10% of the leaf surface in the form of single spots on individual plants (up to about 10 leaves are affected by infection; in total, about 50 spots per plant); 7 points—from 10 to 25% of the leaf surface is affected (damage symptoms can be observed on almost all leaves of the plants, but bushes retain their normal shape, the predominant color is clearly green); 5 points—from 25 to 50% of the surface of plant leaves is affected (almost every plant is affected, but the main color of the bush remains green, although brown spots on the leaves make up a significant part); 3 points—more than 50% of the leaf area of all plants is affected (it is difficult to determine which color is dominant—brown or green, but the stems of most plants remain green); 1 point—all leaves of the plant are completely affected, with the stems dying or already dead [49].

Damage to the plant tops caused by leaf-eating pests was taken into account on a 5-point scale: 1 point—up to 5% of the leaf surface was destroyed; 2—from 5 to 25%; 3—from 25 to 50%; 4—from 50 to 75%; 5—more than 75% of the leaf surface was damaged.

For yield valuation, two manual weightings of green mass (tubers) from 4–8 plants were completed: the first weighting was carried out in the flowering phase for early-wilting herbage plant cultivars; the second one was carried out at the end of October.

In the harvesting samples during the flowering phase of cultivars with early herbage wilting, according to all variants in the experiment, the following findings were determined:

1. Indicators of green mass forage qualities: maximum plant height, cm; number of main stems, pcs; branching; the thickness of the main stem (at the butt and at a height of 40 cm), mm; assimilating leaf area, m^2/plant; the amount of green mass, t, in terms of 1 hectare; feed values in gigajoules of metabolized energy.

2. Productivity of tubers, t/ha.

3. Bioenergetic efficiency analyses of technological method combination according to the methodology of the All-Russian scientific research institute of patent information (1983) and the bioenergy assessment method [50].

The reliability of research findings was confirmed using the accepted methodology of field experiments, conducted for 3 research years, and with the results of statistical processing obtained according to the analysis of variance proposed by B. A. Dospekhov [44].

The analytical study of the macro- and microelement content was carried out at the base of the Kurchatov Institute Research Center—the IREA General Knowledge Center.

3. Results

3.1. Phenological Observations and Biometric Parameters of Plants

Within the research experimental procedure for each cultivar, the following factors were taken into account: number of days from planting to seedling emergence and the onset of budding and flowering phases. The lengths of the phases of cultivar development were different (Table 1).

Table 1. Results of phenological observations and biometric indicators records (on average for 2014–2016).

Sl. No.	Cultivar	Number of Days from Planting to:				
		Seedlings	Budding	Florescence	Herbage Wilting	Harvesting
Cultivars of Early Leaf Wilting (“Early Cultivars”)						
1	Vylgortskiy	37	106	120	162	176
2	Diyeticheskiy	37	106	119	161	176
3	Nadezhda	36	108	121	161	176
4	Nakhodka	35	107	120	162	176
5	Podmoskovniy	36	105	118	160	176
6	Sireniki	35	106	120	162	176
7	Skorospelka	36	108	118	160	176
8	Blank Brekos	37	107	121	161	176
Group average		36.1	106.6	119.6	161.1	176.0
LSD_{05}		0.8	1.0	1.1	0.8	0.0

Table 1. *Cont.*

Sl. No.	Cultivar	Number of Days from Planting to:				
		Seedlings	Budding	Florescence	Herbage Wilting	Harvesting
Cultivars of late leaf wilting ("late cultivars")						
9	Interes	36	176	-	200	176
10	Interes 21	36	-	-	200	176
11	Kaluzhskiy	35	-	-	200	176
12	Korenevskiy	35	165	176	200	176
13	Novost VIRa	34	170	-	200	176
14	Tadzhikskiy	36	176	-	200	176
15	Violet de Rense	36	176	-	200	176
16	Spindle	34	165	176	200	176
Group average		35.3	171.3	176.0	200.0	176.0
LSD_{05}		0.8	5.0	0.0	0.0	0.0
Total average		36	134	131	181	176
LSD_{05}		0.92	32.19	22.57	19.45	0.00

Figure 4 clearly shows the height of JA plants and the area of the assimilating leaf surface, depending on the cultivar. For visual convenience, JA varieties are arranged according to the increased assimilation leaf surface.

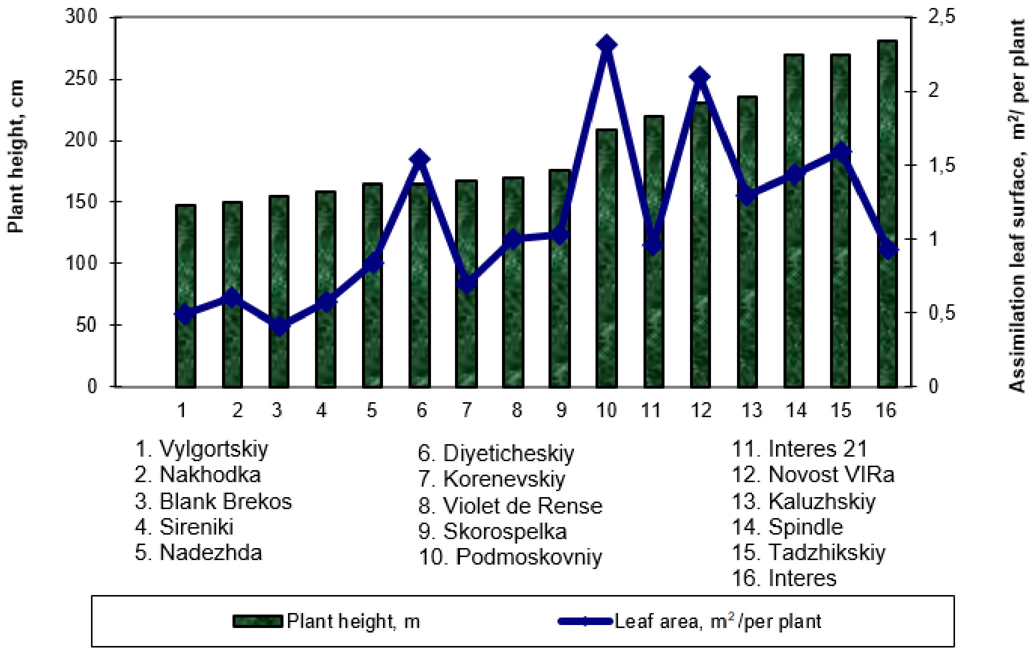


Figure 4. Results of biometric indicator records (on average for 2014–2016).

According to the height across all cultivars, the least significant difference (LSD_{05}) was 0.51 m in 2014, 0.36 m in 2015 and 0.46 m in 2016. In terms of assimilation leaf surface values across all cultivars, LSD_{05} was 0.63 m^2/plant in 2014, 0.44 m^2/plant in 2015 and 0.54 m^2/plant in 2015, respectively.

3.2. Evaluation of Pest and Diseases on Jerusalem Artichoke Plants

The data obtained from the examination of the powdery mildew infestation of leaves (Figure 5) are presented in Figure 6.

Figure 5. Jerusalem artichoke affected by powdery mildew.

