

Article

Evaluation of Chemical Composition of Some *Silphium* L. Species as Alternative Raw Materials

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Abstract: The chemical composition of three *Silphium* species in the aspect of the possibility of their use for various purposes has been evaluated. The plant material of three *Silphium* species (*S. perfoliatum*, *S. trifoliatum* and *S. integrifolium*) was acquired from cultivation located in eastern Poland. The vegetative propagating material consisted of seeds and rhizomes. Content of protein (up to 22.9% in leaves of *S. perfoliatum*), amino acids (aspartic acid—up to 12.0%, glutamic acid—up to 9.5%, and leucine—up to 9.4%), fat (up to 4.2% in inflorescences of *S. perfoliatum*), cellulose (up to 42.9% in stems of *S. trifoliatum*), water-soluble sugars (up to 26.7% in rhizomes of *S. perfoliatum*) and mineral substances (ash up to 20.9% in stems of *S. integrifolium*, with significant levels of elements such as K, Ca, Mg, Fe, Mn) in the tested *Silphium* species can be an important criterion determining a positive evaluation of these plants as sources of alternative raw materials. The conducted research is meant to draw attention to the possibility of use of the biomass of three *Silphium* species as a potential source of ecological and renewable raw material for food, pharmaceuticals, feed and possibly also for energy generation purposes.

Keywords: *Silphium* L.; *Silphium perfoliatum* L.; *Silphium trifoliatum* L.; *Silphium integrifolium* Michx.; chemical composition; alternative plants

1. Introduction

At present, one can observe a trend for the search for plants that can provide, e.g., food products with specific health-promoting properties, raw materials for the pharmaceutical industry, and renewable sources of energy. In addition, research on new crop plants is related to the protection of the natural environment, i.e., organic agriculture, biological reclamation of soils, and counteracting the greenhouse effect. These trends have caused an increase in the interest in new plant species both on the part of farmers and of the users of plant raw materials.

Species of *Silphium* L. genus (*Asteraceae*) are among the most interesting plants referring to the problems mentioned. So far, only *S. perfoliatum* L. has been studied as a medical, melliferous, fodder, and recultivation plant. The literature reports that *S. perfoliatum* is characterised by a high production potential in terms of yields, and contains significant levels of nutrients, i.e., carbohydrates, proteins, L-ascorbic acid, and mineral constituents [1–3] and biologically active substances, i.e., terpenoids and essential oil [4–12], flavonoids [2,13], phenolic acids [14–16], and oleanosides [2,17,18]. In addition, studies have been conducted on the utility features (usefulness for bees, animal feed) and in the range of antimicrobial activity [19–26]. In recent years anatomical-morphological studies were conducted, as well as studies on yield efficiency and on the content of biologically active substances, for three species from the genus *Silphium*: *S. perfoliatum*, *S. trifoliatum*, and *S. integrifolium* [27–31]. There is an interesting

study on the chemical composition of seeds of three *Silphium* species in the aspect of their use for consumption purposes [32]. However, the literature still does not provide reports on detailed research concerning the characterisation of *S. trifoliatum* and *S. integrifolium* in the aspect of the estimation of their content of nutrients and minerals, which was the stimulus for undertaking the research in this area. The results of the study will constitute an important criterion in the estimation of these plant species in the aspect of the possibility of their use for various purposes. Therefore, the objective of the study presented here is the estimation of the content of dry matter (DM), ash, total protein, crude fat, water-soluble sugars, L-ascorbic acid, cellulose, chlorophyll, tannins, minerals, and trace elements, as well as heavy metals in the aboveground and underground organs of *S. perfoliatum*, *S. trifoliatum*, and *S. integrifolium*.

2. Materials and Methods

2.1. Plants Material

The plants material of three *Silphium* species (*S. perfoliatum*, *S. trifoliatum*, and *S. integrifolium*—Figure 1, Table 1) was acquired from cultivation (2012–2014) in an allotment garden (Lubartów, N 51°27'41.0394", E 22°37'5.8152", located in the eastern part of the Lubartów upland which forms a part of the much larger south Podlasie lowland). The presence of continental influences with great amplitudes of annual temperatures, as well as long summers and long cool winters, is characteristic of this area. The length of the growing season in this region is from 190 to 200 days. This area is not included in the hail strip. The last spring frosts are usually recorded in May, and the first autumn frosts take place in October. Figure 2 shows the thermal conditions and rainfall between 1990 to 2019, characteristic of the growing region. The vegetative propagating material consisted of seeds and rhizomes originating from experiments that have been described earlier together with the morphological and anatomical characterisation of the species under study [27,29,31–33].

Table 1. Dates of plant material harvest for chemical studies (the first decade of the month).

Code	Harvest Date			Plants in the First Year of Vegetation		Perennial Plants	
	2012	2013	2014	Plant Material	Plant Development Stage	Plant Material	Plant Development Stage
A	-	May	May	-	-	leaves, stalks	spring regrowth
B	-	Jun	Jun	-	-	leaves, stalks	flower buds
C	-	Jul	Jul	-	-	leaves, stalks, inflorescences	beginning of flowering
D	-	Aug	Aug	-	-	leaves, stalks, inflorescences	full of flowering and fructification
E	Sep	Sep	Sep	leaves	leaf rosette	leaves, stalks	end of flowering and full of fructification
F	-	Oct	Oct	-	-	rhizomes with roots	fructification



Figure 1. *Silphium* plants: P-*S. perfoliatum* (P1—three-year-old plants, P2—inflorescences, P3—shoots) T-*S. trifoliatum* (T1, T2—shoots), I-*S. integrifolium* (I1—inflorescences, I2—shoots, I3—one-year-old plants, I4—rhizomes with roots).

