THE PRODUCTIVITY AND QUALITY INDICES OF BIOMASS FROM SOME *Silphium* SPECIES IN THE REPUBLIC OF MOLDOVA

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Abstract. The primary goal of this study was to evaluate the productivity and quality indices of harvested whole plants and ensiled biomass of *Silphium integrifolium* and *Silphium perfoliatum* cultivated in experimental plots at the National Botanical Garden (Institute) of Moldova State University, Republic of Moldova. The results showed that the fresh mass yield of the studied *Silphium* species ranged from 4.75 to 6.95 kg/m², with a dry matter content between 25.65% and 27.55%. Analysis revealed that the dry matter of the harvested whole plants contained: 138-166 g/kg CP, 317- 345 g/kg CF, 86-89 g/kg ash, 352-369 g/kg ADF, 554-599 g/kg NDF, 46-49 g/kg ADL, 56-58 g/kg TSS, 306-320 g/kg Cel, 202-230 g/kg HC with nutritive and energy values 60.2-61.5 % DDM, RFV=94-103, 11.91-12.15 MJ/kg DE, 9.78-9.97 MJ/kg ME and 5.79-5.98 MJ/kg NEl. The ensiled mass from the *Silphium* species is characterized by specific smell and colour, pH = 4.36-4.54, 6.1-8.1 g/kg acetic acid, 24.3-32.4 g/kg lactic acid, 0.03-0.1 g/kg butyric acid, 126-157 g/kg CP, 95-106 g/kg ash, 311-355g/kg CF, 322-379g/kg ADF, 537-583 g/kg NDF, 40-46 g/kg ADL, 282-330 g/kg Cel, 204-215 g/kg HC, 23-27 g/kg TSS, 59.4-63.8 % DMD, 11.76-12.55MJ/kg DE, 9.66-10.31 MJ/kg ME, 5.79-6.33 MJ/kg NEl. The prepared substrates from *Silphium* species for anaerobic digestion had optimal C/N=19.0-24.6 and biochemical methane potential varied from 332 to 351 l/kg VS. The studied *Silphium* species have optimal nutrient content, and they can be used as an alternative forage source for ruminant animals, or as substrates for biogas production. Among these species, *Silphium perfoliatum* has particularly high economic value.

Keywords: biochemical methane potential, ensiled mass and fresh, forage value, fresh mass, productivity, *Silphium integrifolium, Silphium perfoliatum*.

Rezumat. Productivitatea și indicii de calitate a biomasei unor specii de *Silphium* în Republica Moldova. Scopul prezentului studiu a constatat în evaluarea productivității și indiciilor de calitate a biomase plantelor recoltate și a masei murate din speciile *Silphium integrifolium* and *Silphium perfoliatum*, cultivate în sectorul experimental din Grădina Botanică Națională (Institut), USM, Republica Moldova. S-a stabilit că recolta de masă proaspătă la speciilor cercetate de *Silphium* variază de la 4.75 la 6.95 kg/m², cu un conținut de substanță uscată de 25.65- 27.55%. Rezultatele au demonstrat că substanța uscată din masa proaspătă a plantelor recoltate a speciilor cercetate de *Silphium* au un conținut de: 138-166 g/kg proteină brută (CP), 317-345g/kg celuloză brută (CF), 86-89g/kg cenușă, 352-369g/kg fibre solubile în detergent acid (ADF), 554-599 g/kg fibre solubile în detergent neutru (NDF), 46-49 g/kg lignină sulfurică (ADL), 34-145 g/kg total zaharuri solubile (TSS), 272-328 g/kg celuloză (Cel), 202-230 g/kg hemiceluloză (HC), cu o valoarea nutritivă și energetică de 60.2-61.5 % substanță uscată digestibilă (DDM), valoare relativă furajeră RFV=11.91-12.15, 9.78-9.97 MJ/kg energie metabolizantă (ME) și 5.79-5.98 MJ/kg energie netă pentru lactație (Nel). Masa murată din speciile cercetate de *Silphium* se caracterizează printr-o aromă și culoare specifică, pH = 4.36-4.54, 6.1-8.1 g/kg acid acetic, 24.3-32.4 g/kg acid lactic, 0.03-0.1 g/kg acid butiric, 126-157 g/kg CP, 95-106 g/kg cenușă, 311-355g/kg CF, 322-379g/kg ADF, 537-583 g/kg NDF, 40-46 g/kg ADL, 282-330 g/kg Cel, 204-215 g/kg HC, 23-27 g/kg TSS, 59.4-63.8 % DMD, 11.76-12.55MJ/kg DE, 9.66-10.31 MJ/kg ME, 5.79-6.33 MJ/kg NEl. Substraturile preparate din speciile cercetate de *Silphium* se evidențiază printr-un raport optimal de carbon și azot – C/N=19.0-24.6, iar potențialul biochimic de obținere a metanului variază de la 332 la 351 l/kg materie organică. Speciile cercetate de *Silphium* au un conținut optimal de nutrienți, ceea ce permite utilizarea lor ca furaje pentru animale rumegătoare, de asemenea, ca substraturi pentru producerea de biogaz. Un deosebit interes economic prezintă specia *Silphium perfoliatum.*

Cuvinte cheie: potențialul biochimic de obținere a metanului, masă murată și proaspătă, valoare furajeră, productivitate, *Silphium integrifolium, Silphium perfoliatum*.

