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Study of some biochemical parameters and productivity of *Silphium* L. genotypes as perspective energetic crops

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Purpose. This study was aimed to determine some biochemical parameters and productivity of the gene fund of *Silphium* L. genus in the M. M. Gryshko National Botanical Garden of the NAS of Ukraine. **Methods.** Plant raw material investigated at the flowering stage (17 genotypes) and the end of vegetation (20 genotypes) of *Silphium* spp. 3 species and 4 cultivars studied for the content of nutrients at the flowering. Determination of dry matter, ash, calcium, nitrogen-free extractives conducted according to Hrytsaienko et al. (2003), phosphorus, protein – according to Pochinok (1976), sugars – according to Krishchenko (1983), cellulose – according to Zheng et al. (2018), lipids – according to Zamowski, Suzuki (2004). It was used productivity parameters: yield of above-ground mass, the yield of dry mass, energetic value, yield of energy. Data analyzed statistically. **Results.** Investigation of nutrients content showed that content of dry matter was in the range of 18.90–29.3%, protein – in the range of 8.88–23.56%, cellulose – 15.10–36.14%, ash – 8.13–12.19%, lipids – 1.83–3.97%; yield of above-ground mass – 45.0–139.0 t/ha, the yield of dry matter – 10.31–36.92 t/ha, energy value – 3933–4249 cal/g, and yield of energy – 43.81–149.27 Gcal/ha. A study of genotypes at the flowering and end of vegetation identified that the content of dry matter for all samples was in a range of 18.38–67.49%, sugars – 2.78–19.0%, ash – 3.93–11.20%, calcium – 1.68–5.99%, phosphorus – 0.14–1.21%, energy value – 3153.36–3770.28 cal/g. **Conclusions.** Plant raw material of genotypes of *Silphium* L. spp. is a valuable source of nutrients. The content of ash, its components, energetic value, and parameters of productivity depending on genotype and stage of growth. The results allow recommending selected *Silphium* genotypes as perspective energetic crops in Ukraine as well as other countries.

Keywords: *Silphium; genotypes; energetic value; productivity; ash.*

Introduction

Natural flora includes an inexhaustible gene fund that can be used in the introductive and selective process more actively to create valuable varieties and cultivars for practical use [1].

Last time numerous scientists indicated on the advantages of growing of representatives of *Silphium* L. (cup flower) as a highly adaptive and perspective energetic crop that from the second year of vegetation provide 13–20 t/ha of absolutely dry mass [1–3]. Some authors denoted that these plants are native to America and about 12 species of *Silphium* are aboriginal plants of the prairies of the northern United States and Canada [4–6]. In Ukraine, these species are known as cultural plants [7].

Cup flower plants demonstrated high potential in the production of bioenergy in the South and North of America, Europe. *S. perfoliatum* is an extremely perspective crop for biogas production throughout Europe due to high yield of biomass, durability (up to 25 years), and the ability to grow in marginal lands [8–12]. Also, these species known as valuable forage, technical, honey, ornamental and phytomeliorative crops [8].

As energy plants, highly productive varieties and hybrids of cup flower plants can provide phyto raw materials yield up to 200 t/ha, dry matter yield – up to 35 t/ha, conventional phytofuels up to 30 t/ha, biogas yield – 20 thousand m^3/ha, biofuel calorific value – up to 4500 kcal/kg and energy yield from 1 ha over

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60 Gcal [13–15]. It was found that the application of mineral fertilizers, in particular nitrate, affects the energy yield of *S. perfoliatum* biomass [16].

Plants of *S. laciniatum* L. use at all as ornamental and medicinal and create interspecific hybrids with *S. terebinthianaceum* on the border of overlapping of their ranges [17]. *S. terebinthianaceum* growth in the natural flora of Indiana, southern Michigan, northern Wisconsin, and Missouri. It is distributed on both plains and mountain prairies and cultivated as a drought-resistant medicinal plant [17].

