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MELLIFEROUS POTENTIAL AND BIOMASS WASTE VALORIZATION OF *Coriandrum sativum*, *Salvia hispanica*, and *Lavandula angustifolia* FOR RENEWABLE ENERGY APPLICATIONS

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Abstract

We investigated some biological characteristics of Coriandrum sativum, Salvia hispanica, and Lavandula angustifolia. It was established that the studied plant species are characterized by an extended flowering period, providing food for bees from end May to mid-August, with a honey potential ranging from 60 to 330 kg/ha. The analysis of the lignocellulose composition of the collected waste biomass (dry stalks) indicated that the dry matter contained 357-504 g/kg cellulose, 197-248 g/kg hemicellulose, and 72-135 g/kg acid detergent lignin. The estimated theoretical ethanol yield from cell wall carbohydrates ranged from 398 to 533 L/t. We found that the biochemical methane potential of the studied substrates varied from 173 to 280 L/kg ODM. The physical and mechanical properties of the dry stalk biomass showed an ash content of 3.36-4.48%, volatile matter content of 73.17-79.39%, a higher heating value (HHV) of 17.19-19.83 MJ/kg, and a lower heating value (LHV) of 15.86-18.46 MJ/kg. These characteristics indicate that the biomass can serve as a feedstock for the production of solid densified fuel (pellets) for renewable energy generation.

Key words: *biomass, biomethane potential, Coriandrum sativum, Lavandula angustifolia, melliferous potential, Salvia hispanica, solid densified fuel, pellets, theoretical ethanol yield.*

INTRODUCTION

The importance of medicinal and aromatic plants is widely acknowledged, especially given the renewed interest in phytotherapy, herbal medicine, the cosmetics industry, and perfumery. These plants have been used for thousands of years, and since the mid-20th century, interest in plant-based pharmaceuticals has grown steadily due to their greater biocompatibility with humans and animals. Being metabolically similar to endogenous compounds, they are generally better tolerated than many synthetic drugs.

The use of plants for medicinal and culinary purposes has deep roots in this region (Chisnicean et al., 2011). Today, numerous species are being researched and cultivated, both from local flora and from other parts of the world. In this context, special attention is given to species from the *Lamiaceae* and *Apiaceae* families, which serve not only medicinal and aromatic functions but also provide pollen and nectar for bees and other beneficial insects.

Lavender (*Lavandula angustifolia*) is a species in the family *Lamiaceae*, native to the Mediterranean region. It typically grows in natural habitats at lower mountain elevations. Lavender is a hardy, strongly aromatic shrub with bushy, branched stems reaching 40-50 cm in height. The plant has small, silver-grey leaves and deep violet-blue inflorescences. It is a highly valuable plant with aromatic, medicinal and ornamental uses. Lavender essential oil is especially popular and widely used in medicine, food, and cosmetics due to its antibacterial, antifungal, antioxidant, and anti-inflammatory properties. According to Gonceariuc (2014), new cultivars of *Lavandula angustifolia* developed in Moldova have reached essential oil yields of up to 245 kg/ha.

Chia (*Salvia hispanica*), also a member of the *Lamiaceae* family, is an annual herb native to Central America. It develops an extensive system of fibrous roots, forming a dense root mass under favourable conditions. The stems are erect, quadrangular, and can reach up to 200 cm in height, either simple or sparsely branched. The leaves are petiolate, with ovateelliptic blades and serrated margins; the upper (adaxial) surface is pubescent, while the lower (abaxial) surface is densely covered with whitish hairs. The inflorescence is a dense raceme composed of 6-12-flowered verticillasters. The fruits are ovoid nutlets, and the seeds are oval, measuring 1-2 mm. Seed colour varies from black and grey to white, including black-spotted forms. Today, chia is studied and cultivated in various regions around the world (Brandán et al. 2019; Rossi et al. 2020; Bhardwaj H.L. 2021; Chernov et al. 2022; Filik et al. 2022; Rodríguez et al. 2022; Rahal et al. 2023). The use of chia seeds for human consumption has been approved by the European Parliament and the European Council (European Commission, 2020).