INTRODUCTION

In recent years, there has been renewed interest in mobilizing new perennial plant species with optimal genetic potential for productivity and quality. These species are valued for important quality traits such as stable yields, multipurpose economic value, and high tolerance to weeds, pests, diseases, drought and frost. They are also winter-hardy and capable of growing with low nutrient and energy input.

The Asteraceae family comprises approximately 1,765 plant genera and 27,773 annual and perennial species. Its relevance lies in the fact that it includes many plants of high economic, culinary and medicinal value, as well as numerous ornamental species and a large number of weedy species. The genus *Silphium* L., belonging to the tribe Heliantheae within the Asteraceae family, consists of 17 accepted perennial herbs species native to North America. Among these, only *Silphium perfoliatum* L., *S. laciniatum* L., *S. terebinthinaceum* Jacq., and *S. integrifolium* Michx. have, to date, attracted economic interest and are being utilized or developed as agricultural crops.

In Europe, *Silphium perfoliatum* L. (commonly known as "cup plant") was introduced in the 18th century, and was initially used as ornamental plant in gardens and parks in Germany, France, Switzerland and the United Kingdom. It is polycarpic plant, with erect, square, slightly hairy stem, branched in the upper part, reaching a height of 250-370 cm and a thickness at the base of 2-4 cm. The leaves are light green, cordate, 25-35 cm long and 16-22 cm wide, opposite, the lower ones are petiolate but the upper ones are widely winged and fused around the stem forming a cup that allows the efficient use of humidity and sunlight. The inflorescence is composed of 20-30 yellow flowers of 3-5 cm in diameter; the flowering period lasts over 51-60 days. Due to the long flowering period, this species has high potential as a honey plant, with a productivity of 150-220 kg/ha of honey. The fruit is a brown-grey, winged achene. The weight of 1000 achenes is on average 22-24 g. Seed productivity reaches 290-450 kg/ha. It develops a taproot system reaching 3.5 m deep. The plants also develop numerous shallow rhizomes, which allow them to spread and to form large colonies. The *Silphium perfoliatum* prefers damp, moist, and fully or partially sunny habitats. It may be found in floodplains, low thickets, fencerows, roadside ditches, degraded areas, wet woodlands and forest edges, stream banks, wet meadows and wet prairies. It is tolerates to various soil and climatic factors and produces high yields of biomass rich in proteins and essential amino acids. The leaves, inflorescence and rhizomes of the cup plant are rich in phenolic acids, such as caffeic, p-coumaric, ferulic, protocatechuic, p-hydroxybenzoic, vanillic and chlorogenic acid, both in free and bound form. *Silphium perfoliatum* is currently subject of scientific investigations in several universities and scientific centres around the world. The increased interest in this species is associated with its potential as honey, fodder, medicinal, technical and energy crop (ALBRECHT & GOLDSTEIN, 1997; HAN et al., 2000; VETTER et al., 2007; BOE et al., 2012; GANSBERGER et al., 2015; KLIMEK et al., 2016; JUCSOR & SUMALAN 2018; MUELLER et al., 2019; RAKHMETOV et al.,2019; VON COSSEL, 2019; BURY et al., 2020; CUMPLIDO-MARIN et al., 2020; KAPSAMUN et al., 2020, 2021; KONIUSZY et al., 2020; KOWALSKA et al., 2020; PENI et al., 2020, 2022; REINHARDT et al., 2021; ŢÎŢEI &ROȘCA, 2021; HÖLLER, 2022; MOLL et al., 2022; ŠURIĆ et al., 2022; WITASZEK et al., 2022; CEREMPEI et al., 2023; GREVE et al., 2023; KEMMANN et al., 2023; ŢÎŢEI, 2023; EMELIN & SHELYUTO, 2024; XU et al., 2024; SUMALAN et al., 2025).

Silphium integrifolium Michx. (commonly known as “rosinweed, whole-leaf rosinweed, entire-leaf rosinweed, prairie rosinweed and silflower”) is a long-lived perennial prairie species, native to eastern North America, including Ontario in Canada and the eastern and central United States as far west as New Mexico. The plants are caulescent, their height may range between 40 and 200 cm tall. It emerges from its underground root crown each year. It can form a large clump of up to 100 stems. Stems are terete to slightly square in shape and range from sparsely scabrous to glabrous, occasionally appearing glaucous. Leaves are differentiated by position: basal leaves are caducous, while cauline leaves are opposite, sessile, and vary in blade shape from lanceolate to ovate. Leaf bases range from rounded to caudate; margins are finely serrate or entire; apices are acute to acuminate. Leaf surfaces may be hispid, scabrous, or glabrous. The inflorescence holds one to 15 flower heads. The head is lined with 2 or 3 rows of phyllaries which are hairless or rough and sometimes glandular, and have rounded bases and pointed tips. The head has up to 36 yellow ray florets and many yellow disc florets. The fruit is achenes 11.54 to 20.75 mm length and 4.61 to 11.76 mm width, with short pappus 1-4 mm. The weight of 1000 achenes varied from 22 to-79 g and seed yield achieved 1300 kg/ha. The achene contains 17.7- 20.0% crude fat, 32.9-33.5% crude protein, 43.59% total carbohydrates and 5.01% ash. *Silphium integrifolium* has a long taproot system with short rhizomes, which can penetrate deeper into the soil to access water and nutrients below the root zones of most annual crops. It usually grows in stands or clusters within mixed prairie communities. The domestication of *Silphium integrifolium* began in the early 2000s, and currently it is studied in several research centers as a perennial oilseed and forage crop (VAN TASSEL et al. 2017; SCHIFFNER et al., 2020; VILELA et al., 2020; EVANGELISTA et al., 2022; PETERSON, 2022; ASHWORTH et al., 2023; GREVE et al., 2023).