Extracts of cup flower herb demonstrated diuretic activity and able to decrease the cholesterol level. Herb of this plant is used in folk and traditional medicine as a diaphoretic, tonic, and kidney disease. Also, fresh herbs are used in homeopathy. Plant raw material of *Silphium perfoliatum* contains caffeic, p-coumaric, p-hydroxybenzoic, vanillic, etc. phenolic acids [18; 19]. Extracts of these plants show antioxidant, antibacterial, immunomodulatory activity [20]. The lipid fraction of the seeds of these plants contains 44% linolenic and 13.2% oleic fatty acids [21].

Previous reports showed that more attention was paid to research and the use of *S. perfoliatum* among other species in Ukraine as well as in the world [3; 10]. Based on many-years observations and obtained data about introductive and selective studies of *Silphium* spp. in the M. M. Gryshko National Botanical Garden of the NAS of Ukraine it should be noted that will be relevant a comprehensive study of individual species and created genotypes in the conditions of a specific agroclimatic zone of Ukraine.

The goal of this study was to determine and compare certain biochemical parameters and selected aspects of productivity of the plant raw material of *Silphium* L. genotypes as perspective crops in Ukraine and the world.

Material and methods

Plant material

The investigation was conducted in the M. M. Gryshko National Botanical Garden of the NAS (NBG) of Ukraine during 2018–2020. In this study used plant raw material of *Silphium* L. (cup plant) genotypes that represented the gene fund of these plants: *S. perfoliatum* L., var. PP-1; *S. perfoliatum,* var. PP-2; *S. perfoliatum*, var. NRK-7; *S. perfoliatum,* var. SR-6; *S. perfoliatum*, cv. Bogatyr; *S. perfoliatum,* cv. Peremozhets; *S. perfoliatum,* cv. Kanadchanka; *S. perfoliatum* × *S. integrifolium*; *S. integrifolium* Michx., var. GD-5; *S. integrifolium,* var. GKR-1; *S. integrifolium,* var. LPL-4; *S. integrifolium,* f. EBSFS; *S. integrifolium,* cv. Yuvileinyi-90; *S. integrifolium* × *S. trifoliatum* L.; *S. laciniatum* L.; *S. laciniatum*, f. 1; *S. laciniatum,* f. 2; *S. laciniatum*, var. PL-3; *S. trifoliatum* L.; *S. trifoliatum* × *S. integrifolium*; *S. terebinthinaceum* Jacq.; *S. asperrimum* Hook.

Plants took for analyses at the stages of flowering and the end of vegetation [22].

Study of plant productivity

Field experiments were established by the existing methods for the State Variety Network and research institutions lasting from three to six years in four replications. The size of sown plots is 60–100 m^2, their registration area is 30–60 m^2. The placement of variants on repetitions depending on the experiment is systematic and randomized [23]. It was conducted measurement of plant mass (yield).

Biochemical analyses

Biochemical analyses were carried out in the biochemical laboratory of the Cultural Flora Department of NBG. The dry matter is determined by the drying at the temperature of 105 °C till constant mass. The content of ash was investigated by the method of combustion of the samples in the muffle oven (SNOL 7.2-1100, Termolab) at the 200–500 °C. After combustion, the ash is used for the determination of calcium and phosphorus content by titrimetric methods. Ash was dissolved in hydrochloric acid solution to determine total calcium content. After the routine procedure described in the method, a solution was titrated by Trilon-B in the presence of hydroxylamine and murexide [24].

Ash was dissolved in the nitric acid solution to determine the total phosphorus content. After adding molybdenum acid ammonium, a solution of potassium oxalate, all mixture was titrated by sodium hydroxide in presence of phenolphthalein [25].

The total content of sugars determined by the Bertrand method with the use of Fehling solutions [26]. The content of protein is carried out by chloramine method [25], cellulose – by washing 4% sulphuric acid and 2% sodium hydroxide [27], nitrogen-free extractives – by [24], lipids – with Soxhlet apparatus in petroleum ether according to [28] with slight modification. Caloricity of raw measured on the calorimeter IKA C-200 (benzoic acid as standard). Obtained data analyzed with Microsoft Excel Software and given as averages and standard deviation of the mean. Data represented in Table 1 and Figures 1–6.

