

THE QUALITY INDICES OF ENERGY BIOMASS FROM AGRICULTURAL RESIDUES OF *Asteraceae* SPECIES

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Abstract

The objective of this research was to evaluate the quality indices of the dry matter from agricultural residues - stems of *Asteraceae* species: *Artemisia absinthium*, *Cynara cardunculus*, *Silphium integrifolium*, *Silphium perfoliatum*, *Solidago canadensis* collected in the experimental plot of the NBGI Chișinău. It has been found that elemental composition of the collected stems dry matter was 41.36-50.00% carbon, 4.32-6.14% hydrogen, 0.62-1.37% nitrogen, 0.03-0.10% sulphur, 2.18-5.66% ash and gross calorific value varied from 18.2 to 19.0 MJ/kg dry matter. The dry biomass contained 461-545 g/kg cellulose, 180-320 g/kg hemicellulose, 85-112 g/kg acid detergent fibre and the estimated theoretical ethanol yield varied from 522 to 575 L/t organic dry matter and biomethane potential from 167 to 266 L/kg VS. The investigate agricultural residues have optimal concentration of structural carbohydrates and energy value, which make them suitable to be used as a part of a diverse mix for solid biofuel production and feedstock for cellulosic bioethanol as renewable energy.

Key words: agricultural residues, *Asteraceae* species, biomethane potential, quality indices of biomass, theoretical ethanol yield.

INTRODUCTION

Facing climate change, energy security, and sustainable development challenges, biomass has emerged as a crucial alternative to fossil fuels. Phytomass can provide energy and multiple products, with biorefineries offering efficient conversion into bioenergy (solid, liquid, gas) and bioproducts (fibres, starch, oils, chemicals).

The *Asteraceae* (*Compositae*) family is among the largest flowering plant families, comprising approximately 1,911 genera and 32,913 species. Its diversity spans annual and perennial herbaceous plants, shrubs, trees, climbers, succulents, aquatic plants, etc. Economically, it includes food, forage, oilseeds and technical crops, medicinal plants, ornamentals and weedy species. Key genera include *Artemisia* (474 species), *Helianthus* (71 species), *Cynara* (11 species), *Silphium* (17 species), and *Solidago* (138 species), with many species native to North America and some also in South America, Asia and Europe.

In the flora of Moldova, genera *Artemisia* comprises 10 species, while genera *Solidago* (1 species), important medicinal and aromatic

plants used to treat malaria, hepatitis, inflammation, cancer and various infections. Domesticated *Asteraceae* agricultural crops include *Helianthus annuus*, *Helianthus tuberosus*, *Lactuca sativa*, *Cynara cardunculus*, *Cichorium endivia*, *Carthamus tinctorius*. Species such as *Calendula officinalis*, *Echinacea purpurea*, *Inula helenium*, *Matricaria recutita*, *Polymnia sonchifolia*, *Solidago canadensis* have notable pharmacological properties, offering therapeutic potential.

Among the species of the genus *Silphium*, only *Silphium perfoliatum* and *Silphium integrifolium* are of considerable economic significance, as forage, oilseeds and honey crops, also as energy biomass (Rakhmetov, 2018; Reinert et al., 2019; Cumplido et al., 2020; Mueller et al., 2020; Wu et al., 2020; Daraduda, 2024; Titei, 2025; Wöhl et al., 2025).

In our previous studies we present the results regarding the fodder value and energy biomass potential of some *Asteraceae* species (Ivanova et al., 2015; Țîței, 2014, 2019, 2025; Țîței & Roșca, 2021; Cerempei et al., 2023; Guțu et al., 2023).

Harvesting *Asteraceae* plants produces agricultural residues, which require proper collection

and processing to avoid environmental impacts. In recent decades, European energy, agricultural, and environmental policies have promoted Asteraceae as biomass crops. These species are increasingly researched for conversion into solid (pellets, briquettes, chips), liquid (biodiesel) and gaseous (biomethane, syngas) biofuels, providing a renewable energy source from agricultural and industrial residues. This research aimed to assess the biochemical and physical quality indices of dry matter from agricultural residues – stems of five Asteraceae species (*Artemisia absinthium*, *Cynara cardunculus*, *Silphium integrifolium*, *Silphium perfoliatum* and *Solidago canadensis*) – to determine their suitability as feedstock for biofuel production.