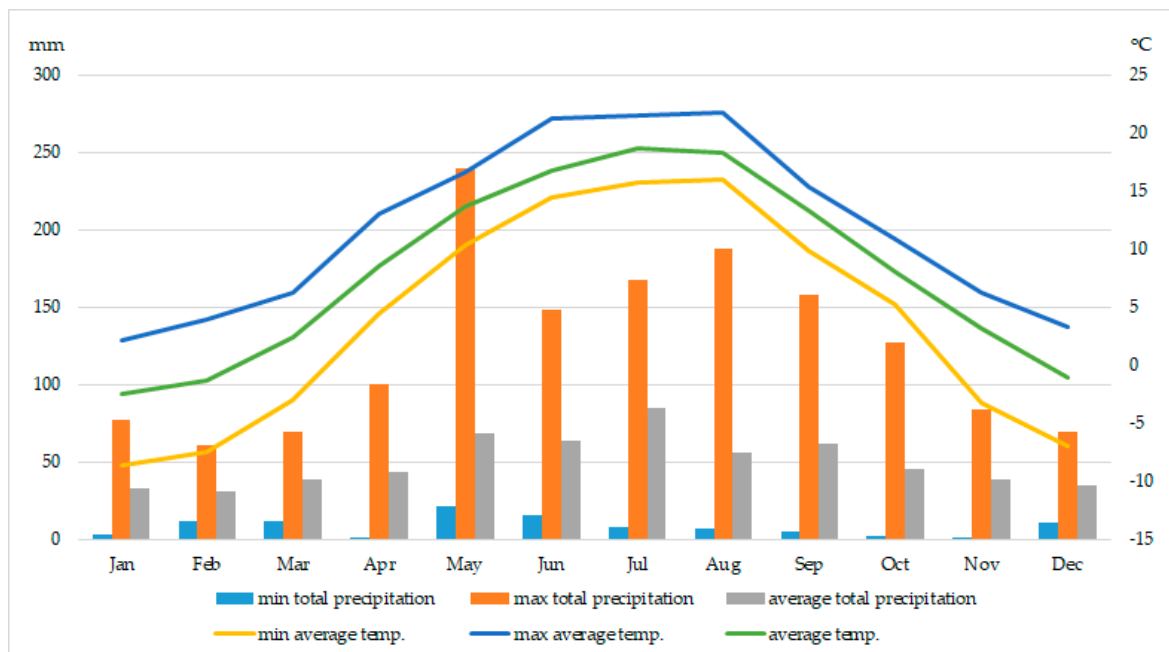


Figure 2. The mean monthly temperature and precipitation sums for the period 1990–2019, and the highest and lowest monthly means measured in Lubartów in the same period.

2.2. Evaluation of Proximate Chemical Composition

The plants collected were determined for DM content by the use of a moisture analyser (Radwag WPS50SW) after drying samples at 100 °C; ash after dry digestion at 550 °C [34]; total and reducing soluble sugars of the Luff-Schoorl (LS) titrimetric method by the AOAC method 942.15 [35]; L-ascorbic acid-vitamin C [36], chlorophyll [37], and total tannin by gravimetrically by copper acetate method [38]; cellulose by Kürchner and Hanak's method [39]; crude fat by means of extraction-gravimetric Soxhlet's method [40]; and the content of crude protein was determined as 6.25 times the nitrogen content of the sample; nitrogen was determined by the Kjeldahl-method (PN-EN ISO 5983-1:2006) using Kjeltec 2300 apparatus (FOSS, Hoganas, Sweden) after prior mineralisation with H₂SO₄ in the Tecator Digestor Auto 20 system (FOSS, Hoganas, Sweden). All analyses were performed in triplicate.

2.3. Evaluation of the Contents of Mineral Components and Trace Elements

The content of minerals in the analysed *Silphium* species was determined after prior microwave mineralisation [41]. Approximately 0.5 g of plants sample were placed in a Teflon vessel. Then, 10 mL of 65% HNO₃ (suprapur grade) supplied by (Merck, Darmstadt, Germany) was added into the vessel and the sealed vessel was put into microwave mineraliser MARS Express (CEM, Matthews, NC, USA). The microwave mineralisation was performed stepwise at 400 W and 363 K, at 800 W and 393 K, at 1600 W and 483 K. The cooled digestion solution was then diluted to 50 mL using high purity deionised water.

2.3.1. AAS

The concentration of minerals, i.e., Na, K, Ca, Mg, Zn, Fe, Mn, Cr, and Cu, was determined by AAS (atomic absorption spectroscopy) method using a spectrometer SpectrAA 280 FS with autosampler SPS 3 (Varian, Melbourne, Australia), which was equipped with a deuterium lamp, hollow cathode lamp for each element and an air-acetylene burner. In order to avoid sample ionisation during potassium analysis, Schinkel buffer solution (mixture contents 10 g·L⁻¹ cesium chloride and 100 g·L⁻¹ lanthanum chloride) was used.

2.3.2. ICP-MS

To determine Se, Pb, Cd, and As of the plant samples, the inductively coupled plasma mass spectrometer ICP-MS 820-MS (Varian, Mulgrave, Australia) with quadrupole mass analyser was used. The instrumental conditions for trace elements determination by ICP-MS were as follows: plasma: argon plasma; plasma flow: 18 L·min⁻¹; auxiliary flow: 1.8 L·min⁻¹; stealth gas flow: 0.12 L·min⁻¹; nebuliser flow: 0.95 L·min⁻¹; sampling depth: 6 mm; RF power: 1,35 kW; pump rate: 0.1 Hz; stabilisation delay: 35 s; first extraction lens: 5 V; second extraction lens: 190 V; third extraction lens: 225 V; corner lens: 200 V; left mirror lens: 39 V; right mirror lens: 34 V; bottom mirror lens: 36 V; entrance lens: 1.00 V; fringe bias: -2.90 V; entrance plate: -39 V.

All certified single-element standard solutions used to prepare the calibration curve (1000 mg·L⁻¹) used were of the highest purity grade (99.999%) and were supplied by Ultra Scientific. The calibration standards for ICP-MS and AAS analysis were prepared by diluting solutions in 1% HNO₃ and in high purity deionised water, respectively. The results were expressed in mg·100⁻¹·g⁻¹ of dry matter (DM). During the analysis, the analytical quality was controlled by means of measurement of a blind sample, a double sample, and the certified reference materials: tea leaves (INCT-TL-1) and mixed polish herbs (INCT-MPH-2) (Table 2).

Table 2. Validation parameters of the analytical procedure for the determination of minerals.

Validation Parameters	Minerals												
	Na	K	Ca	Mg	Zn	Fe	Mn	Se *	Cr *	Cu	Cd *	Pb *	As *
LOD (mg·kg ⁻¹), (µg·kg ⁻¹) *	20	20	28	18	0.4	4.3	1.1	2.5	0.28	1.3	0.04	0.05	0.04
LOQ (mg·kg ⁻¹), (µg·kg ⁻¹) *	40	40	56	36	0.9	8.6	2.2	5.0	0.55	2.2	0.07	0.1	0.09
Linearity	1	1	1	1	1	1	1	0.9999	0.9999	1	0.9999	0.9999	0.9999
Reproducibility (%)	3.4	4.9	7.0	13.9	5.1	8.6	9.2	2.55	2.40	2.3	2.42	6.07	3.18
Recovery (%)	75	90	99	99	117	117	119	97	100	121	99	99	101
Expanded uncertainty (%)	50	28	15	28	30	39	43	17	8	41	6	12	7

LOD—Limit of Detection; LOQ—Limit of Quantification; * Se, Cr, Cd, Pb, As—LOD (µg·kg⁻¹), LOQ (µg·kg⁻¹); Na, K, Ca, Mg, Zn, Fe, Mn, Cu—LOD (mg·kg⁻¹), LOQ (mg·kg⁻¹).

2.4. Isolation and Chromatographic Analysis of Protein Amino Acids

In order to determine the amino acid composition, plant samples were hydrolysed in 6 mol·L⁻¹ HCl [42]. In addition, separate samples were subjected to oxidation hydrolysis to determine the sulfuric amino acids [43]. Amino acid composition in hydrolysates (with ninhydrin post-column derivatisation) was recorded using an automatic amino acid analyser AAA 400 (INGOS Praha) with UV-vis ($\lambda = 570$ nm) detector [32].

2.5. Statistical Analysis

Data were analysed using one-way ANOVA followed by Duncan's test using the SAS statistical system (SAS Version 9.1, SAS Inst., Cary, NC, USA). The significance of all tests was set at $p \leq 0.05$.