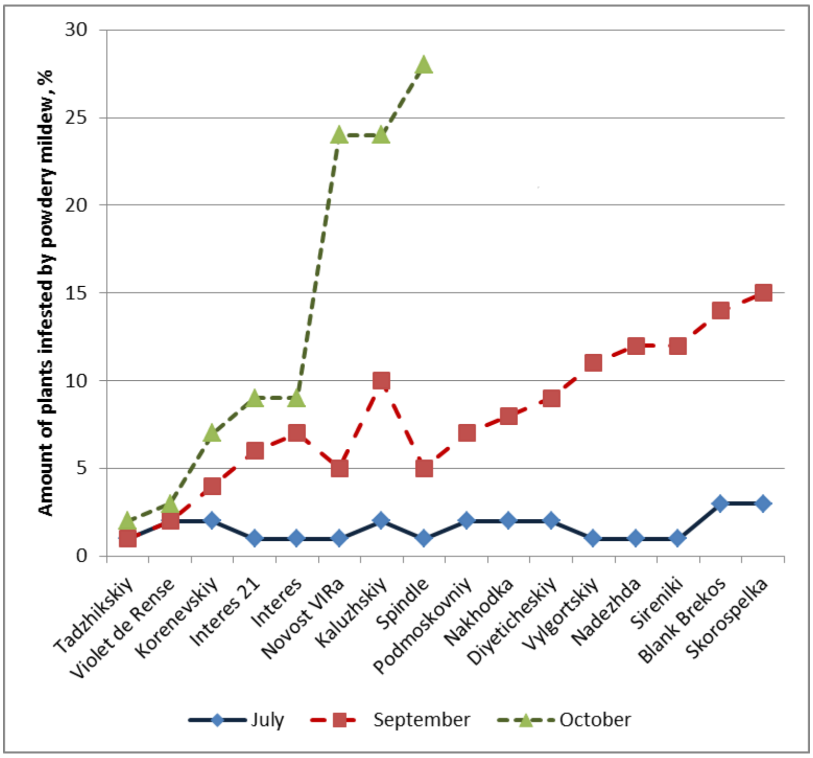


Figure 6. Distribution of powdery mildew on Jerusalem artichoke cultivars (on average for 2014–2016), Korenevo, Moscow Region.

Considering the incidence of powdery mildew on Jerusalem artichoke cultivars, the least significant difference (LSD_{05}) was 0.65% in June, 3.3% in September and 9.12% in December (2014); 0.75% in June, 4.7% in September and 10.26% in December (2015); and 0.70% in June, 4.0% in September and 9.72% in December (2016).

3.3. Green Mass Morphological Characteristics

Figure 7 illustrates the thickness range (diameter) of the main stems of different JA cultivars, as one of the morphological stem mass characteristics. For visual convenience, JA cultivars are arranged according to the decrease in the main stem diameter.

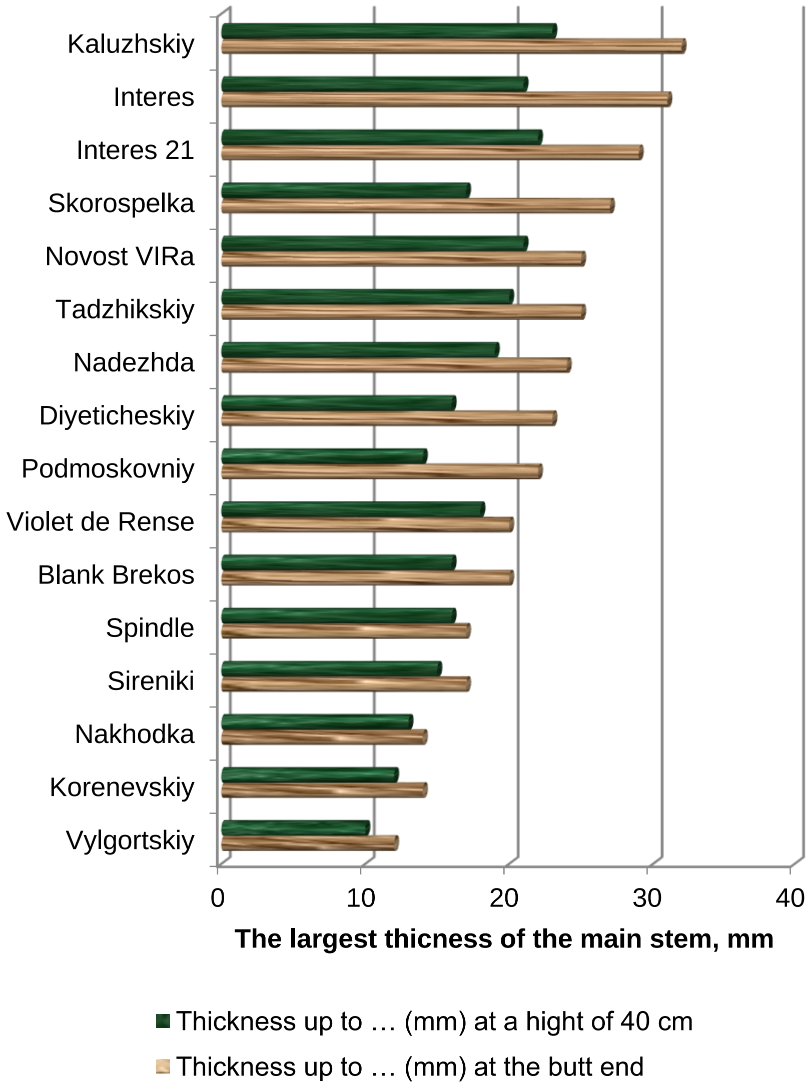


Figure 7. Thickness (diameter) of the main stem of different JA cultivars, mm.

The least significant difference (LSD_{05}) in thickness (diameter) of the main stem of Jerusalem artichoke cultivars was 4.66 mm at the butt end and 2.84 mm at a height of 40 cm in 2014; 7.23 mm at the butt end and 4.45 mm at a height of 40 cm in 2015; and 45.94 mm at the butt end and 3.65 mm at a height of 40 cm in 2016.

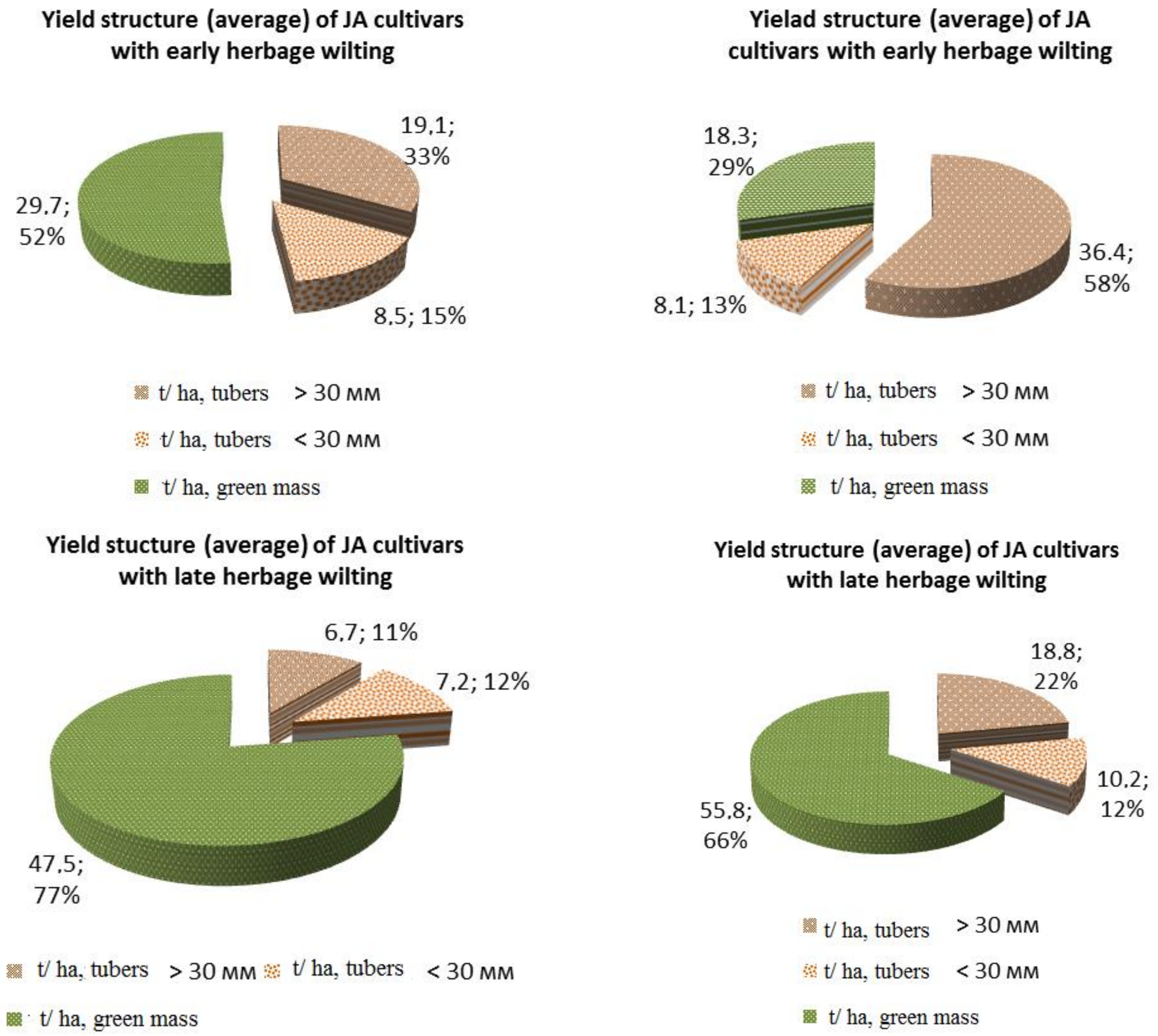
3.4. Jerusalem Artichoke Green Mass and Tuber Yield Recording

The total productivity of the JA herbage and tuber yield produced in sod-podzolic sandy loam soils under the Korenevo experimental base conditions, in Lyubertsy District, Moscow Region, per 1 ha, is shown in Table 2. The measurements were carried out in two periods: (1) the flowering phase of cultivars with early leaf wilting (early September) and (2) the budding–flowering phase of cultivars with late leaf wilting (the third ten-day period of October).