The goal of this study was to evaluate the productivity and quality indices of harvested whole plants and ensiled mass from *Silphium integrifolium* and *S. perfoliatum* grown under the climatic conditions of the Republic of Moldova, as well as the possibility of using them as forage for ruminant animals and substrates for the biomethane production as a source of renewable energy.

MATERIALS AND METHODS

The introduced Asteraceae species *Silphium integrifolium* and *S. perfoliatum* which grow in the experimental plots of the “Alexandru Ciubotaru” National Botanical Garden (Institute) Chişinău, N 46°58′25.7″ latitude and E 28°52′57.8″ longitude, served as subjects of the research, and the multipurpose crops – maize (*Zea mays* L.) served as control. Green biomass samples of *Silphium integrifolium* and *S. perfoliatum* were collected at the early flowering stage from three-year-old plants, while *Zea mays* was harvested at the wax stage of grain development. Dry matter content was determined by drying the samples to constant weight at 105 °C. For ensiling, whole plants were shredded and tightly packed into sealed containers. After 45 days, the containers were opened, and the silages were evaluated for sensory and fermentation characteristics according to standard laboratory procedures and the Moldavian standard SM 108 for forage quality analysis. For biochemical analysis, green biomass and silage samples were dried at 60 °C. Key biochemical parameters—including crude protein (CP), crude fibre (CF), ash, acid detergent fibre (ADF), neutral detergent fibre (NDF), acid detergent lignin (ADL), and total soluble sugars (TSS)—were measured using near-infrared spectroscopy (NIRS) with the PERTEN DA 7200 device at the Research and Development Institute for Grasslands in Brașov, Romania. Hemicellulose (HC) and cellulose (Cel) concentrations, as well as digestible dry matter (DDM), relative feed value (RFV), digestible energy (DE), metabolizable energy (ME), and net energy for lactation (NEl), were calculated following standard procedures. Carbon content was estimated using an empirical equation according to BADGER et al. (1979), and the biochemical methane potential was calculated based on equations according to DANDIKAS et al. (2015).

RESULTS AND DISCUSSIONS

As a result of the phenological observations, it has been found that, in the first year of vegetation, the two studied *Silphium* species were characterised by similar growth and development rates. Early in the growing season, both formed a basal rosette consisting of 7–12 leaves. In subsequent years, both species resumed growth from generative buds—*Silphium perfoliatum* in late March and *Silphium integrifolium* in early April. Leaf rosettes expanded throughout April, and stem elongation began in early May. Flowering times varied among the species: *Silphium perfoliatum* flower heads appeared in the end June - first days of July, while *Silphium integrifolium* flower heads appeared in the middle of July. At the time of the harvest, in the early flowering stages, *Silphium integrifolium* plants (154-167 cm) were shorter than *Silphium perfoliatum* plants (275-295 cm), also the stems were thinner. The fresh mass yield of the *Silphium integrifolium* was 4.75 kg/m², with a dry matter content of 27.55%. In contrast, the *Silphium perfoliatum* produced 6.95 kg/m² of fresh mass with a dry matter content of 25.65%.

Analysing the quality indices of biomass from the studied *Silphium* species, Table 1, we found that the dry matter of the harvested whole plants contained 138-166/kg CP, 317-345 g/kg CF,86-89 g/kg ash, 352-359 g/kg ADF, 554-599 g/kg NDF, 46-49 g/kg ADL, 56-68 g/kg TSS, 306-320 g/kg Cel, 202-230g/kg HC with nutritive and energy values of 602-615 g/kg DDM, RFV=94-103, 11.91-12.15 MJ/kg DE, 9.78-9.97 MJ/kg ME and 5.79-5.98 MJ/kg NEl. *Silphium perfoliatum* forage was notable for its significantly higher crude protein content and lower amount of crude fibre, structural carbohydrates and lignin than *Silphium integrifolium*, which had a positive impact on the dry matter digestibility, relative feed value and the energy concentration of the feed. The natural fodder from the studied *Silphium* species were characterised by higher concentration of crude protein, cellulose and ash, but lower dry matter digestibility, relative feed value, metabolizable energy and net energy for lactation as compared with the control – *Zea mays* fresh forage.

Table 1. The biochemical composition and the forage value of the fresh mass from the studied *Silphium* species.