Results and discussion

In the Cultural Flora Department of the NBG last decades conducted the comprehensive introduction and selection study with the species of *Silphium* L. genus, as a result of which were cultivars (4), varieties and forms (11), and interspecific hybrids (4) [22]. Results of the many-years investigations conducted in the NBG showed that phyto raw of these plants is a valuable source of nutritive compounds such as vitamins, sugars, cellulose, protein, etc. [1, 7, 29]. 100 kg of green mass of these plants contains the 14–16 feed units, one of which includes 140–160 g of digestible protein [7].

Investigation of biochemical composition and peculiarities of nutrient accumulation is an important direction for the evaluation of plant raw material, especially as forage.

It is established that the above-ground mass yield of investigated genotypes of *Silphium* spp. was from 45 (*S. asperrimum*) to 126 (*S. integrifolium*, cv. Yuvileinyi-90) t/ha, dry matter yield – from 10.31 (*S. asperrimum*) to 36.92 (*S. integrifolium*, cv. Yuvileinyi-90) t/ha (Table 1). The highest yield of above-ground mass had *S. perfoliatum*, cv. Peremozhets, the highest dry matter yield – *S. integrifolium*, cv. Yuvileinyi-90. *S. asperrimum* (4249 kcal/kg) characterized by the most caloricity, while the least found for *S. perfoliatum*, cv. Peremozhets (3933 kcal/kg). The maximal yield of energy determined for *S. integrifolium*, cv. Yuvileinyi-90 (149.27 Gcal/ha) and minimal – for *S. asperrimum* (43.81 Gcal/ha).

Table 1

Energetic productivity of the plants of *Silphium* L. genus depending on genotype at the stage of start of budding–flowering

Species, cultivar	Yield of above-ground mass, t/ha	Yield of dry matter, t/ha	Caloricity, kcal/kg	Yield of energy, Gcal/ha
S. asperrimum	45.0	10.31	4249	43.81
S. integrifolium, cv. Yuvileinyi-90	126.0	36.92	4043	149.27
S. lacinatum	54.0	11.88	4175	49.60
S. perfoliatum, cv. Bogatyr	119.0	25.23	4175	105.34
S. perfoliatum, cv. Peremozhets	139.0	30.58	3933	120.27
S. perfoliatum, cv. Kanadchanka	106.0	20.03	3979	79.70
S. terebinthinaceum	97.0	25.71	4192	107.78
$LSD_{0,05}$	2.25	–	–	–

According to Bury et al. (2020), the yield of biomass increased in the first two years of full vegetation [30]. As reported Kowalski (2007), the yield of biomass and dry matter at the cultivation of *S. trifoliatum* can give up to 28.8 t/ha of dry biomass [31]. In our study, this result was closed to *S. perfoliatum*, cv. Peremozhets.

The biochemical composition is also an important aspect concerning the introduction of energy crops. In this case, ash content and mineral composition are very useful [32]. Also, selected biochemical analyses were conducted with seventeen genotypes at the periods of flowering and end of vegetation as perspective energetic plants. The content of dry matter and total content of sugars at the flowering stage for seventeen genotypes of *Silphium* represented in Figure 1. Dry matter content at this stage was from 18.38 (*S. perfoliatum*, cv. Kanadchanka) to 34.77 (*S. asperrimum*) % depending on the sample. The total content of sugars at the flowering stage was from 6.36 to 19.0% depending on genotype. The most sugars accumulated in raw of *S. perfoliatum* SR-6, the least – in hybrid *S. integrifolium* × *S. perfoliatum*.

One of the important parameters in the research of energetic plants is the total content of ash that is correlated with calorific value [33]. Ash is the remainder of unburned compounds, which obtained after the combustion of raw at high temperatures. Total ash it's a complex of mineral components, among which highlighted macro- and microelements [34]. Content of ash in the investigated genotypes at the flowering stage determined from 4.20 (*S. perfoliatum*, SR-6) to 8.12 (*S. integrifolium*, f. EBSFS) % (Fig. 2). According to Franzaring et al. (2014), the content of ash in the raw *S. perfoliatum* was 15.4% [2]. Comparing with our investigation this parameter was approximately 2 times less. The content of calcium at the flowering stage was in a range from 1.68 (*S. laciniatum*, f. 2) to 3.38 (*S. integrifolium*, f. EBSFS) % and phosphorus – in a range from 0.42