Table 2. Total yield of Jerusalem artichoke green mass and tubers, t/ha.

Sl. No.	Leaf Wilting Time	Cultivar	Green Mass			Tubers		
			September, 1st Ten-Day Period	October, 3rd Ten-Day Period	Increase in Yield	September, 1st Ten-Day Period	October, 3rd Ten-Day Period	Increase in Yield
1	Cultivars of early leaf wilting ("early cultivars")	Vylgortskiy	24.9	18.8	−6.1	13.4	37.5	24.1
2		Diyeticheskiy	23.6	18.1	−5.5	43.5	46.1	2.6
3		Nadezhda	42.3	25.4	−16.9	40.8	46.0	5.2
4		Nakhodka	13.5	13.0	−0.5	23.3	51.1	27.8
5		Podmoskovniy	28.4	19.0	−9.4	26.5	44.4	17.9
6		Sireniki	32.5	19.4	−13.1	23.1	46.9	23.8
7		Skorospelka	37.6	18.7	−18.9	19.4	50.7	31.3
8		Blank Brekos	34.8	14.1	−20.7	30.8	33.1	2.3
Group average			29.7	18.3	-	27.6	44.5	-
LSD_{05}		2014	7.98	1.77	-	7.75	4.03	-
		2015	9.02	5.,27	-	11.53	7.65	-
		2016	8.52	3.50	-	9.70	5.81	-
9	Cultivars of late leaf wilting ("late cultivars")	Interes	53.8	53.9	+0.1	15.8	27.1	11.3
10		Interes 21	25.3	29.2	+3.9	13.6	35.5	21.9
11		Kaluzhskiy	31.0	31.4	+0.4	10.1	19.4	9.3
12		Korenevskiy	38.4	57.3	+18.9	35.9	42.9	7.0
13		Novost VIRa	86.0	86.9	+0.9	12.1	25.2	13.1
14		Tadzhikskiy	56.5	79.3	+22.8	9.3	23.4	14.1
15		Violet de Rense	23.6	28.2	+4.6	6.0	14.4	8.4
16		Spindle	65.4	80.0	+14.6	8.5	43.9	35.4
Group average			47.5	55.8	-	13.9	29.0	-
LSD_{05}		2014	16.87	15.69	-	4.88	7.23	-
		2015	23.99	30.03	-	12.68	12.9	-
		2016	20.45	22.83	-	8.81	10.11	-
Total average			38.6	37.0	-	20.8	36.7	-
LSD_{05}		2014	14.56	19.66	-	6.97	7.34	-
		2015	21.44	30.08	-	16.03	15.27	-
		2016	18.03	24.84	-	11.47	11.29	-

Figure 8 clearly shows the general structure of Jerusalem artichoke yield (commercial tubers—more than 30 mm, small tubers—less than 30 mm and green mass), depending on herbage wilting time over a period of three years.



(**a**) (**b**)

Figure 8. Structure of JA yield (tubers and green mass) according to groups of herbage wilting time: (**a**) harvesting in the 1st ten-day period, (**b**) harvesting in the 3rd ten-day period of October and September.

3.5. The Value of Jerusalem Artichoke as a Forage Crop

We conducted studies to determine the dry matter chemical composition of Jerusalem artichoke green mass and tubers, considering the period of herbage wilting. Figure 9 shows the averaged values by groups.

Studies on the content of trace elements in Jerusalem artichoke green mass and tubers, depending on the period of herbage wilting (mg%), were also conducted (Figure 10).

3.6. Energy Efficiency of Jerusalem Potato Varieties Cultivation

While calculating the energy efficiency of artichoke varieties (Table 3), it is necessary to take into account the yield obtained of both tubers and herbage, with the latter being considered as high-quality animal feed or a full-fledged green manure crop.

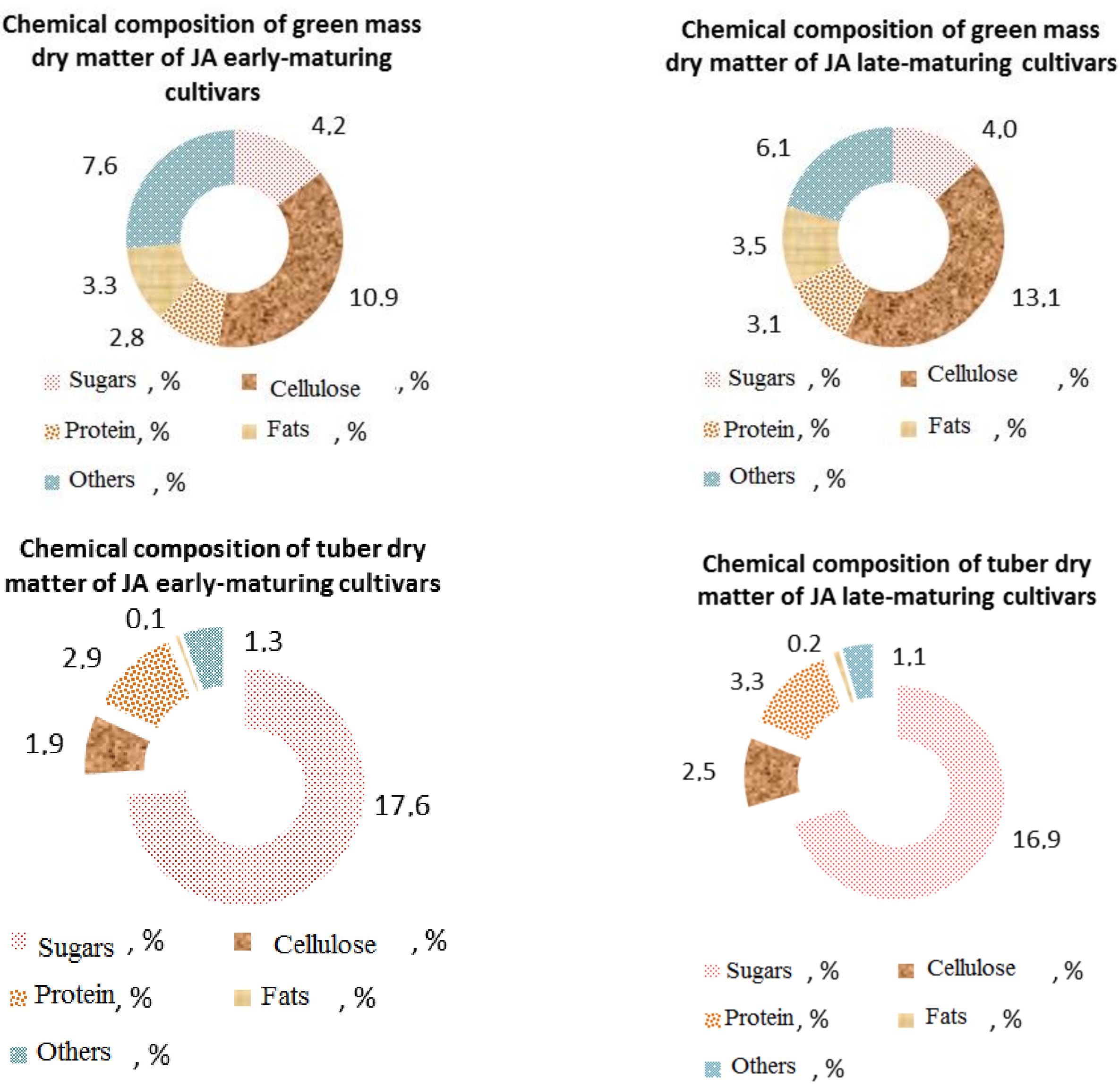


Figure 9. Dry matter chemical composition of Jerusalem artichoke green mass and tubers considering the period of herbage wilting (average by groups).