Indices	*Silphium integrifolium*	*Silphium perfoliatum*	*Zea mays*
Crude protein, g/kg DM	138	166	84
Crude fibre, g/kg DM	345	317	248
Ash, g/kg DM	86	89	52
Acid detergent fibre, g/kg DM	369	352	271
Neutral detergent fibre, g/kg DM	599	554	474
Acid detergent lignin, g/kg DM	49	46	48
Total soluble sugars, g/kg DM	68	56	-
Cellulose, g/kg DM	320	306	223
Hemicellulose, g/kg DM	230	202	203
Dry matter digestibility, g/kg DM	602	615	678
Digestible energy, MJ/kg DM	11.91	12.15	13.28
Metabolizable energy, MJ/kg DM	9.78	9.97	10.90
Net energy for lactation, MJ/kg DM	5.79	5.98	6.91
Relative feed value	94	103	133

Several authors have reported different findings regarding the quality of green biomass from *Silphium* species. Thus, ALBRECHT & GOLDSTEIN (1997) reported that the green mass quality of three cup-plant accessions ranged from 144-156 g/kg DM, 15.8-18.2% CP, 38.0-38.7% NDF, and 28.4-29.4% ADF. HAN et al. (2000b) found that the quality of green mass from *Silphium perfoliatum* plants harvested at the budding stage included 11.35-11.38% ash, 29.42-32.00% ADF, 4.09-4.39% ADL, and 69.7-72.3% IVDDM, while plants harvested at the mid-flowering stage contained 10.03-10.37% ash, 31.88-37.54% ADF, 5.05-6.52% ADL, and 52.2-63.5% IVDDM. Țîței (2012) mentioned that the forage from cup plant harvested in late May contained 167.1 g/kg DM, 16.33% CP, 2.26% EE, 24.70% CF, 14.16% minerals, 42.55% NFS, and 133.4 g of digestible protein per nutritive unit. CHUPINA& STEPANOV (2017) reported that forage value of green mass of *Silphium perfoliatum* harvested in budding stage was 20.7 % CP, 4.0% EE, 24.5 % CF, 35.2 % NFE, 16.5 % ash, 0.61 fodder unit/kg, 9.8MJ/kg ME, 223 g digestible protein content per fodder unit and can be used as raw material for the preparation of artificially dried herbal forages, while the green forage harvested at the flowering stage contained 20.2 % CP, 3.5% EE, 24.8 % CF, 37.1 % NFE, 14.0 % ash, 0.60 fodder unit/kg, 9.6MJ/kg ME, 211 g digestible protein content per fodder unit, meeting the standards for raw material suitable for silage production. RAKHMETOV et al. (2019) reported that the investigated species of the *Silphium* genus cut in the flowering stage had 211.4-290.2 g/kg DM with 3.54-12.17 % TSS, 29.46-48.24 % CF, 77.12-296.35 mg% ascorbic acid, 0.23-1.54 mg% carotene, 14.18-26.08 % CP, 2.34-4.26 % EE. 3.25-7.82 % ash, 0.78-2.18 % K, 1.66-3.07 % Ca, 0.13-0.35 %P; the species *Silphium integrifolium* stands out due to the highest content of crude protein. COȘMAN et al. (2020) mentioned that cup plant contained 10.33-16.53% DM, 9.56-12.25% ash, 8.25-13.35 % CP, 1.86-2.73% EE, 20.32-34.13 % CF, 42.15-52.32 % NFE. KOWALSKA et al. (2020) mentioned that the leaves collected in July-August from *Silphium integrifolium* contained 187-213 g/kg DM, 16.2-16.3 % ash, 13.3-13.7 % CP, 2.1% EE, 1.9-2.8 % sugars, 23.6-26.8 % cellulose; *Silphium perfoliatum* leaves contained 191-198 g/kg DM, 17.4-18.1 % ash, 14.9-15.8 % CP, 2.1-2.3% EE, 3.1-3.7 % sugars, 21.3-24.6 % cellulose; *Silphium trifoliatum* leaves – 199-200g/kg DM, 17.2% ash, 14.9-15.0 % CP, 2.2-2.3% EE, 4.3-4.4 % sugars, 22.5-27.7 % cellulose. VILELA et al., (2020) found that *Silphium* *integrifolium* harvested at pre-flowering stage contained 121.08-27.70% CP, 17.9-27.03% aNDF, 14.60-18.97% aADF, 41.34-45.40% NFC, and 74.13-77.50% TDN. In one of the previous publications, ŢÎŢEI et al. (2020) mentioned that the cup plant, at the end of the flowering stage, reached 320-373 cm in height, and the yield of aerial phytomass was 12-15 kg/m^2 and the dry matter contained 66 g/kg CP, 46 g/kg ash, 604 g/kg NDF, 411 g/kg ADF, 83 g/kg ADL, 328 g/kg Cel, 193 g/kg HC, 569 g/kg DDM, RFV = 92, 11.32 MJ/kg DE, 9.2 MJ/kg ME and 5.31 MJ/kg NEl. KAPSAMUN et al. (2021) remarked that the content of crude protein decreased in the *Silphium perfoliatum* plants from 25.7% at the beginning of budding stage to 15.3% at flowering stage. SHELIUTO et al. (2021) mentioned that the green forage from *Silphium perfoliatum* harvested at the budding stage contained 14.8-15.3 % CP, 2.11- 2.31% EE, 19.6-19.9 % CF, 5.41-7.46 % SS, 14.2-13.6 % ash, 17.1 MJ/kg GE, 10.0MJ/kg ME and 131.8 g digestible protein content per fodder unit, while the green forage harvested at beginning of flowering stage 12.9-13.1 % CP, 2.14- 2.42% EE, 20.9-21.8 % CF, 3.97-5.77 % SS, 11.9-13.9 % ash, 16.84 MJ/kg GE, 9.7MJ/kg ME and 120.5 g digestible protein content per fodder unit. RUF & EMMERLING (2022) reported that cup plant biomass contained 291-307 g/kg DM, 5.9-9.8% HC, 20.2-29.6% Cel and 12.3-12.8% lignin. In comparison, silage maize biomass had a DM content of 365-383 g/kg, with 16.1-20.0% HC, 18.8-24.2% Cel and 4.3-5.6% lignin. According to VAN LOO (2022), the whole plant biomass of *Silphium perfoliatum* contained 336.4 g/kg DM, 4.99% CP, 30.52% CF, 2.34-4.26% starch, 15.84% soluble sugars, 10.01% ash, 1.76% Ca and 0.21% P. ASHWORTH et al. (2023) observed that the biochemical composition of *Silphium integrifolium* forage harvested in mid-to-late June included 6.68% CP, 44.87% ADF, 39.35% aNDF, and 5.52% HC. The forage harvested in mid-to-late September had 9.06% CP, 36.08% aNDF, 33.47% ADF, and 2.60% HC. Tóth (2023) reported that the lignocellulosic composition of green phytomass from *S. perfoliatum* included 31.32-48.94% ADF, 34.94-54.69% NDF, 7.21-12.54% ADL, 24.11-37.30% CEL, and 2.33-5.75% HC. Baumgart et al. (2024) found that the dry matter content and chemical composition of *S. perfoliatum* green biomass, depending on the harvest date, ranged from 193-316 g/kg DM, with 3.71-5.75% CP, 1.60-2.42% EE, 31.85-42.08% CF, 39.58-51.12% ADF, and 46.23-52.19% NDF. JIN et al. (2024) reported that green forage from *S. perfoliatum* contained 314.3 g/kg DM, 82.26% OM, 22.97% CP, 61.50% NDF, 26.18% ADF, 9.43% ADL, 4.68% WSC, 15.24 MJ/kg GE, 11.70 MJ/kg DE, 8.72 MJ/kg ME and 5.33 MJ/kg NEl. PRIGGE et al. (2024) studied the nutrient composition of plant from *Asteraceae* family and found that *Silphium perfoliatum* contained 13.5% CP, 22.1% NDF, 21.7% ADF, while in *Rudbeckia hirta*, there was 10.7% CP, 41.0% NDF, 36.8% ADF; *Helianthus maximiliani* included 14.2% CP, 30.6% NDF, 29.4% ADF; *Echinacea purpurea* – 12.6% CP, 32.6% NDF, 27.8% ADF; *Coreopsis lanceolate* – 10.5% CP, 32.0% NDF, 28.2% ADF; *Helopsis helianthoides* - 14.2% CP, 27.7% NDF, 23.4% ADF and *Ratibida columnifera* 14.2% CP, 40.4% NDF, 35.3% ADF.