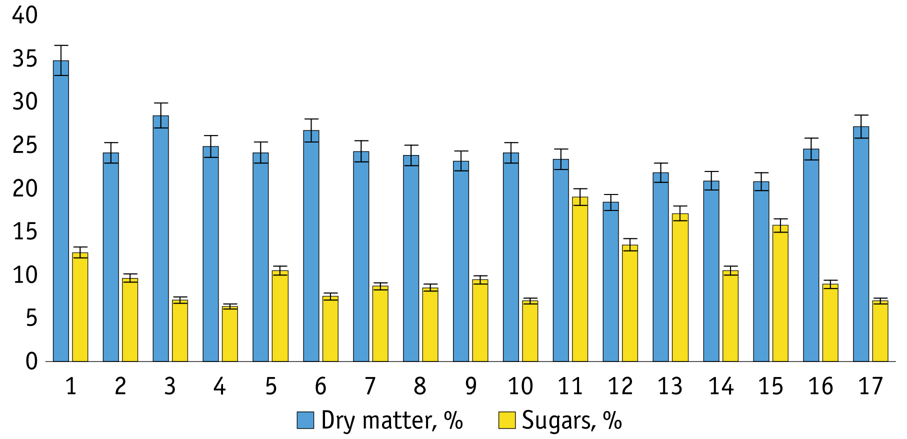

Figure 1. The dry matter content and total content of sugars in the raw of *Silphium* L. genotype at the period of flowering

(1 – *S. asperrimum*; 2 – *S. integrifolium*, f. EBSFS; 3 – *S. integrifolium*, GKR-1; 4 – *S. integrifolium* × *S. perfoliatum*; 5 – *S. integrifolium*, cv. Yuvileinyi-90; 6 – *S. integrifolium*, LPL-4; 7 – *S. integrifolium*, GD-5; 8 – *S. laciniatum*, PL-3; 9 – *S. laciniatum*, f. 2; 10 – *S. laciniatum*, f. 1; 11 – *S. perfoliatum*, SR-6; 12 – *S. perfoliatum*, cv. Kanadchanka; 13 – *S. perfoliatum*, cv. Bogatyr; 14 – *S. perfoliatum*, PP-1; 15 – *S. perfoliatum*, PP-2; 16 – *S. trifoliatum* × *S. integrifolium*; 17 – *S. trifoliatum*)

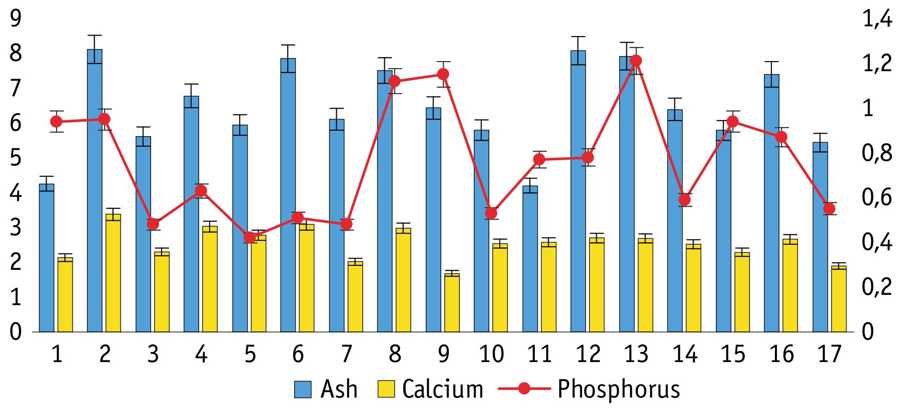

Figure 2. The content of ash, calcium and phosphorus (%) in the genotypes of *Silphium* L. genus at the stage of flowering