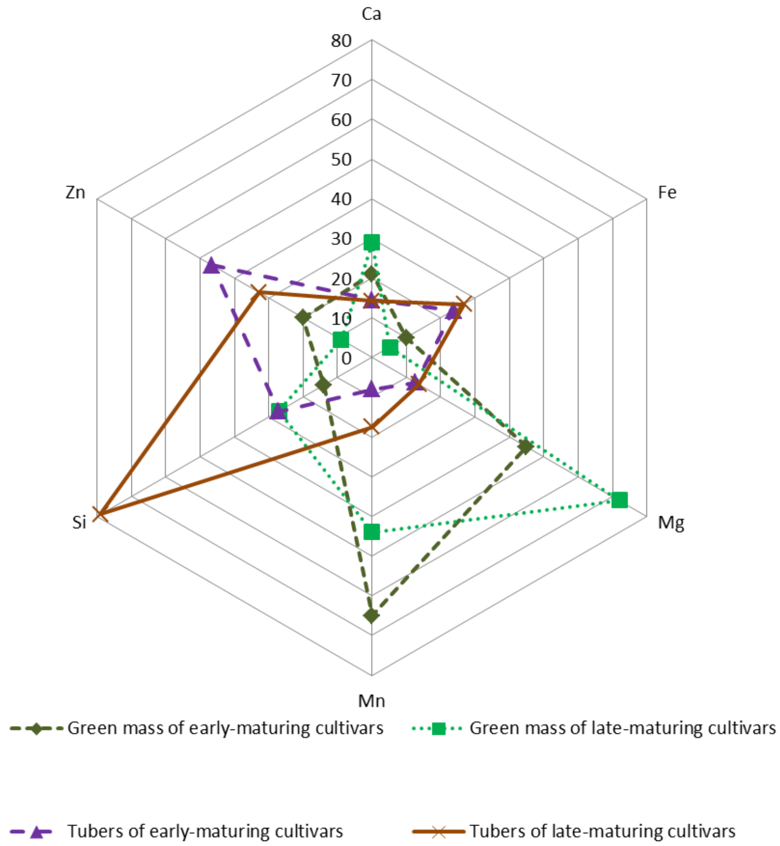


Figure 10. The content of trace elements in JA green mass and tubers, depending on the period of herbage wilting, mg/100 g.

Table 3. Energy efficiency of JA cultivars (2014–2016), Korenevo, Moscow Region.

No.	Cultivar	Tuber Yield, Ton per Hectare	Energy Costs, GJ per Hectare	Energy Obtained (Tubers), GJ per Hectare	Energy Efficiency Coefficient (Tubers)	Herbage Yield, Ton per Hectare	Energy Obtaned (Herbage), GJ	Total Energy Obtained GJ	Energy Efficiency Coefficient (Tubers + Tops)
Cultivars of early leaf wilting ("early cultivars")									
1	Vylgortskiy	37.5	36.2	40.7	1.12	24.9	19.4	60.1	1.66
2	Diyeticheskiy	46.1	39.4	52.7	1.34	23.6	18.4	71.1	1.80
3	Nadezhda	46.0	39.4	51.4	1.30	42.3	32.9	84.4	2.14
4	Nakhodka	51.1	41.3	56.8	1.37	13.5	10.5	67.3	1.63
5	Podmoskovniy	44.4	38.8	48.2	1.24	28.4	22.1	70.4	1.81
6	Sireniki	46.9	39.7	45.9	1.16	32.5	25.3	71.3	1.80
7	Skorospelka	50.7	41.2	52.2	1.27	37.6	29.3	81.5	1.98
8	Blank Brekos	33.1	34.5	41.8	1.21	34.8	27.1	68.9	2.00
Average (early)		44.5	38.8	48.7	1.3	29.7	23.1	71.9	1.9
LSD_{05}		5.83	2.20	5.25	0.08	8.51	6.63	7.25	0.16

Table 3. *Cont.*

No.	Cultivar	Tuber Yield, Ton per Hectare	Energy Costs, GJ per Hectare	Energy Obtained (Tubers), GJ per Hectare	Energy Efficiency Coefficient (Tubers)	Herbage Yield, Ton per Hectare	Energy Obtaned (Herbage), GJ	Total Energy Obtained GJ	Energy Efficiency Coefficient (Tubers + Tops)
Cultivars of late leaf wilting ("late cultivars")									
9	Interes	27.1	32.2	25.7	0.80	53.9	42.0	67.7	2.10
10	Interes 21	35.5	35.4	32.8	0.93	29.2	22.7	55.5	1.57
11	Kaluzhskiy	19.4	29.3	25.6	0.87	31.4	24.5	50.0	1.71
12	Korenevskiy	42.9	38.2	48.2	1.26	57.3	44.6	92.8	2.43
13	Novost VIRa	25.2	31.5	29.6	0.94	86.9	67.7	97.3	3.09
14	Tadzhikskiy	23.4	30.8	23.9	0.78	79.3	61.8	85.7	2.78
15	Violet de Rense	14.4	27.4	15.0	0.55	28.2	22.0	37.0	1.35
16	Shpindel	43.9	38.6	41.1	1.06	80.0	62.3	103.4	2.68
Average (late)		29.0	32.9	30.2	0.9	55.8	43.5	73.7	2.2
LSD_{05}		10.08	3.82	9.76	0.20	22.85	17.80	22.98	0.59
Total average		36.7	35.9	39.5	1.1	42.7	33.3	72.8	2.0
Total LSD_{05}		11.30	4.29	12.11	0.23	21.61	16.84	17.06	0.47

4. Discussion

4.1. Phenological Observations and Biometric Parameters of Plants

During the growing season of Jerusalem artichoke plants, the following phenological phases of development were observed: shoots, budding, flowering, tuberization and wilting of the aboveground part of the plant.

The process intensity of passing the phenological phases of plant development depends on: varietal characteristics, meteorological conditions and agricultural practices. The optimum temperature for the germination of Jerusalem artichoke tubers is 18–20 °C. Flowering does best at 20–22 °C. The growth of tubers stops at temperatures below 7 °C. The optimum temperature for tuberization is considered to be in the range of 18–19 °C. The yield and quality of Jerusalem artichoke are significantly affected by the deviation of soil and air temperature from the optimal values [1,36].

The rate of passing phenological phases of plant development depends on: varietal characteristics, meteorological conditions and agricultural practices. The optimum temperature for the germination of Jerusalem artichoke tubers is 18–20 °C. Flowering does best at 20–22 °C. The growth of tubers stops at temperatures below 7 °C. The optimum temperature for tuberization is considered to be in the range of 18–19 °C. The yield and quality of Jerusalem artichoke are significantly affected by the deviation of soil and air temperature from the optimal values [4,51].

The full shoots of all cultivars were established in the first ten days of June, i.e., 34–37 days after planting (Table 1).

The budding phase in the cultivars with early herbage wilting began in the second ten-day period of August, that is, 105–108 days after planting, and in the cultivars with late herbage wilting, it started in the second half of October, that is, 165–176 days after planting. Meanwhile, in two cultivars (Interest 21 and Kaluzhskiy), the budding phase did not have time to set in until frost, during which, the green mass of plants was frozen, and the processes of plant top development stopped.

The flowering phase in the cultivars with early herbage wilting began in the third ten-day period of August, that is, 118–121 days after planting, and in the cultivars Korenevskiy and Shpindel, it started at the end of October, that is, 176 days after planting. For varieties Interest, Interest 21, Kaluzhskiy, Novost VIRa, Tadzhikskiy and Violet de Rense, the flowering phase did not have time to begin before frost.