Ensiling is one of the most effective methods for preserving forage and plays a vital role in maintaining a consistent supply of high-quality fodder throughout the year. In recent decades, ensiled biomass has also been increasingly used as a substrate for biogas production. It is worth noting that when opening the glass vessels containing ensiled material from *Silphium* species, there was no evidence of gas release or juice leakage. The preserved material exhibited an appealing appearance, with dark green leaves and yellow-green stems, and had a distinct, pleasant aroma reminiscent of pickled tomatoes. The texture remained consistent with that of the original fresh biomass, and no signs of mold or mucus were observed. The fermentation characteristics and nutritional quality of the ensiled biomass from the studied *Silphium* species are presented in Table 2. The pH of the *Silphium* silage ranged from 4.36 to 4.54, which was higher compared to that of *Zea mays* silage (pH 3.77). The concentration of organic acids in the *Silphium* silage varied from 30.4 to 40.6 g/kg, which was lower than the control. Lactic acid was the predominant organic acid present. Butyric acid was detected only in trace amounts, ranging from 0.01 to 0.25 g/kg DM. The biochemical composition and the nutritive value of the ensiled mass from the studied *Silphium* species was 126-157 g/kg CP, 95-106 g/kg ash, 311-355g/kg CF, 322-379g/kg ADF, 537-583 g/kg NDF, 40-46 g/kg ADL, 282-330 g/kg Cel, 204-215 g/kg HC, 23-27 g/kg TSS with 59.4-63.8 % DMD, 11.76-12.55MJ/kg DE, 9.66-10.31 MJ/kg ME, 5.79-6.33 MJ/kg NEl. The concentration of crude protein and ash was much higher than in maize silage. However, the ensiled biomass of *Silphium perfoliatum* was distinguished by higher protein content and lower levels of structural carbohydrates and lignin. These characteristics contributed positively to its digestibility, as well as its nutritional and energy value, in comparison with the ensiled mass of *Silphium integrifolium*.

The content of structural carbohydrates and lignin was notably high in *Silphium* species ensiled mass, which influenced negatively on digestibility, relative feed value and the energy concentration compared to that of *Zea mays* ensiled mass.