MATERIALS AND METHODS

The Asteraceae species *Artemisia absinthium*, *Cynara cardunculus*, *Silphium integrifolium*, *Silphium perfoliatum* and *Solidago canadensis*, grow in the experimental field of the “Alexandru Ciubotaru” National Botanical Garden (Institute) of MSU, Chişinău, were used as research material, while *Helianthus annuus* served as the control. Stem biomass from the investigated Asteraceae species was collected after seed harvest. The material was initially cut into small pieces using a stationary forage chopper, then further reduced in size with a beater mill equipped with a 6 mm mesh sieve. For analytical purposes, the resulting biomass was oven-dried at 85°C, ground to a particle size below 1 mm, and homogenized thoroughly. Elemental composition - total carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) - was determined by dry combustion using a Vario Macro CHNS elemental analyser. The ash content and energy properties, including higher and lower heating values of both raw biomass and derived pellets, were assessed according to standardized methods. The structural components of the plant cell wall were evaluated by determining neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) using near-infrared spectroscopy (NIRS) with a PERTEN DA 7200 analyser at the Research-Development Institute for Grassland in Braşov, Romania. The cellulose content was calculated as the difference between ADF and

ADL, whereas hemicellulose content was obtained as the difference between NDF and ADF. The theoretical ethanol potential (TEP) was estimated based on the conversion of cellulose and hemicellulose into hexose and pentose sugars, following the equations proposed by Goff et al. (2010). The biochemical methane potential (BMP) was calculated according to the methodology described by Dandikas et al. (2015).

RESULTS AND DISCUSSIONS

The conversion of biomass into solid biofuels represents an important approach to meeting contemporary energy demands while promoting renewable and sustainable energy sources. Densified biomass in the form of solid biofuels, such as pellets and briquettes, is widely preferred because it reduces volume, lowers transportation costs, facilitates handling and increases the energy content per unit of volume. The application of biomass as a solid fuel for energy production requires a detailed characterization of its elemental composition. It is well established that the energy released during combustion is positively correlated with the carbon and hydrogen content, reflecting the high energy value of these elements. Conversely, higher levels of oxygen and nitrogen reduce the calorific value, thereby diminishing the energy potential of the fuel. Moreover, low nitrogen and sulphur contents are desirable, as elevated concentrations of these elements contribute to environmental pollution. The elemental composition of the dry biomass from the agricultural residues studied – stems of Asteraceae species – is presented in Figures 1-5.