The phase of top wilting in cultivars with early herbage wilting began in early October, that is, 160–162 days after planting, and in cultivars with late herbage wilting, it started in the second ten-day period of November, that is, 200 days after planting.

The results were confirmed by experiments conducted by other authors [14–16]. Consequently, to obtain larger yields of green mass and tubers as early as possible, early-maturing cultivars of Jerusalem artichoke may be recommended to be grown in the middle zone of Russia with a temperate climate and in the northern zones with a colder climate. Additionally, "late" varieties will be able to achieve better results in more southern areas.

Analyzing the data in Figure 4 in terms of plant height, it can be noted that all cultivars studied reached due heights at the end of the growing season: Vylgortskiy, Dieticheskiy, Nadezhda, Nakhodka, Sireniki, Skorospelka, Blank Brekos and Kaluzhskiy—155–170 cm; Podmoskovniy and Interes—175–208 cm; Interes 21, Tadzhikskiy and Violet de Rense—220–235 cm; Korenevskiy, Novost VIRa and Spindle—270–280 cm. To summarize, the "early" cultivars and Kaluzhskiy were less than two meters high and almost all the "late" varieties reached the height of two to three meters. The average height for all cultivars was 1.98 m.

The area of the assimilating leaf surface at the beginning of September (Figure 4) in the cultivars Vylgortskiy, Dieticheskiy, Nadezhda, Nakhodka, Sireniki and Blank Brekos was 0.41–0.84 m^2/plant; the areas of Podmoskovniy, Skorospelka, Interes 21, Korenevskiy and Violet de Rense were 0.93–1.30 m^2/plant; and varieties Kaluzhskiy, Novost VIRa, Spindle—1.44–1.59 m^2/plant. The average leaf surface area for all cultivars was 1.11 m^2/plant. The greatest area of the assimilating leaf surface (2.10–2.31 m^2/plant) was found in the late-maturing cultivars Interes and Tadzhikskiy, which could not display their height.

According to the data obtained, illustrated in Figure 4, it can be seen that plant height and assimilating leaf surface area are not directly related.

The "early" cultivars have been better studied, since the late ones may not have had enough time to set fruit under any conditions [14,17,52]. Additionally, our data obtained for different cultivars are broadly congruent with the data of other authors [7,16,26].

4.2. Control of Diseases and Pests on Jerusalem Artichoke Plants

Jerusalem artichoke is affected by pathogens of various etiologies: bacteria, viruses and fungi. Furthermore, plants suffer from nonparasitic functional diseases caused by various environmental factors such as the lack of nutrients, in particular nitrogenous and phosphorus compounds, etc. [53].

Four types of bacteria periodically parasitize and develop as semi-parasites and saprophytes on Jerusalem artichoke in different areas of the distribution area.

No bacterial diseases were found in the samples of our experiments.

At present, Jerusalem artichoke viruses are not widespread, but due to abrupt changes in climatic conditions and associated plant stress, the number of viral pathotypes of Jerusalem artichoke may increase. Currently, nine viral and mycoplasma diseases are known. They occur in the form of spots, mosaics, the curly deformation of apical leaves, the corrugation of leaf blades, the overgrowth of and reduction in leaves, the deformation of the corolla and the sterility of seeds [1,54].

We should mention that no viral diseases were found on Jerusalem artichoke samples in our research.

In different areas of the distribution, Jerusalem artichoke were infected by 32 species of phytopathogenic fungi which periodically parasitize and develop as parasites, semi-parasites and saprophytes. As for pathogens of stems and leaves, the most widespread ones were: sclerotiniasis (two types of pathogen—Jerusalem artichoke sclerotinia sclerotiorum (*Sclerotinia sclerotiorum* (Lib,) Mass.) and rolfsi Sclerotium (*Sclerotium Rolfsii* Sacc.)). Jerusalem artichoke Fimatotricha omnivora (*Phymatotrichum* = *Ozonium omnivorum* (Shear.)

Dugg.) and powdery fungi—powdery mildew (*Erysiphe cichoracearum* DCF *helianthi* Jacz.) should be mentioned [1,55,56].

In July, a slight infestation of leaves with powdery mildew (1–3%) was noted (Figure 6). In this case, the plant damage was 1–10% of the leaf surface in the form of single spots on individual plants, which corresponds to 8 points. Among plants heavily diseased were early cultivars (Skorospelka and Blank Brekos) for up to 14–15% of leaves, mid–early caltivars (Vylgortskiy and Nadezhda) for up to 11–12% and mid-ripening cultivars (Dieticheskiy, Kaluzhskiy, Nakhodka, Podmoskovniy and Sireniki) for up to 8–12%. Late-ripening plant (Interes, Interes 21, Novost VIRa and Spindle) varieties were slightly affected up to 5–7%. The least affected plants were mid-season varieties (Korenevskiy, Podmoskovniy and Violet de Rense) and late Tadzhikskiy varieties—up to 1–4% of leaves. In this case, the damage of plants was 1–10% of the leaf surface in the form of single spots on individual plants, which corresponds to 8 points.

Plants of the following cultivars were the most affected by powdery mildew in the third ten-day period of September: Kaluzhskiy, Novost VIRa and Spindle (24–28% of leaves). Plants of the following cultivars were slightly affected: Interest, Interest 21 and Korenevskiy (7–9%). In this case, the damage to plants was 1–10% of the leaf surface in the form of single spots on individual plants, which corresponds to 8 points. Almost all leaves were clean in the cultivars Tadzhikskiy and Violet de Rense (2–3%).

The average number of plants affected by powdery mildew was 1.6% in July, 8.0% in September and 13.3% in October. Therefore, if Jerusalem artichoke is grown for green fodder, then it is better to mow the aboveground mass before the third ten-day period of September in order to avoid serious leaf damage due to powdery mildew. However, it can be noted that leaf damage may be up to 95 . . . 99% in thick plantings [15,23].

The destructiveness of JA leaves with powdery mildew on space plantings was also reported less by other researchers [14,16].

The pest infestation assessment was carried out on the basis of a plant visual examination in the registration plot.

Pests in Jerusalem potato collection in 2014–2016:

June: aphids (*Aphidoidea*)—0.46 pieces/m^2, cruciferous flea beavers (genus *Phyllotreta*)—0.14 pieces/m^2, yellow sawflies (*Nematus leucotrochus*)—0.02 pieces/m^2, sunflower moths—*Homoeosoma nebulellum* Den. et Schiff.–0.01 pieces/m^2, thrips (*Thrips* spp.)—0.01 pieces/m^2, weevils (*Tanymecus palliates* Fabr.)—0.006 pieces/m^2, beetles (*Rhizotrogus solstitialis*)—0.004 pieces/m^2 and spider mites (*Tetranychus urticae*)—0.001 pcs/m^2.

July: rape bugs (*Eurydema oleracea* L.)—1.22 pcs/m^2, leaf beetles (*Chrysomelidae*)—0.6 pcs/m^2, small moths of various species (*Pyralidae* family)—0.27 pcs/m^2 and moths (family *Geometridae*)—0.2 pcs/m^2.

Taking into account the herbage damage by leaf-eating pests on a 5-point scale, it was noted that only some plants were destroyed, which corresponds to 1 point on the scale—up to 5% of the leaf surface was damaged.

4.3. Morphological Characteristics of Green Mass

On average, the number of main stems on "early" cultivars turned out to be 2.25 pcs./per plant; on the "late" ones, there were 1.88 pcs./plant.

Cultivars Interes, Interes 21 and Kaluzhskiy were found to have a larger diameter of stems at the butt (29–32 mm); hence, it is more difficult to use the green mass of these cultivars in a fresh, unprocessed form (Figure 7). From this point of view, the following cultivars are more attractive for animals: Vylgortskiy, Korenevskiy, Nakhodka, Podmoskovniy and Sireniki. In the case of repeated mowing without harvesting tubers, cultivars with thick stems can also be used [16,57].

The average stem thickness value in the "early" cultivars was 19.9 mm at the butt end and 15.0 mm at the height of the stem cut with a mower (40 cm). In the "late" cultivars, it was 24.1 mm at the butt end, and at a height of 40 cm, it was 19.1 mm. The data highlight that thicker and stronger stems are favored for a longer growing season in "late" cultivars.