(1 – *S. asperrimum*; 2 – *S. integrifolium*, f. EBSFS; 3 – *S. integrifolium*, GKR-1; 4 – *S. integrifolium* × *S. perfoliatum*; 5 – *S. integrifolium*, cv. Yuvileinyi-90; 6 – *S. integrifolium*, LPL-4; 7 – *S. integrifolium*, GD-5; 8 – *S. laciniatum*, PL-3; 9 – *S. laciniatum*, f. 2; 10 – *S. laciniatum*, f. 1; 11 – *S. perfoliatum*, SR-6; 12 – *S. perfoliatum*, cv. Kanadchanka; 13 – *S. perfoliatum*, cv. Bogatyr; 14 – *S. perfoliatum*, PP-1; 15 – *S. perfoliatum*, PP- 2; 16 – *S. trifoliatum* × *S. integrifolium*; 17 – *S. trifoliatum*)

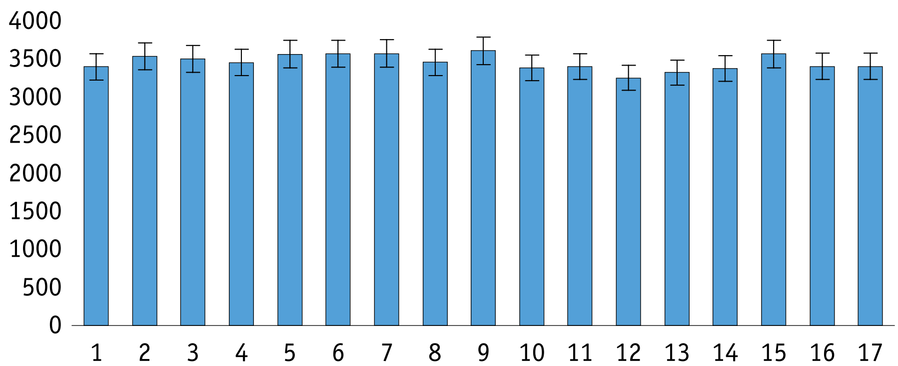

Figure 3. Energetic value of plants (cal/g) of different genotypes of *Silphium* L. genus at the stage of flowering

(1 – *S. asperrimum*; 2 – *S. integrifolium*, f. EBSFS; 3 – *S. integrifolium*, GKR-1; 4 – *S. integrifolium* × *S. perfoliatum*; 5 – *S. integrifolium*, cv. Yuvileinyi-90; 6 – *S. integrifolium*, LPL-4; 7 – *S. integrifolium*, GD-5; 8 – *S. laciniatum*, PL-3; 9 – *S. laciniatum*, f. 2; 10 – *S. laciniatum*, f. 1; 11 – *S. perfoliatum*, SR-6; 12 – *S. perfoliatum*, cv. Kanadchanka; 13 – *S. perfoliatum*, cv. Bogatyr; 14 – *S. perfoliatum*, PP-1; 15 – *S. perfoliatum*, PP-2; 16 – *S. trifoliatum* × *S. integrifolium*; 17 – *S. trifoliatum*)

(*S. integrifolium*, cv. Yuvileinyi-90) to 1.21 (*S. perfoliatum*, cv. Bogatyr) %.

Bury et al. (2020) determined that the content of ash in the raw material of *S. perfoliatum* was from 2.84 to 4.46%, the most of it determined in the seeds [30]. The energetic value of different genotypes of investigated plants at the stage of flowering was from 3253.21 to 3608.54 cal/g (Fig. 3). The higher value of caloricity determined for *S. laciniatum*, f. 2, and the less – for *S. perfoliatum*, cv. Kanadchanka.

The content of dry matter in the raw of investigated plants at the end of vegetation was identified on twenty genotypes and was of 24.76–67.49% (Fig. 4). The most of dry matter content found in *S. laciniatum*, PL-3, the least – in *S. perfoliatum*, NRK-7. The total content of sugars in the plants at the end of vegetation was from 2.78 (*S. integrifolium*, GD-5) to 13.12 (*S. integrifolium*, GKR-1) %. This parameter decreased comparing with the period of flowering.

At the end of the vegetation content of ash was in a range from 3.93 (*S. integrifolium*, cv. Yuvileinyi-90) to 11.2 (*S. perfoliatum*, PP-1) % (Fig. 5). The content of calcium and phosphorus in this period was determined as 1.92–5.99 and 0.14–0.86%, respectively.