Several literature sources describe the quality indices of silage prepared from *Silphium* species. HAN et al., (2000b) found that the quality of the silage prepared from *Silphium perfoliatum* plants harvested in the mid-flowering period was 265 g/kg DM with pH = 5.3, 16.8 g/kg N, 373 g/kg ADF, 503 g/kg NDF, but in the silage prepared from the regrown plants harvested in mid-October was 305 g/kg DM with pH = 4.5, 17.9 g/kg N, 217 g/kg ADF, 290 g/kg NDF. ALBRECHT et al. (2007) reported that the nutrient composition of cup plant silage was 275-295 g/kg DM, 13.3-15.0-16.5% ash, 9.8-11.8 % CP, 34.9-36.3 % ADF, 45.4-49.3 % NDF, 3.6-4.0% ADL, while maize silage contained 317-358 g/kg DM, 3.3-3.7% ash, 7.4-7.5 % CP, 20.3-22.7 % ADF, 38.238.5 % NDF and 1.2-1.4% ADL. LEHMKUHLER et al. (2007) revealed that nutrient composition of mono-crop maize silage was 9.9-10.5% CP, 28.9-38.3% NDF, 18.8-21.0% ADF, while the mixt silage from 30% cup plant and 70% maize included 10.0-11.4% CP, 36.8-38.3% NDF, 22.6-22.8% ADF and the mixt silage from 60% cup plant and 40% maize contained 10.5-13.0% CP, 42.5-43.0% NDF, 25.0-26.4% ADF. PIŁAT et al. (2007) remarked that the silage produced from whole plants of *Silphium* species mowed at beginning of flowering stage was characterized by 208.9-222.2 g/kg DM, 89.41-90.98 % OM, 5.91-6.89 % CP, 1.88-2.20 % EE, 26.03-30.29 % CF, 29.96-35.32 % ADF, 35.33-41.05 % NDF, 4.25-5.52 % ADL, 1.39-1.76 % WSC. ȚÎȚEI (2012) found that the quality indices of silage from cup plant harvested in mid-June was pH= 4.22, 163.6 g/kg DM, 11.41% ash, 10.30 % CP, 2.09 % EE, 29.52 % CF and 46.30 % NFE. HERRMANN et al. (2016) studied the biochemical composition of crop silages in Germany, and reported that the silages from cup plant contained 254-291 g/kg DM and 87.5-89.0 % OM, pH=4.3-6.2, 0.0-8.5 % lactic acid, 1.2-2.8 % acetic acid, 0.0-1.1% butyric acid, 9.9-13.1% CP, 2.1-5.4% EE, 40.3-44.6% NFE, 48.3-58.0% NDF, 35.0-39.1% ADF and 7.7-8.5% ADL, while maize silage included 152-421g/kg DM and 93.7-96.9% OM, pH=3.1-4.1, 3.5-9.5% lactic acid, 0.2-3.6 % acetic acid, 0.0-0.3 % butyric acid, 4.4-12.1 % CP, 1.0-3.9 % EE, 53.8-71.4 % NFE, 26.8-53.7 % NDF, 14.7-37.1 % ADF, 1.0-6.1 % ADL. COŞMAN et al., (2020) reported that that the silage from *Silphium perfoliatum* plants had pH ranging between 4.22 and 4.44, and contained 20.03-2.3 g/kg lactic acid, 5.4-6.4 g/kg acetic acid, 0 g/kg butyric acid, 17.73-23.75 % DM, 10.15-12.04 % ash, 4.42-9.11 % CP, 2.79-4.03 % EE, 35.35-39.02 % CF. VILELA et al. (2020) found that the quality of silage from *Silphium integrifolium* was characterized by the following indices: 9.63% CP, 17.9-54.53% aNDF, 42.28% aADF, 23.58 NFC, 55.93% TDN and RFV=93.59. HAN & ALBRECHT (2021) mentioned that *Silphium perfoliatum* silage contained 275-305 g/kg DM, 11.8-16.5% ash, 9.8-11.5 % CP, 22.0-36.3 % ADF, 39.2-45.4 % aNDF, 36-41% lignin. According to RIVERA (2022), the quality of silage from *Silphium perfoliatum* was characterized by 262 g/kg DM, 10.9% ash, 5.9 % CP, 48.6 % ADF, 61.3 % NDF, 51.8 % NFC, 12.1 % lignin, 2.3 % EE, 1.8 % Ca, 0.1 % P, 0.80 Mcal/kg ME. BAUMGART et al., (2024) revealed that the dry matter content, fermentation profile and nutrient concentration of silage from *Silphium perfoliatum* harvested in different periods were 191-280 g/kg DM, pH=4.35-6.47, 30.96-107.2 g/kg lactic acid, 6.83-21.89 g/kg acetic acid, 0.44-4.20 g/kg propionic acid, 8.03- 34.32 g/kg n-butyric acid and 1.85-8.72 g/kg ethanol with 3.71-5.75 % CP, 1.60-2.42% EE, 31.85-42.08 % CF, 39.58-51.12 % ADF, 46.23-52.19% NDF. EMELIN & SHELYUTO (2024) reported that the chemical composition and nutritional value of cup plant silage prepared at beginning of the flowering stage contained 198 g/kg DM, pH=4.4, 20.1 g/kg lactic acid, 3.8 g/kg acetic acid, 0.005 g/kg butyric acid, 10.9% ash, 9.4 % CP, 3.86% EE, 24.3 % CF, 51.5% NFE and 9.0 MJ/ kg ME, while the silage prepared at the flowering stage – 210 g/kg DM, pH=4.6, 20.5 g/kg lactic acid, 4.7 g/kg acetic acid, 0.5 g/kg butyric acid, 10.4% ash, 9.2 % CP, 3.57% EE, 27.4 % CF, 49.3% NFE and 8.87 MJ/ kg ME; but silage prepared from plant cut at the end flowering stage 226 g/kg DM, pH=4.8, 15.4 g/kg lactic acid, 4.9 g/kg acetic acid, 0.2 g/kg butyric acid, 11.5% ash, 8.7 % CP, 3.95% EE, 28.0 % CF, 47.8% NFE and 8.81 MJ/ kg ME, respectively. JIN et al. (2024) remarked that *Silphium perfoliatum* produced silage with 246.8 g/kg DM, pH 4.64, 2.63% lactic acid, 0.45% acetic acid, 0.49% butyric acid, 77.36% organic matter, 16.76% CP, 60.55% NDF, 24.86% ADF, 7.39% ADL, 15.74 MJ/ kg GE, 11.85 MJ/ kg DE, 9.47 MJ/ kg ME, 5.75 MJ/ kg NEl.