Varieties Interes, Interes 21 and Kaluzhskiy are considered to be more suitable for processing into green pelleted feed, since the herbage mass of these cultivars remains green until the end of October.

4.4. JA Green Mass and Tuber Yield Reports

The green mass performance of "early" JA cultivars at the beginning of September averaged 29.7 t/ha. By the third ten-day period of October, the plants had mostly withered and even dried up.

Analyzing the data in Table 2, it can be noted that at the end of October, for all early cultivars, the value of herbage yield decreased by 0.5–20.7 t/ha due to significant drying of plant tops.

The green mass performance of "late" JA cultivars in early September averaged 47.5 t/ha. By the third ten-day period of October, the plants had significantly increased in weight to an average of 55.8 t/ha.

The cultivation practices of Jerusalem artichoke in different climatic zones have shown that in "late" varieties, the aboveground part grows much larger than in the "early" ones, and the plant green mass weight continues to increase up to the onset of frost [16,28,55].

The highest gross yield of tubers in early September was mainly found in the following early-maturing JA cultivars Diyeticheskiy (43.5 t/ha) and Nadezhda (40.8 t/ha). The average yield of the "early" cultivars was 27.6 t/ha, while that of the "late" cultivars was 13.9 t/ha. In the third ten-day period of October, tubers of all cultivars significantly increased in weight: "early" cultivars increased by 2.3–31.1 t/ha and the average yield of tubers rose to 44.5 t/ha; "late" cultivars did by 7.0–35.4 t/ha and the average yield was reported as 29.0 t/ha (Table 2).

Being harvested in early September, the yield of tubers with a fraction of more than 30 mm was obtained from the following varieties: Diyeticheskiy (40.1 t/ha), Korenevskiy (31, 7) and Blank Brekos (27.1 t/ha). The yield slightly lower than 25 t/ha was obtained from the following varieties: Nakhodka (21.2 t/ha), Podmoskovniy (24.4 t/ha) and Skorospelka (16.7 t/ha).

Jerusalem artichoke is a unique crop which can be used wholly, i.e., all its elements (large tubers, small tubers, stems, leaves, flowers, stolons and roots) [15,29]. Thus, it is important to take into account the yield of tubers not only of the coarse fraction, but also small tubers (less than 30 mm). At the same time, the largest total (gross) yield was obtained from the following varieties: Diyeticheskiy (43.5 t/ha), Nadezhda (40.8 t/ha) and Korenevskiy (35.9).

When tubers were harvested in the third ten-day period of October, the highest yield of tubers with a fraction of more than 30 mm in transverse diameter was obtained from the following varieties: Nakhodka (50.3 t/ha), Skorospelka (47.2 t/ha), Podmoskovniy (43.5 t/ha), Nadezhda (41.2 t/ha) and Dieticheskiy (40.1 t/ha).

At the same time, the total (gross) yield (more than 25.0 t/ha) was obtained in all cultivars with early leaf wilting, as well as for five varieties of late leaf wilting: Spindle (43.9 t/ha), Korenevskiy (42.9 t/ha), Interes 21 (35.5 t/ha), Interes (27.1 t/ha) and Novost VIR (25.2 t/ha). The research results confirm the data that suggest the possibility to achieve JA tuber yield up to 54.2–58.5 t/ha [14].

Being harvested in the first ten-day period of September, the total performance structure of "early" JA cultivars comprised on average 52% of green mass, 33% of commercial tubers and 15% of small tubers, while the structure of the "late" varieties averaged 77% of green mass, 11% of commercial tubers and 12% of small tubers. Being harvested in the third ten-day period of October, "early" varieties produced only 29% of green mass, 58% of commercial tubers and 13% of small tubers; the "late" varieties produced 66% of green mass, 22% of commercial tubers and 12% of small tubers (Figure 8). The data obtained can be useful for farmers who are going to cultivate this useful and essential crop, considering the purpose of this crop.

4.5. The Value of Jerusalem Artichoke as a Forage Crop

In our studies, on average, the dry matter content of JA "early" cultivars was 28.8% in herbage and 23.8% in tubers; for "late" ones, it was 29.8% in herbage and 24.0% in tubers. According to the chemical composition, it can be noted that cellulose prevails in the green mass of both "early" and "late" cultivars: 10.9 and 13.1%; in second place—sugars: 4.2 and 4.0%; in third place—fats: 3.3 and 3.5%; in fourth place—protein: 2.8 and 3.1%, respectively. In Jerusalem artichoke tubers, the sugar content prevails: 17.6 and 16.9%; in second place—protein: 2.9 and 3.3%; in third place—cellulose: 1.9 and 2.5%; in fourth place—fats: 0.1 and 0.2%. Thus, the data obtained by us are consistent with the data of other authors [58,59].

Tubers and the green mass of Jerusalem artichoke are sources of vital macronutrients, such as phosphorus—100 to 140 mg/100 g—and potassium—350 to 500 mg/100 g of the raw weight of the green mass; 70.7 to 80.7 mg/100 g (phosphorus) and 450 to 620 mg/100 g (potassium) of the raw weight of tubers. Similar data are given by T.I. Anikienko [58].

Studies on the content of trace elements Ca, Fe, Mg, Mn, Si and Zn have shown that the green mass contains more Mg (45 to 72 mg/100 g) and Mn (44 to 65 mg/100 g). Additionally, tubers of "late" cultivars are rich in Si (27.2 to 79.0 mg/100 g), while tubers of "early" cultivars are high in Zn (32.8 to 46.5 mg/100 g). The data were confirmed by the findings of other authors [58,59].

4.6. Energy Efficiency of Jerusalem Artichoke Varieties' Cultivation

The analyses of main energy assessment indicators of different JA cultivar tubers (Table 3) showed that with an increase in energy consumption (on average by 5.9 GJ/ha) in the case of growing varieties with early leaf wilting (compared with late-green-mass-wilting cultivars), the amount of energy received also increases (on average by 18.5 GJ/ha).

The analyses of the main energy assessment indicators of different JA cultivar green mass showed that in the case of growing cultivars with early leaf wilting (compared with late-leaf-wilting cultivars), the amount of energy received was lower (on average by 20.4 GJ/ha).

Despite the low tuber yield of Novost VIRa, the highest total energy efficiency coefficient of 3.09 was obtained, since this cultivar had the highest herbage yield. The total coefficient of energy efficiency was slightly lower in the cultivars: Tadzhikskiy—2.78; Spindle—2.68; Korenevskiy—2.43. The highest total coefficient of energy efficiency among cultivars with early green mass wilting was found in cultivars: Nadezhda—2.14; Black Brekos—2.00; Skorospelka—1.98.

Thus, Jerusalem artichoke is one of the most promising bioenergetics crops [3,11,24], and its cultivation is economically feasible.

5. Conclusions

The purpose of the work was to evaluate the herbage and tubers of 16 JA cultivars of different maturation periods based on lab and on-farm research, taking into account their feed production potential. The plants were grown on sod-podzolic sandy loam soils rich in mobile (available) phosphorus and low in exchangeable potassium and humus content. The research was conducted under moderate–continental climatic conditions considering the cultivar features.

Field experiments, records and observations were carried out in accordance with the requirements of the field experiment methodology, the Program and methodology for evaluating Jerusalem artichoke cultivars. The research was conducted in test nurseries.

The growing plants passed phenological phases following no particular pattern. Observation-based findings allowed us to group 16 cultivars into cultivars of early leaf wilting ("early cultivars") and cultivars of late leaf wilting ("late cultivars").

During the growing season, cultivars of early leaf wilting underwent all phenological phases of development: shoots, budding, flowering, tuberization and wilting of the above-ground plant parts. They were 155–208 cm high. The average stem thickness value was

19.9 mm at the butt end and 15.0 mm at the height of the stem cut with a mower (40 cm). The green mass yield averaged 29.7 t/ha at the beginning of September. By the third ten-day period of October, the plants had mostly withered and dried up. The highest gross yield of tubers in early September was mainly produced by the cultivars Diyeticheskiy (43.5 t/ha) and Nadezhda (40.8 t/ha). At the end of October, cultivars Nakhodka (51.1 t/ha) and Skorospelka (50.7 t/ha) did the best. To summarize, the average yield of tubers in early September was 27.6 t/ha; at the end of October—44.5 t/ha.