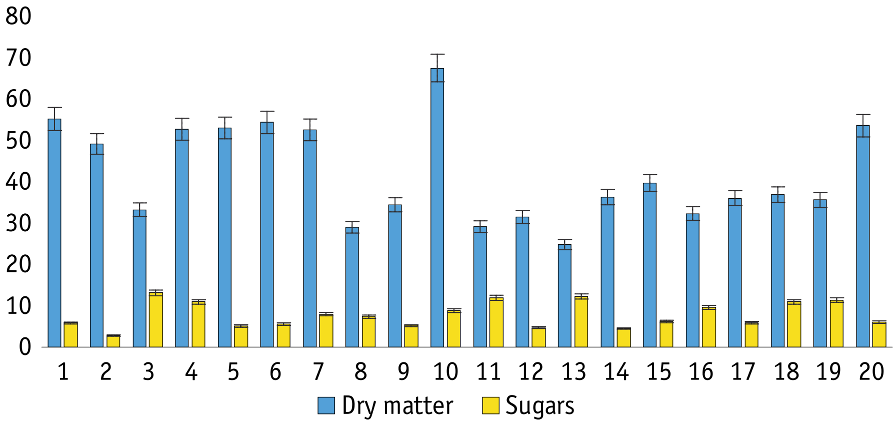

Figure 4. The content of dry matter and total content of sugars in the different genotypes of *Silphium* L. genus at the end of vegetation, %

(1 – *S. asperrimum*; 2 – *S. integrifolium*, GD-5; 3 – *S. integrifolium*, GKR-1; 4 – *S. integrifolium*, cv. Yuvileinyi-90; 5 – *S. integrifolium*, LPL-4; 6 – *S. integrifolium*, f. EBSFS; 7 – *S. integrifolium* × *S. trifoliatum*; 8 – *S. laciniatum*, f. 2; 9 – *S. laciniatum*, f. 1; 10 – *S. laciniatum*, PL-3; 11 – *S. perfoliatum*, PP-1; 12 – *S. perfoliatum* × *S. integrifolium*; 13 – *S. perfoliatum*, NRK-7; 14 – *S. perfoliatum*, cv. Bogatyr; 15 – *S. perfoliatum*, cv. Peremozhets; 16 – *S. perfoliatum*, SR-6; 17 – *S. perfoliatum*, PP-2; 18 – *S. perfoliatum*, cv. Kanadchanka; 19 – *S. trifoliatum* × *S. integrifolium*; 20 – *S. trifoliatum*)

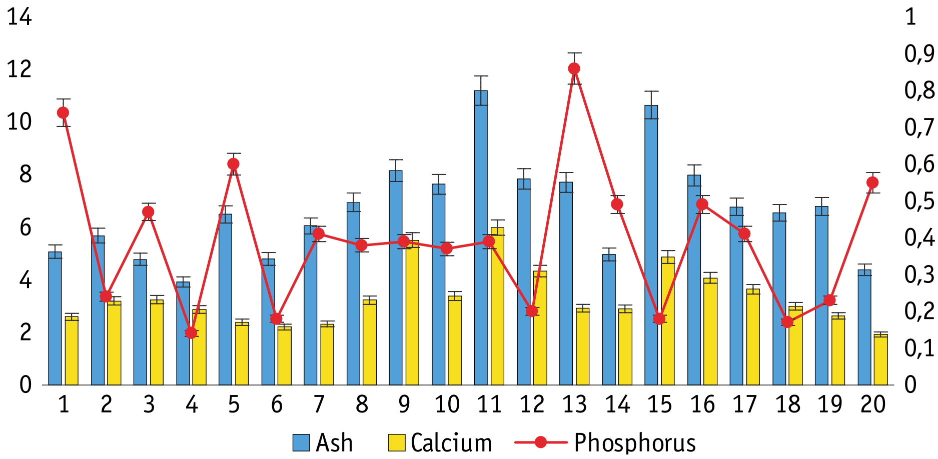

Figure 5. The total content of ash, calcium and phosphorus in the different genotypes of *Silphium* L. at the end of vegetation, %