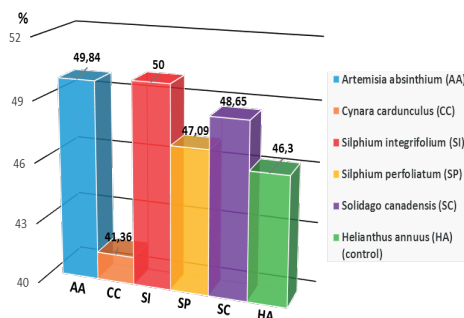


Figure 1. Carbon, %

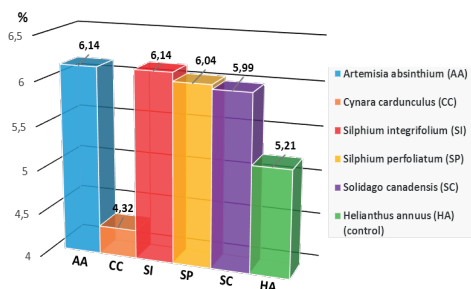


Figure 2. Hydrogen, %

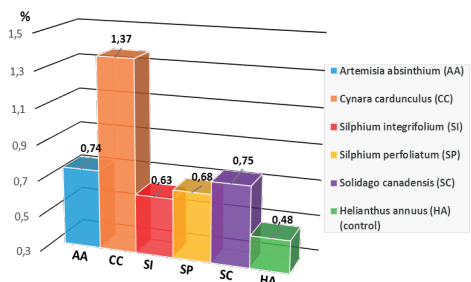


Figure 3. Nitrogen, %

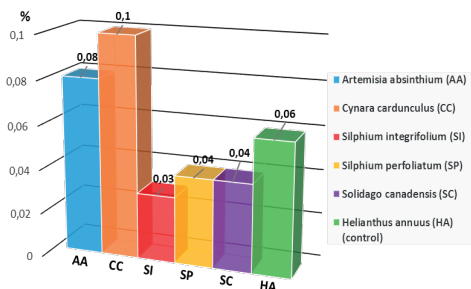


Figure 4. Sulphur, %

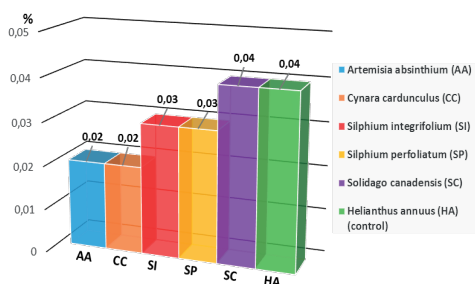


Figure 5. Chlorine, %

The elemental composition of the collected dry biomass ranged from 41.36 to 50.00% carbon, 4.32 to 6.14% hydrogen, 0.62 to 1.37% nitrogen, 0.03 to 0.10% sulphur, and 0.02 to 0.04%

chlorine. Among the studied species, the stems of *Silphium integrifolium* and *Artemisia absinthium* exhibited the highest carbon (50.00%) and hydrogen (6.14%) contents compared with the control, *Helianthus annuus*. In contrast, stem biomass from *Cynara cardunculus* showed lower carbon and hydrogen concentrations. The levels of these elements in *Silphium perfoliatum* and *Solidago canadensis* were higher than in the control, but lower than in *Silphium integrifolium* and *Artemisia absinthium*.

The investigated stem biomass generally contained higher nitrogen concentrations than *Helianthus annuus*, with *Cynara cardunculus* stems exhibiting approximately three times the nitrogen content of the control. Sulphur levels were the highest in *Artemisia absinthium* and *Cynara cardunculus*, while these species also showed lower chlorine concentrations compared with the control and other studied species. Sulfur and chlorine contents in *Silphium integrifolium*, *Silphium perfoliatum*, and *Solidago canadensis* were not substantially different from each other. Ash content is a key parameter for evaluating solid fuel quality, as it represents the non-combustible inorganic residue remaining after combustion. High ash content reduces heating value, increases handling and operational costs, and can lead to issues such as slagging, fouling and corrosion in boilers. Moreover, elevated ash levels can affect environmental compliance by increasing particulate emissions. The ash content of the studied Asteraceae stem residues is presented in Figure 6.

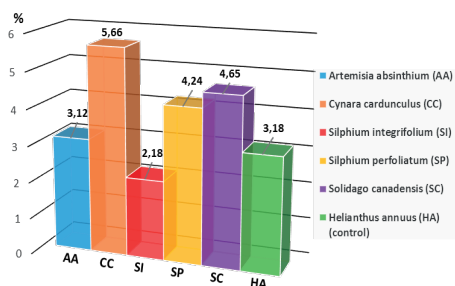


Figure 6. Ash content of biomass, %

Among the species analyzed, *Silphium integrifolium* exhibited the lowest ash content. In contrast, *Cynara cardunculus* stems showed the highest ash concentration at 5.64%, with

Silphium perfoliatum and *Solidago canadensis* also having higher ash levels compared with the *Helianthus annuus* control. This elevated ash content in *Cynara cardunculus*, *Silphium perfoliatum* and *Solidago canadensis* may be attributed to the prolonged retention of leaves on the stems.

Calorific value is the most important property of a fuel, as it determines its energy potential. The energy content of the investigated stem biomass is shown in Figures 7 and 8. The gross calorific value of the stem biomass ranged from 18.20 to 19.00 MJ/kg, while the net calorific value varied between 16.93 and 17.60 MJ/kg. The highest energy values were observed in the biomass of *Artemisia absinthium*, *Silphium integrifolium* and *Solidago canadensis*, followed by *Silphium perfoliatum*, all exceeding the calorific value of the control, *Helianthus annuus* stems. In contrast, the net calorific value of *Cynara cardunculus* stem biomass was comparable to that of the control.