Under the conditions of the Republic of Moldova, *Salvia hispanica* genotypes exhibit optimal growth and development, with a growing season lasting 122-126 days, ending with seed maturation. The weight of 1,000 seeds was 1.2-1.4 grams, and the potential seed yield reached 2,030 kg/ha (Chisnicean, 2017). The green biomass yield of *Salvia hispanica* varied from 6.02 to 6.56 kg/m², with a crude protein content of 87-107 g/kg, making it suitable both as forage for livestock and as feedstock for biogas production (Ababii et al., 2023).

Coriander (*Coriandrum sativum* L.), an annual herb from the *Apiaceae* family and native to the Mediterranean Basin, is an important multipurpose crop. It is an upright, branched plant that grows up to 80 cm tall. The leaves vary in shape: they are broadly lobed near the base and slender and feathery along the flowering stems. The small, white to pink flowers are arranged in compound umbels. The fruit is a globular dry schizocarp, measuring 3-5 mm in diameter. When fully mature, the seeds are light brown in colour. All parts of the plant – seeds, leaves and roots – are edible, although each has distinct flavours and culinary uses. In recent years, coriander has seen increased market demand due to its wide range of applications in industry, human and veterinary medicine, animal husbandry, and agriculture. The seeds, in particular, are valued for their content of essential oils, lipids, fatty acids, carbohydrates, amino acids, caffeic acid, chlorogenic acid, umbelliferone, scopoletin, carotenoids, vitamin C and mineral salts. The green leaves are also consumed fresh in salads, soups, and pickles. According to Yadav et al. (2001), coriander seed yields ranged from 0.34 to 1.73 t/ha, while straw yields was 0.84-3.12 t/ha. Garid et al. (2015) found seed yield was 1.236-1.925 t/ha.

Beekeeping is one of the key pillars of agricultural development in Moldova and has been practiced for thousands of years using traditional methods. Bees search for nectar and pollen not only in forests, grasslands, ruderal and marshy vegetation, but also in agrophytocenoses such as orchards, vineyards, and plantations of rapeseed, sunflower, leguminous crops, medicinal and aromatic plants.

The need to reduce dependence on fossil fuels, the growing global demand for energy, and the widespread goal of lowering atmospheric greenhouse gas emissions have all driven research into alternative fuels that utilize readily available renewable resources with minimal environmental impact. It is well known that agricultural residues from the cultivation of medicinal, spice and aromatic plants have often been burned directly in the field, while residues from the processing of raw materials were not properly stored, contributing to environmental pollution.

Currently, one way to make use of these agricultural and industrial residues is by converting them into various types of biofuels, serving as a renewable energy source.

The goal of this study was to determine the melliferous potential of *Lavandula angustifolia* (lavender), *Coriandrum sativum* (coriander), and *Salvia hispanica* (chia), as well as to evaluate the quality indices of their agricultural residues, specifically – stem biomass, for potential use as feedstock in biofuel production.

MATERIALS AND METHODS

The local cultivar *'Lavinia de Grădină'* of lavender (*Lavandula angustifolia*), the Romanian cultivar *'Omagiu'* of coriander (*Coriandrum sativum*), and the introduced ecotype of chia (*Salvia hispanica*), which grow in the experimental plot of the "Alexandru Ciubotaru" National Botanical Garden (Institute) of MSU, Chișinău, served as the subjects of the research. The cultivar *'Vital'* of cup plant (*Silphium perfoliatum*) and rapeseed (*Brassica napus* subsp. *oleifera*) were used as controls. Some biological characteristics of the studied species were investigated according to standard methodological procedures. The melliferous potential was calculated number of flowers per plants, sugar in flower and blooming duration.