(1 – *S. asperrimum*; 2 – *S. integrifolium*, GD-5; 3 – *S. integrifolium*, GKR-1; 4 – *S. integrifolium*, cv. Yuvileinyi-90; 5 – *S. integrifolium*, LPL-4; 6 – *S. integrifolium*, f. EBSFS; 7 – *S. integrifolium* × *S. trifoliatum*; 8 – *S. laciniatum*, f. 2; 9 – *S. laciniatum*, f. 1; 10 – *S. laciniatum*, PL-3; 11 – *S. perfoliatum*, PP-1; 12 – *S. perfoliatum* × *S. integrifolium*; 13 – *S. perfoliatum*, NRK-7; 14 – *S. perfoliatum*, cv. Bogatyr; 15 – *S. perfoliatum*, cv. Peremozhets; 16 – *S. perfoliatum*, SR-6; 17 – *S. perfoliatum*, PP-2; 18 – *S. perfoliatum*, cv. Kanadchanka; 19 – *S. trifoliatum* × *S. integrifolium*; 20 – *S. trifoliatum*)

Comparing with the flowering stage the energetic value of plant raw material of *Silphium* genotypes at the end of vegetation increased (Fig. 6). In total, the caloricity of raw was from 3153.36 (*S. perfoliatum*, PP-1) to 3770.28 (*S. perfoliatum*, cv. Bogatyr) cal/g.

Its should be noted that results of many-years investigations demonstrated that phyto raw of many samples of *Silphium* at the budding-start of the flowering period in selected years energetic value achieved up to 4000 kcal/kg [14].

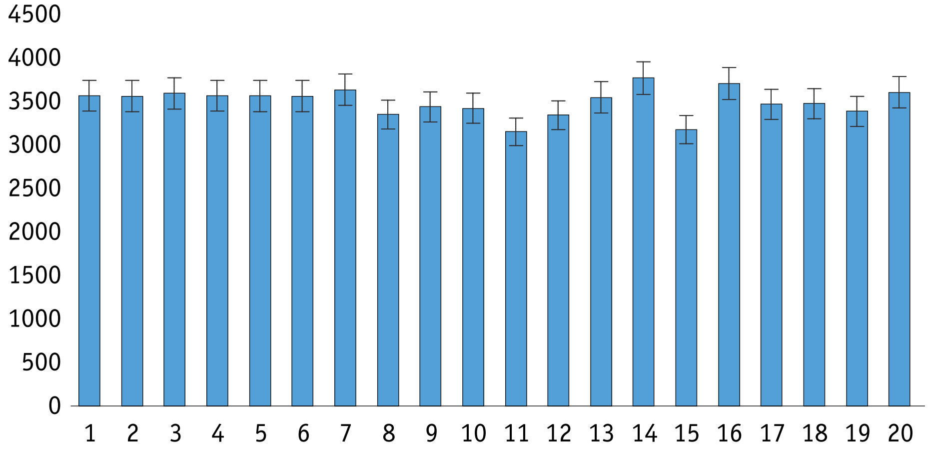

Figure 6. Energetic value of different genotypes of *Silphium* L. genus at the end of vegetation, cal/g

(1 – *S. asperrimum*; 2 – *S. integrifolium*, GD-5; 3 – *S. integrifolium*, GKR-1; 4 – *S. integrifolium*, cv. Yuvileinyi-90; 5 – *S. integrifolium*, LPL-4; 6 – *S. integrifolium*, f. EBSFS; 7 – *S. integrifolium* × *S. trifoliatum*; 8 – *S. laciniatum*, f. 2; 9 – *S. laciniatum*, f. 1; 10 – *S. laciniatum*, PL-3; 11 – *S. perfoliatum*, PP-1; 12 – *S. perfoliatum* × *S. integrifolium*; 13 – *S. perfoliatum*, NRK-7; 14 – *S. perfoliatum*, cv. Bogatyr; 15 – *S. perfoliatum*, cv. Peremozhets; 16 – *S. perfoliatum*, SR-6; 17 – *S. perfoliatum*, PP-2; 18 – *S. perfoliatum*, cv. Kanadchanka; 19 – *S. trifoliatum* × *S. integrifolium*; 20 – *S. trifoliatum*)

In addition, plants of cup flower provide high yield conditional biofuel (10-5, sometimes till 30 t/ha), the energetic value of solid biofuel is 3800–4300 kcal/kg, energetic productivity of plants achieves 40–60 (до 120) Gcal/ha, calculated fuel yield of biogas was 7000–12000 (sometimes to 20000) m^3/ha [15, 35].