3. Results and Discussion

3.1. Dry Matter (DM)

In the first year of cultivation (2012–2014, harvest term E), leaves of the analysed species of *Silphium* had an average DM content in the range from 14.3% (*S. perfoliatum*) to 15.6% (*S. integrifolium*) (Tables 3–5). The average content of DM in the leaves, stems, flowers, and rhizomes of perennial plants was, respectively, up to 22.6% (*S. trifoliatum*—leaves—E), up to 29.7% (*S. integrifolium*—stems—E), up to 20.3% (*S. integrifolium*—flowers—C), and up to 37.6% (*S. trifoliatum*—rhizomes—F). With the regrowth of the plants, an increase of DM content was observed in the leaves and stems of the analysed plants. In the initial growth stage (A), the leaves were characterised by the two-fold lower content of DM compared to material from the previous harvest, while stems from the September harvest even had about four-fold more DM compared to material harvested at the start of vegetation in May. Statistically significant differences were demonstrated for mean levels of DM in the analysed organs of the plants.

Glyaubertene and Ivanovskaya [44] obtained the following results of DM content in aboveground organs of *S. perfoliatum* in the period from the stage of spring regrowth to the stage of full flowering and fructification: in leaves—from 12.8% to 20.1%, and in stems—from 6.7% to 17.8%. In the study conducted in Polish conditions, other authors obtained in the aboveground parts of *S. perfoliatum* contents of DM from 8.8% (at the start of vegetation) to 25.1% (in the stage of fructification) [45]. The continuation study conducted within that scope of research in Bydgoszcz (Poland) revealed that *S. perfoliatum* contained DM in amounts from 14.9% to 24.3%, depending on the plant development stage [46].

High yields of green matter also determine the potential use of plants. According to a three-year study by Daniel and Rompf [3], DM yield of *S. perfoliatum* fell within the range from approximately 19.2 t·ha⁻¹ (for plants harvested in the stage before the formation of flower buds and at plant height of 144 cm) to about 29.3 t·ha⁻¹ (for plants harvested at the flowering stage, at plant height of 248 cm). The average yields of DM for plants of *S. perfoliatum*, *S. trifoliatum*, and *S. integrifolium* were as follows: approx. 2.9, 2.4, and 2.2 t·ha⁻¹ for plants harvested in the stage of spring regrowth, approx. 12.5, 10.7, and 9.9 t·ha⁻¹ for plants in the flower bud stage, and approx. 36.6, 28.8, and 17.8 t·ha⁻¹ for plants harvested at the beginning of the blooming stage, respectively [27,29,31].

3.2. Ash

Among the analysed aboveground and underground organs of plants from the species of *Silphium*, leaves had the highest ash content in DM (Tables 3–5). In leaves of annual plants harvested in September (E), the average ash content was up to approx. 16.8% (*S. trifoliatum*). For perennial plants, the following ash content levels were determined in the leaves, stems, flowers, and rhizomes, respectively: up to 19.7% (*S. perfoliatum*—leaves—E), up to 20.9% (*S. integrifolium*—stems—A), up to 14.0% (*S. integrifolium*—flowers—C), up to 9.3% (*S. perfoliatum*—rhizomes—F). In the May harvest (A), the content of ash in stems was comparable to the level of that parameter in leaves harvested at the same time and amounted to, on average, 20.9% (*S. integrifolium*—stems—A), and then decreased

with the growth of the plant. Statistically significant differences were noted for mean ash content levels in the particular organs of the analysed species of *Silphium*. The literature provides only data on the content of ash in the aboveground organs of *S. perfoliatum*. In leaves of *S. perfoliatum* harvested at the start of vegetation, ash content of comparable with that in stems, and with the growth of the plant, those values diverged and amounted to approx. 14% DM for the leaves and approx. 7% for the stems in the case of plants in the blooming stage, while in the stage of fructification ash content in the leaves was determined at 12%, and in the stems—5% [2,44,47]. To compare the content of ash in the aboveground parts of *S. perfoliatum* to Jerusalem artichoke *Helianthus tuberosus*, the values obtained were 9.2% and 7.9% DM, respectively [48].

3.3. Water-Soluble Sugars and Cellulose

Leaves of annual plants of the analysed species of *Silphium* had the following levels of mean total sugars content in DM – up to 13.4% (*S. trifoliatum*) and up to 8.2% (*S. perfoliatum*) (Tables 3–5). Leaves of perennial plants had the highest content of total sugars in the stage of spring regrowth (A), up to 14.7% DM (*S. trifoliatum*), in which approx. 37.8% were reducing sugars (5.6% DM). With the growth of the plants, the content of total sugars in leaves decreased. Comparing the content of sugars in the aboveground and underground organs of perennial plants, it was noted that the highest level of total sugars was found in the rhizomes, on average up to 26.7% DM (*S. perfoliatum*), while the corresponding content of reducing sugars in the rhizomes was from 1.8% to 2.9% DM. The dominant water-soluble sugars in the rhizomes are complex sugars, with levels from 21.7% to 26.7% DM. From the rhizomes and leaves of *S. perfoliatum*, *S. trifoliatum* and *S. integrifolium* inulin was isolated in amounts of up to 38.3% DM—*S. trifoliatum*, up to 34.0% DM—*S. perfoliatum*, and up to 33.3% DM—*S. integrifolium* [30].

Stems of the species of *Silphium* are also a rich source of water-soluble carbohydrates. The average level of total sugars and reducing sugars in the stems was from 3.1% DM (*S. integrifolium*) to 19.1% (*S. trifoliatum*), and from 0.8% DM (*S. integrifolium*) to 17.7% DM (*S. trifoliatum*), respectively. Significant differences were noted between the mean levels of water-soluble sugars for the analysed organs of the plants. The literature provides data only on the level of soluble sugars in the aboveground parts of *S. perfoliatum*. As reported by Bek and Anikeenko [49], Pavlov et al. [50], and by Daniel and Rompf [3], the fraction of soluble carbohydrates in *S. perfoliatum* constituted a total of from about 12% to approximately 21% DM of the entire aboveground parts, the leaves containing up to 9.9% total sugars while the stems were up to 24.5%. The levels of monosaccharides in *S. perfoliatum* are more than twice as high as the content of disaccharides.

The study shows that with the growth of the plants, there was an increase in the content of cellulose. In the leaves and stems of the three species of *Silphium*, the following levels of cellulose were determined: up to 22.5% DM (*S. integrifolium* leaves harvested in term A from perennial cultivation), up to 33.2% DM (*S. perfoliatum* leaves harvested in term D from annual cultivation), up to 27.7% DM (*S. trifoliatum* leaves harvested in term D from perennial cultivation), up to 27.5% DM (*S. perfoliatum* stems harvested in term A from perennial cultivation), and up to 42.9% DM (*S. trifoliatum* stems harvested in term D from perennial cultivation). The inflorescences of the studied species contained cellulose in the range of 24% to 28% DM, whereas, in the rhizomes of the *Silphium* species, about 25% to 26% cellulose was found. In the flowering phase, the stems of the plants become more lignified and harder to break, which is related to an increase in the levels of hard soluble carbohydrates, cellulose and lignin. In relation to this, from the moment of flowering, there takes place a rapid deterioration of digestibility and nutritional value of most nutrients of *S. perfoliatum*. That is explained by the results of studies on the variation of the content of cellulose in aboveground parts of *S. perfoliatum*: from approx. 14.3% DM in the stage of spring regrowth to about 39.7% in the stage of fructification [1,44,50–52]. Glyaubertene and Ivanovskaya [44] and Pavlov et al. [50] report that stems of *S. perfoliatum* contain up to three-fold more cellulose compared to its content in the leaves, i.e., approx. 30%–35% and 11%, respectively, converted to DM. A study conducted in the Republic of Moldova demonstrated that green matter of *S. perfoliatum* contains cellulose in the amount of 24.7% DM [53]. To compare the content of

cellulose in *S. perfoliatum* to that in Jerusalem artichoke *Helianthus tuberosus*, the values obtained were 30.0% and 21.3%, respectively [48].