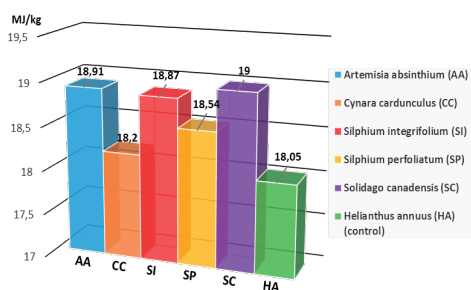


Figure 7. Gross calorific value, MJ/kg

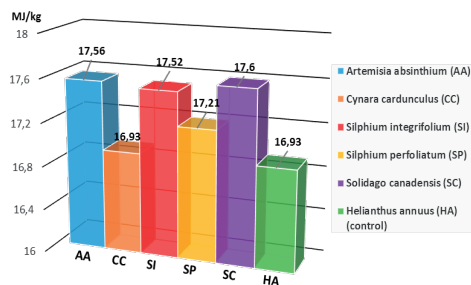


Figure 8. Net calorific value, MJ/kg

According to the literature, Asteraceae species have demonstrated strong potential as feedstock for the production of solid fuels for heat and power generation. Encinar et al. (2002) reported that *Cynara cardunculus* biomass contained

77.3% volatile matter, 14.3% fixed carbon, 8.4% ash, 46.7% carbon, 4.8% hydrogen, 0.7% nitrogen, 0.1% sulphur and a gross calorific value of 18.2 MJ/kg. Dahl & Obernberger (2004) found that cardoon pellets contained 17.4% ash, 1.1% nitrogen, and a gross calorific value of 20.3 MJ/kg. Fernández et al. (2006) reported that *Cynara cardunculus* biomass exhibited a highest heating value of 4083 kcal/kg and a lowest heating value of 3795 kcal/kg. Hua et al. (2007) observed that the energy content of *Solidago canadensis* biomass ranged from 16.7 to 19.2 MJ/kg. Grammelis et al. (2008) analysed *Cynara cardunculus* dry biomass harvested in Central Greece and reported 7.9-8.2% moisture, 6.9-7.2% ash, 70-71.8% volatile matter, 13.4-14.6% fixed carbon, 40.6-43.7% carbon, 5.5-6.0% hydrogen, 0.9-1.8% nitrogen, 0.05-0.1% sulphur and a calorific value ranging from 13.7 to 16.3 MJ/kg. Similarly, Angelini et al. (2009) reported that cardoon biomass contained 10.0% moisture, 73.0% volatile matter, 13.9% ash, 13.1% fixed carbon, 39% carbon, 6.6% hydrogen, 1.5% nitrogen, 0.2% sulphur and a calorific value of 14.9 MJ/kg.

Toscano et al. (2016) documented cardoon pellets with 11.2% moisture, 6.3% ash, high and low heating values of 20,399 and 19,247 J/kg, respectively, along with 0.55% nitrogen, 0.12% chlorine and 0.65% sulphur. Gominhoa et al. (2018) noted that depending on the plant fraction, cardoon biomass calorific value ranged from 18 to 22 MJ/kg dry matter. Hăbășescu (2011) reported that sunflower stem pellets had a net calorific value of 14.8 MJ/kg and 3.78% ash; maize stem pellets contained 14.2 MJ/kg and 5.14% ash, while wheat straw pellets showed 14.3 MJ/kg and 6.25% ash. Stolarski et al. (2014) found that *Silphium perfoliatum* stalks harvested in March-April had 2.97-3.04% ash, 47.40-48.69% carbon, 5.70-5.84% hydrogen, 0.030-0.033% sulphur, 18.70-18.90 MJ/kg high heating value and 13.35-14.95 MJ/kg low heating value. For comparison, *Helianthus tuberosus* stalks contained 3.02-3.12% ash, 46.75-46.98% carbon, 5.67-5.68% hydrogen, 0.032% sulphur, 18.54-18.63 MJ/kg high heating value and 14.04-14.78 MJ/kg low heating value. Meerbeek et al. (2015) reported that *Solidago gigantea* biomass contained 5.44% ash and a high heating value of