Table 2. The fermentation profile, the biochemical composition and the nutritive value of the ensiled mass from the studied *Silphium* species.

Indices	*Silphium integrifolium*	*Silphium perfoliatum*	*Zea mays* (control)
pH index	4.54	4.36	3.77
Organic acids, g/kg DM	40.6	30.4	48.6
Total acetic acid, g/kg DM	8.1	6.1	10.3
Total butyric acid, g/kg DM	0.1	0.03	0.2
Total lactic acid, g/kg DM	32.4	24.3	38.1
Acetic acid, % of organic acids	19.95	19.97	21.19
Butyric acid, % of organic acids	0.25	0.10	0.41
Lactic acid, % of organic acids	79.80	79.93	78.40
Crude protein, g/kg DM	126	157	80
Crude fibre, g/kg DM	355	311	245
Ash, g/kg DM	106	95	59
Acid detergent fibre, g/kg DM	379	322	258
Neutral detergent fibre, g/kg DM	583	537	469
Acid detergent lignin, g/kg DM	46	40	37
Total soluble sugars, g/kg DM	23	27	-
Cellulose, g/kg DM	330	282	221
Hemicellulose, g/kg DM	204	215	211
Dry matter digestibility, g/kg DM	594	638	689
Digestible energy, MJ/kg DM	11.76	12.55	13.45
Metabolizable energy, MJ/kg DM	9.66	10.31	11.04
Net energy for lactation, MJ/kg DM	5.79	6.33	7.06
Relative feed value	95	111	136

Energy serves as a cornerstone of industrial development and societal well-being, underpinning economic growth, technological innovation and improved living conditions. However, the global dependence on non-renewable sources, such as oil, coal, and natural gas, has resulted in significant environmental and health-related challenges. Among renewable alternatives, phytomass (plant biomass) emerges as a highly promising energy source. As a form of chemical energy captured from sunlight through photosynthesis, phytomass is abundant, renewable, and relatively economical. Currently, bioenergy is the fourth-largest contributor to the global primary energy supply, following oil, coal, and natural gas. When subjected to appropriate pre-treatment processes and advanced conversion technologies, phytomass can be efficiently transformed into various biofuels for use in transportation, heating, and electricity generation. One of the most valuable biofuels derived from phytomass is biomethane, which can effectively substitute for fossil-based oil and natural gas in energy production. Furthermore, the digestate produced during biomethane generation can be applied as an organic fertilizer in agriculture. To meet growing energy demands sustainably, biogas plants are increasingly using energy crops cultivated specifically for this purpose. Table 3 presents data on the quality indicators and biomethane production potential of substrates derived from *Silphium* species. Our findings show that the substrates had favorable carbon-to-nitrogen (C/N) ratios, ranging from 19 to 25, along with acid detergent lignin contents of 40-49 g/kg and hemicellulose levels between 202 and 230 g/kg – values that align with the established standards. The biochemical methane potential (BMP) of the studied substrates ranged from 297 to 318 L/kg DM or 332 to 351 L/kg VS. Notably, *Silphium perfoliatum*, particularly in its ensiled form, demonstrated high biochemical methane potential. In contrast, *Silphium integrifolium* substrates exhibited biomethane yields similar to those of *Zea mays*.

Table 3. The biochemical composition and the biomethane production potential of the studied *Silphium* species.

Indices	***Silphium integrifolium***		***Silphium perfoliatum***		***Zea mays* (control)**	
	fresh mass	**ensiled mass**	**fresh mass**	**ensiled mass**	**fresh mass**	**ensiled mass**
Crude protein, g/kg DM	138.0	126.0	166.0	157.0	84.0	80.0
Ash, g/kg DM	86.0	106.0	89.0	95.0	52.0	59.0
Nitrogen, g/kg DM	22.1	20.2	26.6	25.1	13.4	12.8
Carbon, g/kg DM	507.8	496.7	506.1	502.8	526.7	522.8
Ratio carbon/nitrogen	23.0	24.6	19.0	20.0	39.3	40.8
Acid detergent lignin, g/kg DM	49.0	46.0	46.0	40.0	48.0	37.0
Hemicellulose, g/kg DM	230.0	204.0	202.0	215.0	203.0	211.0
Biomethane potential, L/kg DM	306	297	311	318	304	318
Biomethane potential, L/kg VS	335	332	341	351	321	338