Lavender stem biomass was collected in February during rejuvenation works on a 10-year-old plantation, while coriander and chia biomass were collected after seed harvesting. The harvested stem biomass was first chopped into small fragments using a stationary forage chopper. Subsequently, the chopped material was ground in a beater mill fitted with a 6 mm mesh sieve. For analysis purposes, the milled biomass was dried in an oven at 85°C, further ground to a particle size of less than 1 mm, and thoroughly homogenized. Elemental composition, including total carbon (C), hydrogen (H), nitrogen (N), and sulfur (S), was determined via dry combustion using a Vario Macro CHNS elemental analyzer (Elementar Analysensysteme GmbH, Langenselbold, Germany). Biomass densification was carried out using pelleting equipment. The ash content and energy characteristics (higher and lower heating values) of both the dry biomass and resulting pellets were evaluated following standardized protocols at the Technical University of Moldova. To analyse the structural components of the plant cell wall in the dry biomass, the contents of neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) were measured using near-infrared spectroscopy (NIRS) with a PERTEN DA 7200 instrument at the Research-Development Institute for Grassland in Brașov, Romania. Cellulose content was estimated as the difference between ADF and ADL, while hemicellulose content was calculated as the difference between NDF and ADF. The theoretical ethanol potential (TEP) was estimated based on the conversion of cellulose and hemicellulose into hexose (H) and pentose (P) sugars, following the equations developed by Goff et al. (2010). The biochemical methane potential (BMP) was calculated using the methodology proposed by Dandikas et al. (2015).

RESULTS AND DISCUSSIONS

Based on the analysis of the biological characteristics of growth and development, it was observed that lavender (*Lavandula angustifolia*) resumes vegetation in the second half of April, with the flowering period occurring from mid-May to mid-June. The flowers are visited by bees throughout the day. The estimated honey potential of lavender is approximately 230 kg/ha.

In the 'Omagiu' cultivar of coriander (*Coriandrum sativum*), seedling emergence was recorded in mid-April, followed by more vigorous vegetative growth during May. Flowering began 48-55 days after emergence, typically in June, when plants reached a height of 62-75 cm. The flowering period lasted 10-16 days. The flowers were intensely visited by bees throughout the day, with peak activity occurring in the afternoon, when nectar secretion was more abundant. The estimated honey potential for coriander is approximately 330 kg/ha.

Figure 1. *Apis melifera* visiting *Coriandrum sativum* and *Salvia hispanica* plants

In *Salvia hispanica*, seedlings emerge at the soil surface in early May, with more vigorous vegetative growth observed in June. During the flowering stage, plants reach a height of 200-210 cm. The flowering period lasts 12-18 days, and the flowers are intensively visited by bees, particularly in the first half of the day. The estimated honey potential is approximately 60 kg/ha.

The scientific literature presents various data regarding the biological characteristics and honey potential of plant species from the *Lamiaceae* and *Apiaceae* families. According to Iordache et al. (2007), the nectar production of *Coriandrum sativum* is between 0.10 and 0.15 mg per flower, with a honey potential ranging from 100 to 500 kg/ha, and under favourable conditions, up to 1500 kg/ha. For *Salvia nemorosa*, nectar production ranges from 0.3 to 1.5 mg per flower, with a honey potential of 200-400 kg/ha. In *Lavandula angustifolia*, nectar production is reported at 0.07-0.22 mg per flower, with a honey potential of 50-100 kg/ha. According to Auer (2020), Halbritter et al. (2020), and Enache et al. (2021), the flowers of *Lavandula angustifolia*, *Salvia nemorosa*, *Salvia officinalis*, *Salvia pratensis* and *Salvia verticillata* produce medium-sized, hexacolpate pollen grains. In contrast, species such as *Coriandrum sativum*, *Cichorium intybus*, *Fagopyrum esculentum*, *Foeniculum vulgare* and *Robinia pseudacacia* produce medium-sized, tricolporate pollen grains. Rodríguez et al. (2023) reported that the flowering period of *Salvia hispanica* begins 66 days after sowing, with full flowering reached at 76 days. According to Brandán et al. (2019), the flowering period of *Salvia hispanica* lasts 15 to 25 days, with each flower remaining open for 5 to 7 days. Varban et al. (2022) observed that the growing season of the studied *Salvia hispanica* accessions lasted between 150 and 170 days, with the flowering stage accounting for 13.5-18.0% of the total growing season. Dragoman et al. (2024) reported the following melliferous potentials: *Lavandula angustifolia* – 200 kg/ha, *Salvia officinalis* – 400 kg/ha, and *Salvia verticillata* – 600 kg/ha.