Collecting of phytomass for biogas and feed conducts at the May-June – first term and after 50–55 days second and more (3–4-times mowing), seeds – September, dry phytomass as an energetic plant – October–November. Plants should be mowed on biogas purpose at budding-start of the flowering stage [15].

Thus, the gene fund of *Silphium* L. plants that grow in the M. M. Gryshko National Botanical Garden is represented by valuable samples that are sources of high quality of raw for the fodder and energetic purposes. In this case, the most perspective cultivars were *S. perfoliatum* cv. Bogatyr (high content of phosphorus and energetic value), *S. integrifolium* cv. Yuvileinyi-90 (less content of ash, high yield of dry matter, and energy), *S. perfoliatum* cv. Peremozhets (high yield of above-ground mass), *S. perfoliatum* cv. Kanadchanka (high content of protein). *S. asperrimum* had maximal content of cellulose. The highest content of dry matter had variety *S. lacinatum* PL-3, sugars – *S. perfoliatum* SR-6, calcium – *S. perfoliatum* PP-1.

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Рахметов Д. Б., Вергун О. М., Рахметова С. О., Шиманська О. В., Фіщенко В. В. Вивчення деяких біохімічних параметрів і продуктивності генотипів *Silphium* L. як перспективних енергетичних культур. *Plant Varieties Studying and Protection*. 2020. Т. 16, № 3. С. 262–269. https://doi.org/10.21498/2518-1017.16.3.2020.214927

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Мета. Це дослідження мало на меті визначити деякі біохімічні параметри та продуктивність генофонду рослин роду *Silphium* L. у Національному ботанічному саду імені М. М. Гришка НАН України. **Методи.** Рослинна сировина *Silphium* досліджена у фазі квітування (17 генотипів) та в кінці вегетації (20 генотипів). Уміст поживних речовин під час квітування вивчено у 3 видів та 4 сортів рослин. Визначення вмісту сухої речовини, золи, кальцію, безазотистих екстрактивних речовин проводили за Грицаєнком і співавт. (2003), фосфору, білка – за Починок (1976), цукрів –

за Крищенко (1983), целюлози – за Zheng et al. (2018), ліпідів – за Zamowski, Suzuki (2004). Були визначені параметри продуктивності рослин: урожайність наземної маси, вихід сухої маси, енергетична цінність сировини та вихід енергії з одиниці площі. Дані аналізовані статистично. **Результати.** Дослідження вмісту поживних речовин показало, що вміст сухої речовини знаходився в межах 18,90–29,3%, білка – 8,88–23,56, целюлози – 15,10–36,14, золи – 8,13–12,19, ліпідів – 1,83–3,97%; урожайність наземної маси – 45,0–139,0 т/га, вихід сухої речовини – 10,31–36,92 т/га, енергетична цінність фітосировини – 3933–4249 кал/г, вихід енергії з урожаєм – 43,81–149,27 Гкал/га. Дослідження генотипів у період квітування та в кінці вегетації дало змогу виявити, що вміст сухої речовини в усіх зразках становив 18,38–67,49%, цукрів – 2,78–19,0, золи – 3,93–11,20, кальцію – 1,68–5,99, фосфору – 0,14–1,21%, енергетична цінність – 3153,36–3770,28 кал/г. **Висновки.** Рослинна сировина генотипів *Silphium* L. spp. є цінним джерелом поживних речовин. Уміст золи, її компоненти, енергетична цінність та параметри продуктивності залежить від генотипу та періоду росту й розвитку рослин. Результати досліджень дають змогу рекомендувати деякі генотипи *Silphium* як перспективні енергетичні культури в Україні, а також інших країнах.

Ключові слова: *Silphium L.; генотипи; енергетична цінність; продуктивність; зола.*

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