19.35 MJ/kg. Ciesielczuk et al. (2016) found that *Solidago canadensis* biomass had 979 g/kg organic matter, 44.8% carbon, 6.46% hydrogen, 0.37% nitrogen, 0.198% sulphur, a high heating value of 18.12 MJ/kg and a calorific value of 16.49 MJ/kg (288.4 GJ/ha). *Artemisia absinthium* biomass contained 979 g/kg organic matter, 44.6% carbon, 6.30% hydrogen, 1.54% nitrogen, 0.252% sulphur, with a high heating value of 17.87 MJ/kg and calorific value of 16.24 MJ/kg (107.2 GJ/ha). Zihare et al. (2018) reported that *Solidago canadensis* biomass had 7.3% moisture, 6.8% ash, 18.24 MJ/kg high heating value and 16.84 MJ/kg low heating value.

Gheorghe & Neacsu (2019) reported high heating values of 14.94 MJ/kg for *Arctium lappa* (3.48% ash, 0.31% nitrogen), 23.02 MJ/kg for *Silybum marianum* (3.35% ash, 0.563% nitrogen) and 16.15 MJ/kg for *Xanthium spinosum* (6.07% ash, 0.306% nitrogen). Bury et al. (2020) found that *Silphium perfoliatum* biomass contained 3.10-4.08% ash, 33.7-34.5% carbon, 1.37-1.62% nitrogen, 0.05-0.09% sulphur and 16.26-16.95 MJ/kg high heating value. Cavalaglio et al. (2020) reported cardoon biomass with 68.1% volatile matter, 9.12% ash, 14.67% fixed carbon, 41.57% carbon and a 16.15 MJ/kg high heating value.

Țîței (2020) found that *Cynara cardunculus* briquettes had a specific density of 918 kg/m³, high heating value of 19.0 MJ/kg and 2.8% ash. Nguyen et al. (2021) observed that *Solidago canadensis* biomass contained 42.46% carbon, 6.14% hydrogen and 1.48% nitrogen; *Cynara cardunculus* biomass had 7.03-12.46% moisture, 61.92-69.83% volatile matter, 5.67-10.27% ash, 10.21-19.25% fixed carbon, 38.57-48.90% carbon, 5.22-5.90% hydrogen, 0.55-0.80% nitrogen, 0.05-0.1% sulphur and 17.73-18.0 MJ/kg calorific value; while *Silybum marianum* biomass contained 79.3-87.5% volatile matter, 9.6-16.7% ash, 7.5-10.9% fixed carbon, 37.0-42.9% carbon, 5.3-5.9% hydrogen, 5.3-5.9% nitrogen and 16.1-18.1 MJ/kg calorific value.

Peni et al. (2022) reported that *Silphium perfoliatum* biomass contained 8.47% ash, 18.51% fixed carbon, 73.02% volatile matter and 17.73 MJ/kg high heating value. Šurić et al.

(2022) found that *Silphium perfoliatum* biomass had 5.86% ash, 15.49% coke, 9.28% fixed carbon, 74.45% volatile matter, 15.46 MJ/kg high heating value, and 14.54 MJ/kg low heating value. In our previous studies (Țîței, 2020, 2023; Țîței & Roșca, 2021), *Silphium perfoliatum* stem biomass contained 45.02% carbon, 5.96% hydrogen, 0.21% nitrogen, 0.03% sulphur, 3.03-3.83% ash, and 17.8-18.3 MJ/kg high heating value. Tóth (2022) reported a high heating value of 15.21-16.79 MJ/kg for *Silphium perfoliatum* biomass. Wiatrowska et al. (2022) found that *Solidago canadensis* dry biomass had 2.39% ash, 19.894 MJ/kg high heating value, and 18.369 MJ/kg low heating value, while *Solidago gigantea* had 4.93% ash, 19.403 MJ/kg high heating value and 17.868 MJ/kg low heating value. Witaszek et al. (2022) reported that *Silphium perfoliatum* lignocellulosic biomass at a moisture content of 7.17% had 15.78 MJ/kg heat of combustion and 14.08 MJ/kg calorific value.