3.4. Crude Protein

Leaves collected from annual plants of the species of *Silphium* contained, on average, up to 18.37% of total protein (*S. perfoliatum*) (Tables 3–5). The lowest content of crude protein was characteristic of leaves of annual *S. trifoliatum* at the level of 12.7% DM. In the case of perennial plants, the content of protein decreased over the entire period of plant vegetation. Leaves of *S. perfoliatum* harvested at the beginning of May, when the plants were in the stage of spring regrowth (A), contained, in the years of the study, an average of 22.9% of total protein. The content of total protein in leaves of *S. trifoliatum* and *S. integrifolium* decreased in the May (A) to September (E) period as follows: from 19.1% to 13.0% and from 18.4% to 12.0%, respectively. Stems were characterised by statistically significantly lower average levels of total protein relative to the leaves.

As in the case of other analysed components from the group of primary metabolites, the literature provides only data concerning protein content in the species *S. perfoliatum*. In another study, also conducted in Poland, it was noted that green matter of *S. perfoliatum* contained total protein at levels from 6.2% (in the stage of fructification) to 17.0% (at the start of vegetation) [45]. In a continued experiment by the cited authors, aboveground organs of *S. perfoliatum* had an even lower content of protein, i.e., from 4.9% to 8.5% [46]. Green matter acquired from plants of *S. perfoliatum* cultivated at other geographical latitudes, like in the study presented here, was characterised by a considerable total protein content from 8.6% to 32.1% DM, and of protein proper from 7.3% to 21.9% DM [1,3,49,50,53–60]. There is an interesting comparison of crude protein content in *S. perfoliatum* and in Jerusalem artichoke *Helianthus tuberosus* [48], where the values obtained were 15.9% and 9.3%, respectively, in favor of *S. perfoliatum*. Like in the presented study, the literature reports the highest levels of protein in the stage of spring regrowth, and with the development of plants, the level of that component decreased [44,47,61–63].

3.5. Protein Amino Acids

Analysis of the protein fraction of the aboveground organs of species of *Silphium* revealed the presence of 16 amino acids, i.e., glycine, alanine, valine, leucine, isoleucine, serine, threonine, methionine, aspartic acid, glutamic acid, lysine, arginine, phenylalanine, tyrosine, histidine, proline (Table 6). Exogenic amino acids identified in protein include: leucine (up to 9.4% *S. integrifolium*), phenylalanine (up to 6.8% *S. integrifolium*), valine (up to 5.9% *S. integrifolium*), threonine (up to 6.3% *S. trifoliatum*), lysine (up to 5.3% *S. integrifolium*), isoleucine (up to 4.6% *S. integrifolium*), tyrosine (up to 3.5% *S. integrifolium*), cysteine (up to 1.0% *S. perfoliatum*), and methionine (up to 1.2% *S. integrifolium*). The high content of lysine is noteworthy here, which is a deficit amino acid of vegetable proteins. Among the remaining amino acids, the dominant ones are aspartic acid (up to 12.0% *S. trifoliatum*), glutamic acid (up to 9.5% *S. integrifolium*), and glycine (up to 7.7% *S. integrifolium*). Leaves and herbage of the analysed three species of *Silphium* are characterised by a similar quantitative composition of the amino acids in specific protein. This experiment confirmed the beneficial participation of exogenic amino acids in protein occurring in the herbage of *S. perfoliatum*.

Duranti et al. [1] reported that the amino acid composition of protein of the herbage of *S. perfoliatum* included exogenic amino acids, i.e., leucine—mean of 8.6% of specific protein, valine—mean of 6.2%, isoleucine—mean of 5.1%, lysine—mean of 4.2%, phenylalanine—mean of 5.7%, threonine—mean of 4.8%, tyrosine—mean of 3.8%, and methionine—mean of 1.9%. It is interesting to compare the amino acid profile of protein in *S. perfoliatum* to that in Jerusalem artichoke *Helianthus tuberosus* [48], where the cited authors obtained the respective levels: aspartic acid 9.4% and 6.4%, glutamic acid 9.3% and 8.9%, glycine 4.8% and 3.9%, leucine 9.7% and 5.4%, phenylalanine 4.1% and 6.5%, threonine 4.5% and 3.3%, methionine 3.5% and 0.6%, valine 4.4% and 4.0%, isoleucine 4.1% and 3.1%, and tyrosine 6.8%

and 4.0%. The cited study indicates that the amino acid profile of the protein of *S. perfoliatum* contains higher levels of exogenic amino acids compared to Jerusalem artichoke.

3.6. Crude Fat

In the years of the study, leaves of annual plants of the analysed species of *Silphium* contained, on average, approximately 1.5% of crude fat. In the case of organs of perennial plants, the highest content of crude fat was noted in inflorescences of *S. perfoliatum* (the average of approx. 4%) compared to inflorescences of the other analysed species (the average of approx. 0.5%; Tables 3–5). Leaves of perennial plants of *Silphium* were characterised by crude fat content above 2% over the entire period of harvest. Crude fat content in the rhizomes of the plants was, on average, approximately 1% in the years of the study. The content of lipids in the stems was in the range of approx. 0.6%–0.9% for all harvests, with a mean of 0.76%, the highest fat content being observed in the stage of flowering and fructification. Statistically significant differences were noted in fat content between the analysed plant organs and times of harvest.

Unfortunately, the literature does not provide any characterisation of the species *S. trifoliatum* and *S. integrifolium* in terms of their content of fat. Fat content in the aboveground parts of *S. perfoliatum* is varied [61,64]. In an experiment conducted in Polish conditions, crude fat content in the aboveground parts of plants varied from 1.9% (at the start of vegetation) to 2.9% (in the stage of fructification) [45]. A study conducted in the Republic of Moldova showed that green matter of *S. perfoliatum* contains crude fat in the amount of 2.3% DM [53]. Glyaubertene and Ivanovskaya [44] obtained considerably higher values, and so, e.g., leaves and stems of *S. perfoliatum* in the stage of spring regrowth had fat contents of 3.6%–4.4% and 3.2%–4.2%, respectively, while in the blooming stage the corresponding values were 5.7% and 4.6%, indicating an increase compared to the previous harvest. There is an interesting comparison of the content of crude fat in *S. perfoliatum* and Jerusalem artichoke *Helianthus tuberosus* [48], in which the values obtained were 3.25% and 1.93%, respectively, in favor of *S. perfoliatum*.