Several authors have reported findings on the biogas yield and methane potential of *Silphium* substrates. VETTER et al. (2007) using continuous anaerobic digestion found that the methane yield of *Silphium perfoliatum* was 133.1-208.3 l/kg or 4583-7567 m^3/ha, but – of *Zea mays* – 146.6-212.2 l/kg or 4281-8569m^3/ha. MAST et al. (2014) reported that the specific methane yield of *Silphium perfoliatum* varied between 232 and 274 L/kg ODM, depending on the harvest time. The total methane yield reached up to 4,301 m^3/ha, which was approximately 21% lower than that of maize. Similarly, GANSBERGER et al. (2015) noted that substrates derived from *Silphium perfoliatum* harvested at the end of the flowering stage had a biomethane potential of approximately 260 L/kg DM (based on a 35-day digestion period), corresponding to a methane yield of around 3,100 m^3/ha. HAAG et al. (2015) found that the specific methane yield of cup plant (*Silphium perfoliatum*) substrates was 227 L/kg OM in continuous fermentation tests and 251 L/kg OM in batch fermentation tests. HERRMANN et al., (2016) remarked that the studied cup plant silage substrates have C/N=35-46 and the specific methane yields ranged from 181.6 to 237.6l/kg ODM, while in maize silage substrates C/N=25-39 and the specific methane yields were 294.5-376.2 l/kg ODM. VISHNEVSKAYA (2017) revealed that methane yield of *Silphium perfoliatum* was 232- 235 l/kg ODM or 3065-4715 m^3/ha, depending on the on amount of fertilizers applied. RUF & EMMERLING (2018) reported that the biochemical methane potential of cup plant substrate was 0.236-0.282 l/kg ODM. USTAK & MUÑOZ (2018) found that methane yield in *Silphium perfoliatum* substrate reached 276 L/kg VS. SIWEK et al. (2019) observed that the biogas yield from *Silphium* substrates ranged between 483 and 504 L/kg dry matter (DM), with the biomethane concentration in the biogas varying from 51.1% to 52.9%. PENI et al. (2022) reported that the methane production differed significantly in the case of *Silphium perfoliatum* substrate type, ranging from 193.59 to 243.61 L/kg VS. VON COSSEL et al. (2021) mentioned that *Silphium perfoliatum* substrate contained 44.6 % ADF, 52.0 % NDF, 6.7%ADL, 37.9% cellulose, 7.4% hemicellulose, 9.2% ash and specific methane yield was 264.7 l/kg. WITASZEK et al. (2022) noted that *Silphium perfoliatum* untreated raw material substrate had 665.6 g/kg dry matter, 82.53% organic matter, 21.62 % lignin, 30.96% cellulose, 22.6 % hemicellulose and the yield of methane amounted to 204 L/kg, but treated material substrates contained 725.9-903.4 g/kg dry matter, 83.47-87.74% organic matter, 19.71-23.68 % lignin, 21.07-30.49% cellulose, 18.41-20.56 % hemicellulose and the yield of methane reached 244-255 L/kg. ASHWORTH et al. (2023) reported that biomass from *Silphium integrifolium* harvested in mid-to-late June contained 1.06% N with a C/N ratio of 40.50, while the biomass harvested in mid-to-late September contained 1.45% N and had a C/N ratio of 31.11. KEMMANN et al. (2023) stated that the specific methane yield of cup plant biomass substrate was 296.8 ± 50.6 L/kg VS, compared to 383.3 ± 37.4 L/kg VS for maize biomass substrate. BAUMGART et al. (2024) reported that the methane yield of silage substrates from *Silphium perfoliatum* varied depending on the harvest date, ranging from 167 to 257 L/kg ODM, while silage substrates treated with ensiling additives showed yields ranging from 210 to 312 L/kg ODM.

CONCLUSIONS

The fresh mass yield of the of studied *Silphium* species in the third year of vegetation ranged from 4.75 to 6.95 kg/m², with a dry matter content 25.65- 27.55%.

The dry matter of harvested whole plants of studied *Silphium* species contained: 138-166 g/kg CP, 317- 345 g/kg CF, 86-89 g/kg ash, 352-369 g/kg ADF, 554-599 g/kg NDF, 46-49 g/kg ADL, 56-58 g/kg TSS, 306-320 g/kg Cel, 202-230 g/kg HC, 60.2-61.5 % DDM, RFV=94-103, 11.91-12.15 MJ/kg DE, 9.78-9.97 MJ/kg ME and 5.79-5.98 MJ/kg NEl.

The ensiled mass from the *Silphium* species had pH = 4.36-4.54, and had the following composition: 126-157 g/kg CP, 95-106 g/kg ash, 311-355 g/kg CF, 322-379 g/kg ADF, 537-583 g/kg NDF, 40-46 g/kg ADL, 282-330 g/kg Cel, 204-215 g/kg HC, 23-27 g/kg TSS, 59.4-63.8 % DMD, 11.76-12.55 MJ/kg DE, 9.66-10.31 MJ/kg ME, 5.79-6.33 MJ/kg NEl.

The biochemical methane yield of the studied substrates ranged from 332 to 351 l/kg VS.

The studied *Silphium* species have optimal nutrient content, making them suitable as an alternative forage source for ruminant animals, also and as substrates for biogas production. Among these species, *Silphium perfoliatum* has particularly high economic value.

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