The biochemical composition of the collected dry stem biomass from the studied Asteraceae species is presented in Figures 9-12.

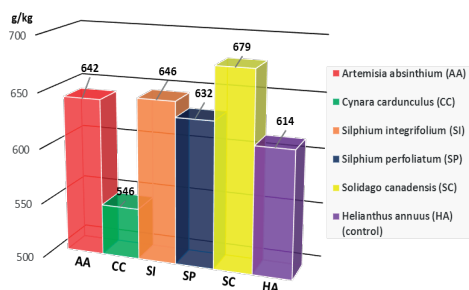


Figure 9. Acid detergent fibre, g/kg

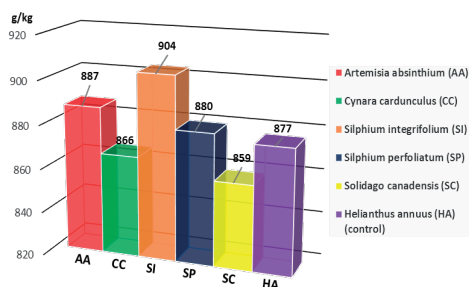


Figure 10. Neutral detergent fibre, g/kg

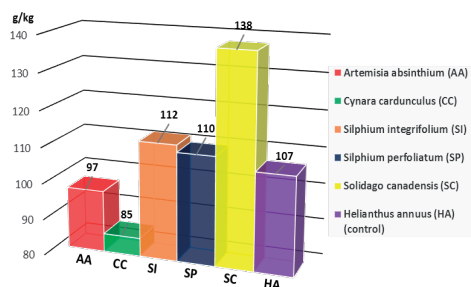


Figure 11. Acid detergent lignin, g/kg

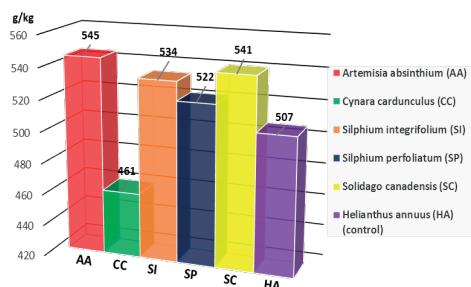


Figure 12. Cellulose, g/kg

The analysed stems contained 461-545 g/kg cellulose, 180-320 g/kg hemicellulose and 85-138 g/kg acid detergent fibre (ADF). For comparison, the control, *Helianthus annuus* stem biomass, contained 507 g/kg cellulose, 263 g/kg hemicellulose and 107 g/kg ADF.

In the context of increasingly stringent environmental regulations and global efforts to reduce greenhouse gas emissions, alternative liquid fuels, including biofuels, are becoming increasingly important. Their development addresses the need to mitigate the environmental impact of transportation while maintaining the accessibility and performance of conventional internal combustion engine systems. Among these fuels, cellulosic bioethanol is regarded as a promising drop-in option that could serve as a viable substitute for gasoline in the transportation sector. Ethanol offers several advantages over gasoline when utilized as a fuel. The theoretical ethanol yield from lignocellulosic substrates of the studied Asteraceae species is presented in Figures 13-15. The estimated yield from hexose sugars ranged from 348 to 405 L/ton, while the yield from pentose sugars was 348-405 L/ton. Compared with the control substrate from *Helianthus annuus*, substrates from *Artemisia*

absinthium, *Silphium integrifolium* and *Solidago canadensis* exhibited higher potential for ethanol production from hexose sugars, whereas *Cynara cardunculus* showed particularly high potential for ethanol production from pentose sugars.