3.7. L-Ascorbic Acid

Leaves of the analysed species of *Silphium* had the highest content of L-ascorbic acid relative to the other analysed organs (Tables 3–5). In leaves of annual plants, the average content of vitamin C was approx. $300 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$. In leaves acquired from perennial plants, the highest level of vitamin C was noted for *S. integrifolium*, mean of $779 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, in the May harvest (A) in the stage of fast regrowth. In the stems of the analysed species of *Silphium* the highest levels of L-ascorbic acid were noted in the harvest in the stage of spring regrowth (A; average of $142\text{--}197 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$). With the development of the plants, the content of vitamin C in the stems decreased, attaining levels below the threshold of detection in harvests D and E. Inflorescences of the *Silphium* species had vitamin C levels from $156 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$ to $339 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, while in the underground parts of the plants the level of vitamin C was below the threshold of detection.

Taking into account published reports on the content of L-ascorbic acid, one should note that at the beginning of vegetation *S. perfoliatum* species are characterised by the highest content of that substance, relative to plants harvested at later stages of development, i.e., from 140 to $500 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$ DM in leaves and up to $20 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$ in stems [47,49,65,66]. In the presented study, considerably higher levels of L-ascorbic acid were noted in stems of plants harvested in the stage of spring regrowth, compared to the literature data. For comparison, the content of L-ascorbic acid in herbage of nettle is from 36 to $269 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, which is a level comparable to that of *Silphium* species [67].

3.8. Chlorophyll

The study shows that leaves of the three species of *Silphium*, harvested at the beginning of flowering (C), were characterised by the highest content of chlorophyll, i.e., from 1.5% (*S. integrifolium*) to 2.3% (*S. perfoliatum*) (Tables 3–5). That content corresponds with the level of magnesium (a component of chlorophyll) in the aboveground parts, where a higher level of that element was observed in leaves,

compared to stems, with a similar trend in the case of chlorophyll. Statistical analysis of the mean levels of chlorophyll for the various organs revealed significant differences in its content. In the available literature, there is a lack of information on the content of chlorophyll in species from the genus *Silphium*. In comparison, the chlorophyll content in nettle herbage varies from 0.3% to 1%, which is a level comparable to that of *Silphium* species [67]. *Silphium* species can be a source of that pigment, e.g., for food products.

3.9. Tannins

Leaves of annual plants of *Silphium*, harvested in September (E), had average tannin levels from 7.3% w *S. perfoliatum* to 8.9% w *S. trifoliatum* (Tables 3–5). In perennial plants, the highest levels of tannins were noted in leaves collected from plants in the stage of flower buds (B) at the beginning of June: mean levels from 9.6% in *S. perfoliatum* and *S. integrifolium* to 11.2% in *S. trifoliatum*. Inflorescences had tannin content from 8.4% (*S. perfoliatum*) to 11.4% (*S. integrifolium*). The material with the lowest levels tanning was the rhizomes, in which the mean tannin content was determined at from 5.7% (*S. perfoliatum*) to 7.5% (*S. trifoliatum*). Statistical analysis of mean levels of tannins for the various plant organs revealed significant differences in the content of those components.

3.10. Minerals, Trace Elements and Heavy Metals

Tables 3–5 compiles the data of the content of minerals and trace elements and also heavy metal content in the tested plants. These data are quite differentiated, which is probably affected by the species-specific traits. In general, the content of mineral compounds in *Silphium* plants is one of the important traits influencing their use-value. Leaves and inflorescences of *S. perfoliatum*, *S. trifoliatum* and *S. integrifolium* can be a supplementary source of mineral elements such as K (from about $3.0 \text{ g} \cdot 100^{-1} \cdot \text{g}^{-1}$ for *S. trifoliatum* inflorescences to about $3.8 \text{ g} \cdot 100^{-1} \cdot \text{g}^{-1}$ for *S. integrifolium* leaves), Ca (from about $1.2 \text{ g} \cdot 100^{-1} \cdot \text{g}^{-1}$ for *S. perfoliatum* inflorescences to about $4.5 \text{ g} \cdot 100^{-1} \cdot \text{g}^{-1}$ for *S. integrifolium* leaves) or Mg (from about 206 mg for *S. trifoliatum* inflorescences to about $333 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$ for *S. integrifolium* leaves), as well as trace elements, e.g., Fe (from about 8 mg in the inflorescences of all three species to about $27 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$ for *S. perfoliatum* and *S. trifoliatum* and leaves) and Mn (from about 3 mg in the inflorescences of all three species to about 6 mg in the leaves). The content of heavy metals was levels lower than the permissible limits for food products [68]. Studies were carried out on the content of metals in *S. perfoliatum* in the aspect of use of that species as a phytoremediation plant. In an experiment, in the control group of plants, which were not burdened with the application of metal salts to the soil, the authors of that experiment noted the following levels of macroelements and trace metals in DM of aboveground parts of the plants: K $1.2 \text{ g} \cdot 100^{-1} \cdot \text{g}^{-1}$, Ca $0.8 \text{ g} \cdot 100^{-1} \cdot \text{g}^{-1}$, Mg $630 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Mn $24.4 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Fe $8.5 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Cr $0.02 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$ [69], those levels being lower than the levels observed in the presented study.

There is an interesting comparison of the content of metals in *S. perfoliatum* to that in Jerusalem artichoke *Helianthus tuberosus* [48], where the cited authors obtained the following respective levels: Na 5.6 and $19.7 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Fe 12.8 and $15.6 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Mn 2.5 and $6.0 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Zn 2.0 and $2.0 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Cu 0.4 and $0.3 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Mg 0.3 and $0.4 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, Ca 1.7 and $1.3 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, K 2.4 and $1.6 \text{ mg} \cdot 100^{-1} \cdot \text{g}^{-1}$, which is in support of the values obtained in the presented study with regard to *S. perfoliatum*.

Table 3. Chemical composition of *Silphium perfoliatum* L.