All cultivars of late leaf wilting passed a phase of full shoots, but some cultivars did not have time to reach budding and flowering phases before the frost. They were 220–280 cm high. The stem thickness was 24.1 mm at the butt end and 19.1 mm at a height of 40 cm, that is, stems were thicker in comparison with the stems of early-leaf-wilting cultivars. The green mass yield averaged 47.5 t/ha in early September. By the third ten-day period of October, the plants had significantly increased in weight to an average of 55.8 t/ha. The average tuber yield was 13.9 t/ha in early September and 29.0 t/ha at the end of October.

With a planting density of 20 thousand pcs./ha, a small lesion of leaf plates with powdery mildew was detected: in July—1.6%, in September—8.0% and in October—13.3%. At the same time, the lesion of plants was 1–10% of the leaf surface in the form of single spots on individual plants, which corresponds to 8 points.

On average, the dry matter content in JA green mass was 28.8% … 29.8%, and in tubers—23.8–24.0%, respectively. According to the chemical composition, it can be noted that cellulose and sugars predominated in the green mass: 14.9–17.3%; while the sugar content was higher in tubers: 16.9–17.6%.

The data obtained may be useful for farmers who want to adapt and produce Jerusalem artichoke considering the intended end-use of this valuable and essential crop.

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References

1. Pazin, M.A. Prospects for the cultivation of non-traditional fodder crops (Jerusalem artichoke) under conditions of the Kemerovo region. In *Modern Trends in Agricultural Production in the World Economy, Proceedings of the XVIII International Scientific and Practical Conference, Kemerovo, Russia, 3–4 December 2019*; Pazin, M.A., Kuznetsov, Y.V., Eds.; Kuzbass State Agricultural Academy: Kemerovo, Russia, 2019; pp. 78–82.
2. Revnivtsev, P.V. Jerusalem artichoke (Heliautus tuberosus)—Innovative multi-purpose crop. In *Young Scientists—Agriculture: A Collection of Articles Based on the Materials of the Student Conference*; Revnivtsev, P.V., Vedina, Y.V., Eds.; Saratov State Agrarian University: Saratov, Russia, 2017; pp. 21–25.
3. Tsuglenok, N.V. Jerusalem artichoke as a high-energy fodder crop in the feed production of the Krasnoyarsk Territory. In *Bulletin of the Krasnoyarsk State Agrarian University*; Tsuglenok, N.V., Tsuglenok, G.I., Anikienko, T.I., Eds.; Krasnoyarsk State Agrarian University: Krasnoyarsk, Russia, 2007; Volume 4, pp. 127–130.

4. Korolev, D.D.; Simakov, E.A.; Starovoitov, V.I. Potatoes and Jerusalem artichoke—Products of the future. *M. FGNU Ros.* **2007**, *1*, 292.
5. Abramchuk, A.V. Productivity of Jerusalem artichoke depending on the timing of planting. *Agrar. Bull. Ural.* **2009**, *12*, 39–40.
6. Anikienko, T.I. Chemical and trace element composition of tubers and green mass of Jerusalem artichoke. *Bull. KrasGAU* **2008**, *2*, 76–80.
7. Zelenkov, V.N. Jerusalem artichoke (Helianthus tuberosus L.). Message 1. Biological aspects of plant development in nature and in Russia (literature review). *Bull. Acad. Nat. Sci.* **2017**, *2*, 71–78.
8. Starovoytov, V.; Starovoytova, O.; Aldoshin, N.; Manohina, A. Jerusalem artichoke as a means of fields conservation. *Acta Technol. Agric.* **2017**, *20*, 7–10. [CrossRef]
9. Zorić, M.; Terzić, S.; Sikora, V.; Brdar-Jokanović, M.; Vassilev, D. Effect of environmental variables on performance of Jerusalem artichoke (Helianthus tuberosus L.) cultivars in a long term trial: A statistical approach. *Euphytica* **2017**, *213*, 23. [CrossRef]
10. Koundinya, A.V.V.; Asha Devi, R.K.; Kumar, P.P.; Pandit, M.K. A review on underexploited nutrient rich perennial vegetables. *Acta Hortic.* **2019**, *1241*, 691–698. [CrossRef]
11. Ilchenko, S.M. Market conditions and Jerusalem artichoke products. *Bull. Omsk. State Agrar. Univ.* **2016**, *1*, 261–266.
12. Zhuchkova, M.A. Jerusalem artichoke—A plant of the XXI century. *Veg. Russ.* **2017**, *1*, 31–33.
13. Starovoitov, V.I.; Starovoitova, O.A.; Aldoshin, N.; Manokhina, A.A. Technology and mechanization of cultivation of Jerusalem artichoke healthier. *Res. Agric. Eng.* **2018**, *64*, 151–156.
14. Usanova, Z.I.; Fridman, Y.A. Productivity of Jerusalem artichoke varieties at different standing density. *Dairy Bull.* **2020**, *2*, 146–155.
15. Ruban, G.A. Jerusalem artichoke as perennial crop in the North (Komi Republic). *Bull. Bot. Gard. Saratov State Univ.* **2019**, *4*, 212–224.
16. Koroleva, Y.S. Accumulation of Jerusalem artichoke green mass and tubers yield in the Upper Volga region. In *Digitalization in Agri Business: Technological Resources, New Opportunities and Challenges: A Collection of Scientific Papers Based on the Materials of the International Scientific and Practical Conference*; Tver State Agricultural Academy: Tver, Russia, 2020; pp. 15–19.
17. Krivoshapkin, K.K. Jerusalem artichoke—A promising forage and food plant for Yakutia. *Acad. Bull. Yakut State Agric. Acad.* **2020**, *9*, 29–36.
18. Safarmadi, M. Productive potential of Jerusalem artichoke (Heliautus tuberosus L.) Tajikistan. *Proc. Orenbg. State Agric. Univ.* **2020**, *4*, 82–85.
19. Zhangabaev, A.S. Effect of cultural practices on Jerusalem artichoke yields in Karakalpakstan. *Int. Sci. Rev.* **2017**, *5*, 15–17.
20. Khristich, V.V.; Kumpan, V.N.; Prokhorova, N.A.; Kling, A.P.; Chupina, M.P. Variety analysis of Jerusalem artichoke under the conditions of the taiga zone of Western Siberia. *Bull. Omsk. State Agrar. Univ.* **2015**, *4*, 19–23.
21. Manokhina, A.A.; Starovoitova, O.A.; Starovoitov, V.I. Improving the technological process for the mini-tubers production of the original seed of Jerusalem artichoke. In Proceedings of the IOP Conference series: Earth and environmental science, Barnaul, Russia, 27 November 2019; p. 012091.
22. Zhao, M.; Zhong, Q.; Tian, M.; Han, R.; Ren, Y. Comparative transcriptome analysis reveals differentially expressed genes associated with the development of Jerusalem artichoke tuber (Helianthus tuberosus L.). *Ind. Crops Prod.* **2020**, *151*, 112455. [CrossRef]
23. Viriyasuthee, W.; Jogloy, S.; Saksirirat, W.; Saepaisan, S.; Gleason, M.L.; Chen, R.S. Biological control of alternaria leaf spot caused by Alternaria spp. in Jerusalem artichoke (Helianthus tuberosus L.) under two fertilization regimes. *Plants* **2019**, *8*, 463. [CrossRef]
24. Kochnev, N.K. Jerusalem artichoke—Bioenergetic crop of the XXI century. *Acad. Bull. Yakut State Agric. Acad.* **2020**, *76*, 29–36.
25. Simakin, A.V.; Ivanyuk, V.V.; Gudkov, S.V.; Dorokhov, A.S. Photoconversion fluoropolymer films for the cultivation of agricultural plants under conditions of insufficient insolation. *Appl. Sci.* **2020**, *10*, 8025. [CrossRef]
26. Steinbauer, C.E. Effects of temperature and humidity upon the length of rest period of tubers of Jerusalem artichoke (Helianthus tuberosus). *Proc. Amer. Soc. Hort. Sci.* **1932**, *29*, 403–408.
27. Moshou, D. Automatic detection of 'yellow rust' in wheat using reflectance measurements and neural networks. *Comput. Electron. Agric.* **2004**, *44*, 173–188. [CrossRef]
28. Onyango, C.M. Segmentation of row crop plants from weeds using color and morphology. *Comput. Electron. Agric.* **2003**, *39*, 141–155. [CrossRef]
29. Berzhanova, M.I. Cultivation of Jerusalem artichoke in the Atyrau region. *Relev. Sci. Res. Curr. World.* **2019**, *2*, 116–121.
30. Razumov, V.A. *Mass Analysis of Feeds: Handbook*; Kolos: Moscow, Russia, 1982; p. 176.
31. Khaziakhmetov, F.S. *Rational Feeding of Animals: A Textbook*, 3rd ed.; Lan: St. Petersburg, Russia, 2019; p. 364. Available online: https://e.lanbook.com/book/115666 (accessed on 5 August 2019).
32. Kotova, Z.P. Nutrient value evaluation of Jerusalem artichoke (Heliantus tuberosus L.) in Karelia. *Kormoproizvodstvo* **2015**, *6*, 41–45.
33. Titok, V. Jerusalem artichoke—A multifunctional crop. *Sci. Innov.* **2014**, *5*, 26–28.
34. Kays, S.J. Genetic variation in Jerusalem artichoke (Helianthus tuberosus L.) flowering date and duration. *HortScience* **2005**, *40*, 1675–1678. [CrossRef]
35. Kolomeichenko, V.V. *Fodder Production: Textbook*; Lan: St. Petersburg, Russia, 2015; p. 656.
36. Tsgoeva, T.E. Chemical analysis of Jerusalem artichoke varieties Skorospelka and Interest. *Izv. Gorsky SAU* **2011**, *2*, 280–282.