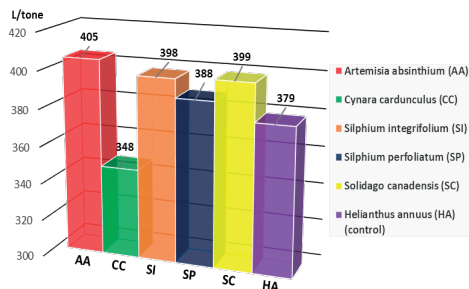


Figure 13. Theoretical ethanol potential from hexose sugars, L/tonne VS

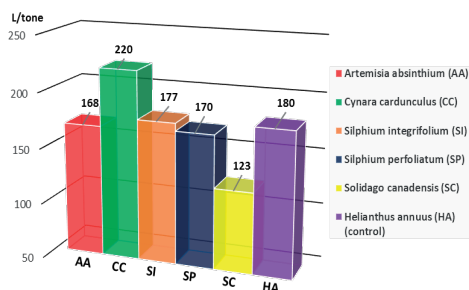


Figure 14. Theoretical ethanol potential from pentose sugars, L/tonne VS

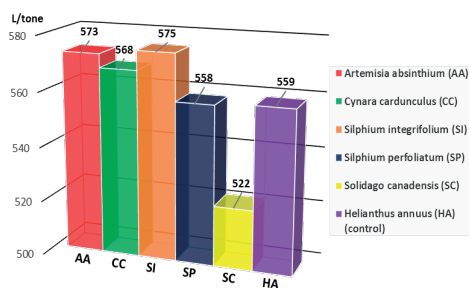


Figure 15. Theoretical ethanol potential from hexose and pentose sugars, L/tonne VS

Several studies have reported on the cell wall composition of Asteraceae species and their corresponding ethanol yields. Coccia et al. (2014) found that *Cynara cardunculus* biomass contained 34.96% cellulose, 16.17% hemicellulose, 4.54% acetyl groups, 11.22%

extractives, and 16.89% lignin. Cotana et al. (2015) reported an ethanol yield from *Cynara cardunculus* biomass of 13.17-13.64 g per 100 g of raw material. Cavalaglio et al. (2020) observed that cardoon biomass contained 37.65% cellulose, 16.70% hemicellulose, 3.96% acetyls, 17.51% lignin and 5.55% extractives. Smuga-Kogut et al. (2020) reported that untreated stems of *Solidago virgaurea* contained 30.4% cellulose, 29.2% hemicellulose, and 19.2% lignin, while other untreated stems contained 38.0-40.6% cellulose, 22.0% hemicellulose and 12.8-13.3% lignin, yielding 2.86 g/L ethanol with up to 81.43% conversion efficiency. Giannoni et al. (2021) noted that prior to organosolv treatment, *Cynara cardunculus* biomass contained 30.52% cellulose, 17.17% hemicellulose, 5.02% acetyls, 14.21% lignin and 7.64% extractives; after treatment, the composition shifted to 87.59% cellulose, 5.06% hemicellulose, and 7.34% lignin, producing 23.42 g of glucose per 100 g raw material (HY of 86.94%). Peni et al. (2022) reported that *Silphium perfoliatum* biomass contained 8.47% ash, 24.47% cellulose, 14.80% hemicellulose and 8.29% lignin. Premjet et al. (2013) analyzed 75 plant species for bioenergy and bioethanol potential, reporting ash content ranging from 2.6 to 17.5%, lignin from 4.6 to 20.4%, cellulose from 18.8 to 56.0%, hemicellulose from 3.3 to 34.2%, and ethanol yields from 239.2 to 584.4 L/t. Ruf and Emmerling (2022) observed that harvest residues (stubbles) from cup plant contained 10.5% hemicellulose, 20.6-31.6% cellulose, and 8.2-11.7% lignin, whereas silage maize contained 16.6-20.0% hemicellulose, 24.2-41.3% cellulose and 10.1-11.2% lignin. In our previous studies (Țiței, 2020, 2023; Țiței & Roșca, 2021), *Silphium perfoliatum* dry stem biomass contained 29.2% hemicellulose, 56.2% cellulose and 11.4% acid detergent lignin (ADL). Tóth (2022) reported lignocellulose quality of *Silphium perfoliatum* as 31.3-48.94% acid detergent fiber (ADF), 34.94-54.69% neutral detergent fiber (NDF), 7.21-12.54% ADL, 24.11-37.30% cellulose, and 2.33-5.75% hemicellulose. Wiatrowska et al. (2022) described *Solidago canadensis* dry biomass as

containing 20.07% pentosans, 38.95% cellulose, 23.78% hemicellulose, 19.17% lignin, 14.42% soluble compounds, and an ethanol yield of 84.2 g/kg biomass; *Solidago gigantea* contained 18.54% pentosans, 38.50% cellulose, 29.59% hemicellulose, 24.79% lignin, 13.27% soluble compounds and an ethanol yield of 50 g/kg biomass.