Parameter	Leaves							Stalks					Inflorescences			Rhizomes	
	First Year							Perennial									
	E *	A	B	C	D	E	Mean	A	B	C	D	E	Mean	C	D	Mean	F
General chemical composition																	
DM (% FM)	14.3b	13.5	15.0	19.1	19.8	20.8	17.6b	7.5	9.7	17.8	22.0	27.1	16.8b	17.9	17.4	17.6b	33.5a
Ash (% DM)	13.1b	19.5	18.4	18.1	17.4	19.7	18.6a	19.2	14.4	12.1	8.5	6.7	12.2ab	12.1	11.3	11.7b	9.3c
Total protein (% DM)	18.4a	22.9	19.2	15.8	14.9	13.1	17.2ab	14.7	6.8	4.0	3.0	2.9	6.3b	13.3	13.3	13.3ab	10.2b
Crude fat (% DM)	1.5b	2.1	2.2	2.1	2.3	2.3	2.2b	0.7	0.7	0.7	0.9	0.8	0.8c	4.1	4.2	4.2a	1.0c
Total sugars ** (% DM)	10.6c	12.9	4.0	3.1	3.7	5.3	5.8cd	17.1	18.8	15.1	16.2	18.8	17.2b	4.3	5.3	4.8d	26.7a
Reducing sugars (% DM)	8.2	7.3	3.4	2.3	2.5	2.8	3.6	15.1	16.8	11.0	8.6	5.7	11.4	4.2	5.2	4.7	2.0
L-ascorbic acid (mg·100 ⁻¹ ·g ⁻¹ DM)	319b	452	344	397	419	448	412a	142	65	40	***	***	49d	250	273	262c	***
Cellulose (% DM)	33.2a	19.9	21.6	21.3	24.6	22.7	22.0b	27.5	32.1	35.3	39.7	40.7	35.1a	27.0	28.1	27.6ab	25.2b
Chlorophyll a (% DM)	0.6	0.7	0.8	1.2	0.9	1.0	0.9	0.1	0.1	0.1	0.3	0.2	0.2	0.3	0.5	0.4	***
Chlorophyll b (% DM)	0.5	0.6	0.7	1.1	0.8	0.7	0.8	0.1	0.1	0.1	0.2	0.1	0.1	0.2	1.2	0.7	***
Total chlorophyll (% DM)	1.0ab	1.3	1.5	2.3	1.7	1.7	1.7a	0.2	0.1	0.2	0.5	0.2	0.3b	0.5	1.7	1.1ab	***
Tannins (% DM)	7.3a	9.5	9.6	8.7	6.9	6.0	8.1a	nd	nd	nd	nd	nd	nd	8.4	8.9	8.7a	5.7b
The contents of mineral and trace elements																	
Na (mg·100 ⁻¹ ·g ⁻¹ DM)	1.4b	1.4	6.4	1.1	0.7	0.9	2.1ab	1.3	3.8	4.3	4.6	4.5	3.7ab	1.4	1.4	1.4b	3.9a
K (g·100 ⁻¹ ·g ⁻¹ DM)	4.2a	4.6	4.5	4.5	2.8	2.0	3.7a	4.3	3.5	2.7	1.5	1.0	2.6a	3.2	3.3	3.3a	2.7a
Ca (g·100 ⁻¹ ·g ⁻¹ DM)	2.3a	1.8	3.2	3.6	4.4	5.7	3.7a	0.8	0.8	1.1	0.9	0.8	0.9c	1.2	1.2	1.2bc	0.8c
Mg (mg·100 ⁻¹ ·g ⁻¹ DM)	269.0a	221	264	322	320	416	308a	151	184	192	207	72	161.1b	210	225	217ab	334a
Zn (mg·100 ⁻¹ ·g ⁻¹ DM)	1.9d	2.7	2.4	2.7	2.4	1.9	2.4cd	1.5	1.4	1.6	1.6	0.6	1.3e	3.7	3.6	3.6b	7.3a
Fe (mg·100 ⁻¹ ·g ⁻¹ DM)	38.9	16.8	16.3	38.2	39.7	23.3	26.9	4.3	4.2	34.0	15.1	40.8	19.7	8.0	8.2	8.1	73.8
Mn (mg·100 ⁻¹ ·g ⁻¹ DM)	4.6a	4.1	4.1	4.0	5.2	11.7	6.3a	0.7	0.6	1.5	1.8	1.9	1.3c	2.7	2.6	2.6b	4.7a
Se (µg·100 ⁻¹ ·g ⁻¹ DM)	5.7bc	4.4	7.1	4.8	6.0	5.3	5.5bc	2.8	3.7	4.6	5.0	15.4	6.3b	4.3	4.3	4.3c	9.6ab
Cr (mg·100 ⁻¹ ·g ⁻¹ DM)	0.1c	0.2	0.2	0.4	0.2	0.2	0.2b	0.2	0.3	0.5	0.2	0.1	0.2bc	0.1	0.1	0.1d	0.9a
Cu (mg·100 ⁻¹ ·g ⁻¹ DM)	0.4d	0.7	0.5	0.5	0.8	0.6	0.7c	0.4	0.4	0.4	0.4	0.2	0.4d	1.2	1.2	1.2b	2.0a
Cd (µg·100 ⁻¹ ·g ⁻¹ DM)	3.0a	1.2	3.1	3.2	6.8	5.7	4.0a	0.8	1.3	1.1	1.3	0.9	1.1b	0.9	1.0	1.0b	***
Pb (µg·100 ⁻¹ ·g ⁻¹ DM)	3.4a	***	1.6	1.9	3.4	5.1	2.4a	***	***	***	***	0.2	0.0b	***	***	***	***
As (µg·100 ⁻¹ ·g ⁻¹ DM)	8.4a	0.3	3.3	2.3	19.4	16.5	8.4a	5.0	5.4	7.3	2.6	5.5	5.2b	***	***	***	***

* Harvest date (A—May, B—Jun, C—Jul, D—Aug, E—Sep, F—Oct); ** Sum of sugars contents after hydrolysis; *** Below the limit of quantitation; (<LOQ); nd—not determined; DM—dry matter; FM—fresh matter; a, b, c, . . . —values designated with the same letters within a line do not significantly differ at 5% error.

Table 4. Chemical composition of *Silphium trifoliatum* L.