37. Yaschuk, M.A. Jerusalem artichoke as raw materials for compound feeds production. *Food Technol.* **2007**, *7*, 57–58.
38. Yaroshevich, M.I. Jerusalem artichoke (Helianthus tuberosus L.)—A perspective crop. In *Theoretical and Applied Aspects of Plant Introduction as a Promising Direction for the Development of Science and National Economy: A Collection of Papers Based on the Materials of the International Scientific Conference Dedicated to the 75th Anniversary of the Formation of the Central Library of the National Academy of Sciences of Belarus*; Yaroshevich, M.I., Evening, N.N., Gorny, A.V., Eds.; Edith VV: Minsk, Belarus, 2007; Volume 1, pp. 323–325.
39. Mikhalchenkova, E.S. Jerusalem artichoke as a promising fodder crop in the Non-Chernozem zone of Russia. *Bull. OrelSAU* **2009**, *2*, 42–43.
40. Kuznetsov, A.F. *Pigs: Maintenance, Feeding and Diseases*; Lan: St. Petersburg, Russia, 2007; p. 544.
41. Anikienko, T.I. The quality of milk, sour cream, sour cream and butter upon the application of Jerusalem artichoke herbal flour in feeding. *Bull. Altai State Agrar. Univ.* **2016**, *6*, 158–163.
42. Zhorovin, N.A. *Growing Conditions and Consumer Qualities of Potatoes*; Urajay: Minsk, Belarus, 1977; p. 94.
43. National Standard of the Russian Federation, Moscow Standartinform. *2014 Approved and Introduced by Order of the Federal Agency for Technical Regulation and Metrology Dated November 8, 2013, 19, Gost, R. 55757-2013 Jerusalem Artichoke (Tubers)*; Seed piece; Varietal and planting qualities; General technical conditions; National Standard of the Russian Federation, Moscow Standartinform: Moscow, Russia, 2014.
44. Dospekhov, B.A. *Methodology of Field Trial (With the Basics of Statistical Processing of Research Results)*, 5th ed.; Agropromizdat: Moscow, Russia, 1985; p. 351.
45. Starovoitov, V.I. Program and methodology for evaluating Jerusalem artichoke varieties in test nurseries within the framework of the implementation of the program of the Union State "Innovative development of potatoes and Jerusalem artichoke" for 2014–2016. *SSI Russ. Potato Res. Cent. Russ. Agric. Acad.* **2014**, *1*, 6.
46. Rogovsky, Y.A. *Methodology of State Variety Testing of Agricultural Crops. Issue 1. General Part*; Fedin, A.M., Ed.; State Commission on Variety Testing of Agricultural Crops under the Ministry of Agriculture of the USSR: Moscow, Russia, 1985; 194p.
47. Nichiporovich, A.A. Methodological guidelines for recording and control of the most important indicators of the crop photosynthetic activity processes in planting. *Nauka* **1967**, *1*, 143.
48. The State Commission of the Russian Federation for Testing and Protection of Breeding Achievements. *Conducting Methods of tests for Distinctness, Uniformity and Stability*; The State Commission of the Russian Federation for Testing and Protection of Breeding Achievements: Moscow, Russia, 2012; No. 12-06/82.
49. Malko, A.A. *Technological Process of Original and Reproductive Seed Potato Production*; Malko, A.A., Nikolaev, Y.N., Makarova, V.S., Eds.; Federal State University "Rosselkhoznadzor": Moscow, Russia; SSI Russian Potato Research Center of the Russian Agricultural Academy Rosselkhoznadzor Academy: Moscow, Russia, 2011; 32p.
50. Litun, B.P. *Methodology of Bioenergetic Assessment in Potato Production*; SSI Russian Potato Research Center of the Russian Agricultural Academy: Moscow, Russia, 2000; 30p.
51. Koroleva, Y.S. Yields and crop structure of Jerusalem artichoke during long-term cultivation in the Upper Volga region. In *Biological Features of Medicinal and Odoriferous Plants and their Role in Medicine: A Collection of Scientific Papers Based on the Materials of the International Scientific and Practical Conference Dedicated to the 85th Anniversary of All-Russian Scientific Research Institute of Medicinal and Aromatic Plants Moscow, Russia, 23–25 June 2016*; Shcherbinskaya Printing House: Moscow, Russia, 2016; pp. 239–243.
52. Zhangabayeva, A.S.; Mavlyanova, R.F. Influence of seed material on the growth, development and yield of Jerusalem artichoke tubers under Karakalpakstan conditions. *Young Sci.* **2017**, *166*, 29–31. Available online: https://moluch.ru/archive/166/45352 (accessed on 5 August 2019).
53. Sadykov, B.K. Cultivation of Jerusalem artichoke (Heliantus tuberosus) under various environmental conditions. *Bull. Al-Farabi Kazakh Natl. Univ.* **2009**, *1*, 89–97.
54. Ustimenko, G.V. *Jerusalem Artichoke*; Selkhozgiz: Moscow, Russia, 1960; 100p.
55. Skoblina, V.I. *Jerusalem Artichoke*; ArmadaPress: Moscow, Russia, 2001; 36p.
56. Yaruk, I.V. Monitoring of pathogen development on Helianthus tuberosus L. In *Youth in science 2017, Proceedings of the International Conference of Young Scientists, Minsk, Belarus, 30 October–2 November 2017*; Publishing House of the Belarusian Science: Minsk, Belarus, 2018; pp. 363–367.
57. Danilov, K.P. *Collection of Jerusalem Artichoke Leaf-Stem Mass and Tubers Harvesting Depending on Harvesting Time and Fertilizer*; Danilov, K.P., Kashkarov, L.V., Eds.; Vestnik of Ulyanovsk State Agricultural Academy: Ulyanovsk, Russia, 2013; pp. 10–14.
58. Anikienko, T.I. Chemical composition and nutritional value of Jerusalem artichoke green mass and tubers in comparison with other crops. In *The Successes of Modern Natural Science*; Publishing House Academy of Natural Sciences LLC: Moscow, Russia, 2015; Volume 9, pp. 278–282.
59. Jaboeva, A.S. *Biochemical Composition of Jerusalem Artichoke*; Jaboeva, A.S., Shaova, L.G., Eds.; The Kuban State University: Kuban, Russia, 2016; Volume 14, pp. 648–653.