Biomethanation is a process in which organic material is microbiologically converted under anaerobic conditions into biogas, a mixture primarily composed of methane and carbon dioxide. Phytomass feedstock can be used as a sole substrate for anaerobic digestion or co-digested with one or more additional substrates. The resulting biogas can be directly combusted for cooking and lighting or utilized for electricity generation. The residual digestate and liquid effluent can serve as valuable fertilizers in organic farming systems.

The carbon-to-nitrogen ratio and biomethane potential of the studied agricultural residues stems of Asteraceae species - are presented in Figures 16-18.

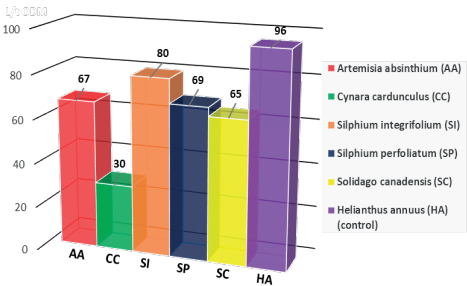


Figure 16. Carbon/nitrogen ratio

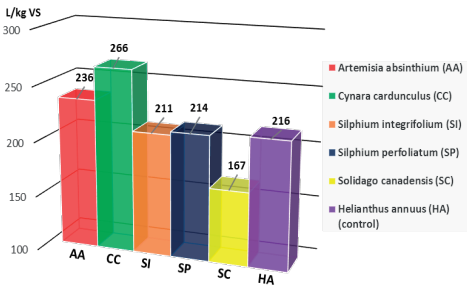


Figure 17. Biomethane potential, L/kg VS

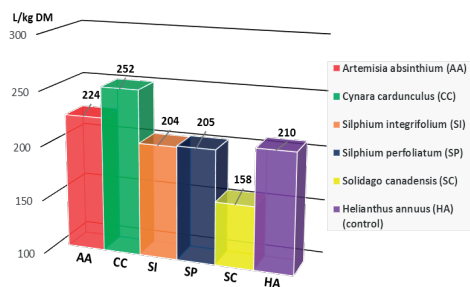


Figure 18. Biomethane potential, L/kg DM

The C/N ratio of the investigated substrates ranged from 30 to 96. The biochemical methane potential of the stems varied between 167 and 266 L/kg VS, corresponding to 158-252 L/kg DM. A notably high biomethane potential was observed in the *Cynara cardunculus* biomass substrate, likely due to its high protein and hemicellulose content combined with relatively low lignin levels. The substrate from *Artemisia absinthium* also exhibited an optimal biomethane potential. The biomethane potential of stem substrates from *Silphium* species did not differ significantly from that of the control substrate, *Helianthus annuus*. In contrast, stem substrates from *Solidago canadensis* displayed lower biomethane potential.

According to the literature, Yao et al. (2016) reported that *Solidago canadensis* biomass contained 90.5% volatile solids, 55.2% carbon, and 1.4% nitrogen, producing a maximum methane yield of 143.7 L/kg. Meerbeek et al. (2015) found that the methane yield of *Solidago gigantea* substrate reached 217.12 L/kg. Havryliuk et al. (2023) reported that the methane yield from *Solidago canadensis* biomass substrate reached 68.2 L/kg of total solids (TS).

CONCLUSIONS

The investigated agricultural residues from Asteraceae species - *Artemisia absinthium*, *Cynara cardunculus*, *Silphium integrifolium*, *Silphium perfoliatum* and *Solidago canadensis* - exhibit high structural carbohydrate content and favourable energy values. These characteristics make them promising candidates for inclusion in mixed solid biofuels, as well as for use as feedstock in the production of cellulosic bioethanol and biomethane. Their utilization not only provides a renewable energy source but

also offers an efficient way to make good use of agricultural residues, contributing to sustainable biomass management.

ACKNOWLEDGEMENTS

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