Parameter	Leaves							Stalks					Inflorescences			Rhizomes	
	First Year							Perennial									
	E *	A	B	C	D	E	Mean	A	B	C	D	E	Mean	C	D	Mean	F
General chemical composition																	
DM (% FM)	15.9b	15.3	16.5	19.9	20.0	22.6	18.9b	7.3	10.4	20.2	22.2	26.7	17.4b	18.7	16.5	17.6b	37.6a
Ash (% DM)	16.8a	19.5	16.9	17.2	17.2	18.7	17.9a	20.3	13.0	8.0	6.4	6.8	10.9ab	11.4	10.0	10.7b	8.0b
Total protein (% DM)	12.7ab	19.1	16.0	15.0	14.9	13.0	15.6a	14.8	7.4	4.4	3.0	2.7	6.5b	15.0	15.3	15.2a	11.0b
Crude fat (% DM)	1.5ab	2.1	2.2	2.2	2.3	2.3	2.2a	0.7	0.7	0.8	0.9	0.9	0.8cd	0.5	0.6	0.6d	1.0bc
Total sugars ** (% DM)	13.3b	14.7	3.7	4.3	4.4	4.4	6.3bc	15.2	19.1	8.3	11.4	11.9	13.2b	5.1	4.3	4.7c	22.3a
Reducing sugars (% DM)	5.0ab	5.6	3.0	2.9	2.1	1.8	3.1c	17.5	17.7	5.0	6.3	4.7	10.3a	4.7	3.9	4.3bc	2.9d
L-ascorbic acid (mg·100 ⁻¹ ·g ⁻¹ DM)	331b	352	414	357	437	445	401a	161	56	41	***	***	52d	306.0	156.0	231c	***
Cellulose (% DM)	31.3ab	19.5	22.1	22.5	27.7	24.3	23.2b	24.6	30.3	35.4	38.7	42.9	34.4a	24.9	24.0	24.4b	26.2b
Chlorophyll a (% DM)	0.5	0.7	0.9	1.0	0.9	1.0	0.9	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	nd
Chlorophyll b (% DM)	0.4	0.5	0.8	0.9	0.7	0.7	0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	nd
Total chlorophyll (% DM)	0.9b	1.2	1.7	1.8	1.6	1.8	1.6a	0.4	0.3	0.3	0.3	0.1	0.3d	0.5	0.5	0.5c	nd
Tannins (% DM)	8.9b	9.9	11.2	9.7	8.8	8.3	9.6ab	nd	nd	nd	nd	nd	nd	9.5	11.4	10.4a	7.5c
The contents of mineral and trace elements																	
Na (mg·100 ⁻¹ ·g ⁻¹ DM)	1.0c	1.4	6.3	1.0	0.6	0.8	2.0bc	1.3	3.6	4.3	4.3	4.5	3.6ab	1.3	1.1	1.2b	3.7a
K (g·100 ⁻¹ ·g ⁻¹ DM)	3.3a	4.5	4.5	4.4	2.9	2.1	3.7a	4.3	3.5	3.0	1.8	1.2	2.7a	2.9	3.2	3.0a	2.5a
Ca (g·100 ⁻¹ ·g ⁻¹ DM)	2.7a	1.9	3.2	3.4	4.3	5.9	3.8a	0.8	0.8	1.0	1.0	0.8	0.9c	1.3	1.4	1.3b	0.8c
Mg (mg·100 ⁻¹ ·g ⁻¹ DM)	325a	229	279	335	320	413	315.2a	151	177	186	213	92	164b	213	199	205b	329a
Zn (mg·100 ⁻¹ ·g ⁻¹ DM)	2.3c	2.8	2.4	2.7	2.4	2.0	2.4c	1.6	1.5	1.6	1.6	0.6	1.4d	3.8	3.4	3.6b	7.5a
Fe (mg·100 ⁻¹ ·g ⁻¹ DM)	27.6b	18.0	17.8	37.2	38.4	24.9	27.3b	4.4	4.5	36.3	26.7	30.6	20.5bc	7.9	8.0	8.0c	71.4a
Mn (mg·100 ⁻¹ ·g ⁻¹ DM)	6.4a	4.2	4.2	4.0	5.0	12.2	5.9a	0.7	0.6	1.5	1.7	1.8	1.3d	2.7	3.1	2.9c	4.8b
Se (µg·100 ⁻¹ ·g ⁻¹ DM)	5.9ab	4.5	7.2	4.7	6.0	5.9	5.7ab	2.9	3.5	4.4	4.9	12.8	5.7ab	4.4	4.4	4.4b	9.7a
Cr (mg·100 ⁻¹ ·g ⁻¹ DM)	0.2c	0.2	0.2	0.4	0.3	0.2	0.3b	0.2	0.3	0.5	0.2	0.2	0.3b	0.1	0.1	0.1c	1.0a
Cu (mg·100 ⁻¹ ·g ⁻¹ DM)	0.5c	0.7	0.4	0.5	0.7	0.6	0.6c	0.3	0.4	0.4	0.4	0.2	0.3d	1.2	1.3	1.2b	2.0a
Cd (µg·100 ⁻¹ ·g ⁻¹ DM)	3.0a	1.3	3.2	3.2	6.7	6.8	4.2a	0.8	1.4	1.4	1.5	1.2	1.3b	1.0	0.9	0.9b	0c
Pb (µg·100 ⁻¹ ·g ⁻¹ DM)	2.7a	0.1	1.4	1.6	3.2	4.7	2.2a	***	***	***	***	0.2	0.0b	***	***	***	***
As (µg·100 ⁻¹ ·g ⁻¹ DM)	8.0a	1.4	6.3	1.0	0.6	0.8	4.4a	4.7	5.3	7.2	2.3	4.9	4.9a	***	***	***	***

* Harvest date (A—May, B—Jun, C—Jul, D—Aug, E—Sep, F—Oct); ** Sum of sugars contents after hydrolysis; *** Below the limit of quantitation; (<LOQ); nd—not determined; DM—dry matter; FM—fresh matter; a, b, c, . . . —values designated with the same letters within a line do not significantly differ at 5% error.

Table 5. Chemical composition of *Silphium integrifolium* Michx.

Parameter	Leaves							Stalks					Inflorescences			Rhizomes	
	First Year							Perennial									
	E *	A	B	C	D	E	Mean	A	B	C	D	E	Mean	C	D	Mean	F
General chemical composition																	
DM (% FM)	15.6b	16.7	16.4	21.3	18.7	20.9	18.8b	9.3	13.8	20.4	21.7	29.7	19.0b	20.3	16.0	18.1b	32.7a
Ash (% DM)	16.3a	15.8	16.4	16.3	16.2	17.3	16.4a	20.9	16.0	11.8	11.2	8.3	13.6ab	14.0	12.3	13.1b	8.2c
Total protein (% DM)	17.8a	18.4	15.1	13.7	13.3	12.0	14.5a	12.3	7.0	4.3	3.0	2.8	5.9c	13.8	13.4	13.6a	9.9b
Crude fat (% DM)	1.5a	2.0	2.0	2.1	2.1	2.2	2.1a	0.6	0.6	0.6	0.8	0.8	0.7b	0.5	0.5	0.5b	0.9b
Total sugars ** (% DM)	8.3b	6.5	3.5	2.8	1.9	2.3	3.4c	6.5	5.7	4.8	3.1	5.8	5.2c	1.9	2.0	2.0	21.7a
Reducing sugars (% DM)	2.0a	2.4	1.9	1.7	1.3	1.9	1.8a	4.3	4.3	2.5	0.8	0.9	2.6a	1.9	1.7	1.8a	1.8a
L-ascorbic acid (mg·100 ⁻¹ ·g ⁻¹ DM)	328b	779	469	390	462	488	517a	197	86	54	***	***	67c	322	339	331b	***
Cellulose (% DM)	31.6a	22.5	23.4	23.6	26.8	23.1	23.9b	27.4	32.6	36.4	40.1	41.6	35.6a	25.0	25.4	25.2b	25.4b
Chlorophyll a (% DM)	0.5	0.8	0.7	0.8	0.6	0.8	0.7	0.2	0.1	0.2	0.2	0.1	0.2	0.4	0.4	0.4	***
Chlorophyll b (% DM)	0.4	0.6	0.7	0.8	0.6	0.7	0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	***
Total chlorophyll (% DM)	0.9b	1.4	1.4	1.5	1.2	1.4	1.4a	0.3	0.2	0.3	0.2	0.2	0.2d	0.6	0.6	0.6c	***
Tannins (% DM)	8.8b	8.1	9.6	8.2	7.8	7.0	8.2b	nd	nd	nd	nd	nd	nd	11.2	10.2	10.7a	6.6c
The contents of mineral and trace elements																	
Na (mg·100 ⁻¹ ·g ⁻¹ DM)	1.1b	1.4	5.9	2.0	1.0	1.0	2.3ab	1.4	4.2	4.5	4.6	4.7	3.9ab	1.5	1.6	1.5b	3.9a
K (g·100 ⁻¹ ·g ⁻¹ DM)	3.3a	4.5	4.6	4.8	2.8	2.2	3.8a	4.3	3.5	2.8	1.5	1.2	2.7a	3.3	3.2	3.3a	2.2a
Ca (g·100 ⁻¹ ·g ⁻¹ DM)	2.4a	2.1	4.0	4.2	5.2	6.8	4.5a	1.0	1.3	1.5	1.6	1.8	1.4b	1.9	1.7	1.8b	1.0c
Mg (mg·100 ⁻¹ ·g ⁻¹ DM)	295a	225	277	333	413	415	333a	154	186	194	213	83	166b	219	201	210ab	349a
Zn (mg·100 ⁻¹ ·g ⁻¹ DM)	2.2c	3.8	4.0	4.1	3.9	3.8	3.9b	2.1	2.4	2.4	2.6	1.9	2.3c	5.0	4.5	4.7b	9.1a
Fe (mg·100 ⁻¹ ·g ⁻¹ DM)	34.6b	14.5	14.7	30.3	30.2	19.2	21.8c	3.9	3.8	30.3	27.9	25.0	18.2cd	7.3	8.3	7.8d	52.6a
Mn (mg·100 ⁻¹ ·g ⁻¹ DM)	5.6a	4.2	4.2	4.0	5.2	10.9	5.7a	0.7	0.6	1.4	1.9	1.9	1.3c	2.8	2.6	2.8b	4.7a
Se (μg·100 ⁻¹ ·g ⁻¹ DM)	6.2b	7.2	12.4	7.3	7.4	7.4	8.4ab	4.2	6.9	7.2	7.3	12.9	7.7ab	6.2	6.3	6.3b	12.8a
Cr (mg·100 ⁻¹ ·g ⁻¹ DM)	0.1	0.2	0.2	0.3	0.2	0.1	0.2b	0.1	0.2	0.2	0.1	0.1	0.1bc	0.1	0.1	0.1c	0.6a
Cu (mg·100 ⁻¹ ·g ⁻¹ DM)	0.4d	0.6	0.5	0.5	0.5	0.6	0.6c	0.4	0.4	0.4	0.4	0.4	0.4cd	1.1	1.1	1.1b	2.0a
Cd (μg·100 ⁻¹ ·g ⁻¹ DM)	2.8a	1.0	2.8	2.9	4.3	4.9	3.2a	0.6	0.9	1.0	1.1	0.8	0.9ab	0.8	0.8	0.8b	***
Pb (μg·100 ⁻¹ ·g ⁻¹ DM)	2.7a	0.0	1.2	1.0	2.6	4.0	1.8a	***	***	***	***	***	***	***	***	***	***
As (μg·100 ⁻¹ ·g ⁻¹ DM)	7.2a	0.2	2.8	2.3	12.3	9.7	5.5ab	3.8	4.3	6.5	2.2	3.0	4.0b	***	***	***	***

* Harvest date (A—May, B—Jun, C—Jul, D—Aug, E—Sep, F—Oct); ** Sum of sugars contents after hydrolysis; *** Below the limit of quantitation; (<LOQ); nd—not determined; DM—dry matter; FM—fresh matter; a, b, c, ... —values designated with the same letters within a line do not significantly differ at 5% error.

Table 6. Percentage of amino acids in total protein of three *Silphium* species leaves (L) and herbs (H).

Amino Acid *	Species					
	<i>S. perfoliatum</i>		<i>S. trifoliatum</i>		<i>S. integrifolium</i>	
	L	H	L	H	L	H
Asp	10.7ab	9.0c	9.2bc	12.0a	11.8a	10.1b
Thr	5.8a	6.0a	5.4b	6.3a	6.0a	5.3b
Ser	4.6a	4.6a	4.7a	4.4a	4.9a	4.9a
Glu	9.1a	8.1b	9.3a	7.9b	9.5a	8.7ab
Pro	3.7cd	4.9b	3.2d	5.6a	4.3bc	4.3bc
Gly	7.7a	7.4a	7.5a	6.8a	7.4a	6.8a
Ala	6.0a	6.3a	6.1a	6.0a	6.1a	6.2a
Val	5.8a	5.0bc	5.4ab	4.7c	5.9a	4.8bc
Ile	4.2ab	3.8b	3.7bc	3.3c	4.6a	3.7bc
Leu	8.9	9.1	8.7ab	7.7b	9.4a	8.5ab
Tyr	3.3a	2.8b	3.2ab	2.4c	3.5a	2.4c
Phe	6.2ab	6.4ab	5.3c	6.4ab	6.8a	5.8bc
Lys	4.5b	4.9ab	4.5b	4.3b	5.3a	4.4b
His	2.3a	2.1ab	2.0b	2.2a	2.1ab	1.9b
Arg	3.7a	3.4b	3.7ab	4.1a	3.9a	3.4b
Cys	1.0a	0.8bc	0.6d	0.7cd	0.9ab	0.7cd
Met	0.8b	0.6c	0.4d	0.6c	1.2a	0.6c
Sum	88.2	85.2	83.0	85.4	93.5	82.6

* Asp—aspartic acid, Thr—threonine, Ser—serine, Glu—glutamic acid, Pro—proline, Gly—glycine, Ala—alanine, Val—valine, Ile—leucine, Leu—leucine, Tyr—tyrosine, Phe—phenylalanine, Lys—lysine, His—histidine, Arg—arginine, Cys—cysteine, Met—methionine; a, b, c, . . . —values designated with the same letters within a line do not significantly differ at 5% error.

Summarising the data obtained in the study and literature reports on the content of primary metabolites and minerals in aboveground organs of *S. perfoliatum*, one can conclude that the plant is characterised by potential which can be used for food and feed purposes [1,3,44,50,52,54,55,59,61,62,64,65,70,71]. In addition, research concerning *S. trifoliatum* and *S. integrifolium*, which was conducted in the presented scope for the first time for the analysed species, indicates that those plants are also characterised by a valuable chemical composition which predisposes them as a source of organic raw material for various applications. The analysis of the chemical composition of perennial plants in the course of their ontogenesis revealed that the vegetative organs of the analysed species of *Silphium*, intensively assimilating CO₂ in the stage spring regrowth (A), have the highest content of primary metabolites and minerals in DM. With further growth and development of the analysed plants, a decrease was noted in the content of primary metabolites and minerals. In the blooming stage of the plants, a further decrease in the content of primary metabolites and minerals was observed.

Summarising the results on the variation of the composition of primary metabolites and minerals in the course of ontogenesis of perennial plants of *Silphium*, one can conclude that biomass with the highest content of protein, water-soluble carbohydrates, fats, and L-ascorbic acid, can be acquired from plants harvested at an early stage of development. However, as yields obtained in that plant development stage are not economically viable, the optimum harvest time can be the period between the appearance of flower buds and the start of the blooming stage. Any later time of green matter harvest involves the risk of a significant reduction of its feed and nutritional values.

4. Conclusions

Content of protein, amino acids, fat, cellulose, water-soluble sugars and mineral substances in the tested *Silphium* species (*S. perfoliatum*, *S. trifoliatum* and *S. integrifolium*) can be an important criterion determining a positive evaluation of these plants as sources of alternative raw materials. The presented results are meant to draw attention to the possibility of use of the biomass of three *Silphium* species

as a potential source of ecological and renewable raw material for food, pharmaceuticals, feed, and possibly also energy generation purposes.

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