The use of biomass as solid fuel for energy supply requires characterizing elemental chemical components. The elemental composition of biomass is a significant asset that defines the amount of energy and evaluates the clean and efficient use of biomass materials, provides significant parameters used in the design of almost all energy conversion systems and projects, for the assessment of the complete process of any thermochemical conversion techniques. The main constituents of dry biomass are carbon (C), oxygen (O) and hydrogen (H). As carbon and hydrogen are oxidised in the combustion process, they release energy. Carbon is obviously representing foremost contributions to overall heating value. Furthermore, higher hydrogen content determines and leads to a higher net caloric value. Nitrogen (N), sulphur (S) and chlorine (Cl) concentrations are some of the main causes of air pollution from biomass combustion. A higher percentage of these elements generally results in a higher level of air contaminants being released. The energy released during the combustion process is positively correlated with the carbon and hydrogen contents as a function of the energy value of these elements. In contrast, high oxygen and nitrogen values decrease the calorific value.

Table 1. The elemental composition of the dry biomass from the studied species, %

Indices	*Coriandrum sativum*	*Salvia hispanica*	*Lavandula angustifolia*	*Brassica napus*	*Silphium perfoliatum*
Carbon	44.35	43.13	51.03	45.60	46.28
Nitrogen	0.42	1.26	0.44	0.92	0.22
Hydrogen	6.04	5.24	6.15	5.14	6.14
Sulphur	0.09	0.11	0.02	0.07	0.03
Oxygen	49.11	50.26	42.36	48.30	47.33

The elemental composition of the dry biomass from the studied species is presented in Table 1. We found that the *Lavandula angustifolia* dry biomass is characterized by a very high concentration of carbon and very low concentration of sulphur, as compared with biomass from *Salvia hispanica, Brassica napus* and *Coriandrum sativum.* The biomass from *Salvia hispanica* and *Brassica napus* had higher levels of nitrogen and lower – of hydrogen, as compared with other investigated species.

The valorization of energy biomass in the form of solid fuels, such as pellets and briquettes, is commonly preferred, as it reduces biomass volume, thereby lowering transportation costs, improving handling, and increasing the energy amount per unit of volume.

Densified solid fuels like pellets also offer structural consistency, making them particularly suitable for automated boiler systems in individual households, schools, kindergartens, and other public institutions.

The quality indices of the biomass and resulting pellets from the studied species are presented in Figures 2-7.

Ash content is a key parameter in determining the quality of solid fuels, as higher ash levels negatively affect combustion efficiency, promote clinker formation in combustion chambers, and can lead to physical damage and wear of heating systems. *Lavandula angustifolia* dry biomass exhibited an optimal ash content (3.74%). The biomass of *Salvia hispanica* and *Coriandrum sativum* had lower ash content compared to *Brassica napus* subsp. *oleifera* and *Silphium perfoliatum.*

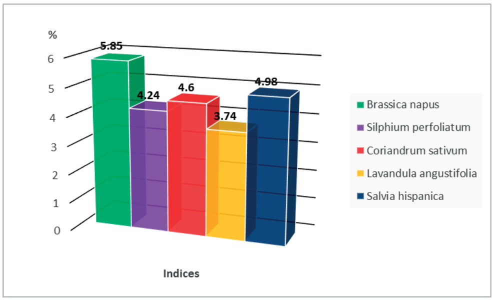

Figure 2. Ash content of biomass

The gross calorific value (higher heating value) was highest in *Lavandula angustifolia* biomass (19.84 MJ/kg), followed by *Coriandrum sativum*, which showed a significantly higher value than both *Brassica napus oleifera* and *Silphium perfoliatum*. *Salvia hispanica* biomass had a lower calorific value (17.24 MJ/kg).

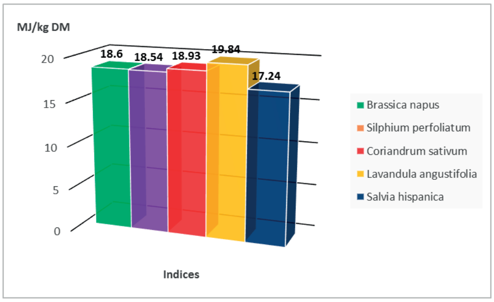

Figure 3. Gross calorific value of biomass

The net calorific value of dry biomass from the studied species varied significantly (15.88-18.46 MJ/kg). Compared to *Silphium perfoliatum* and *Brassica napus* subsp. *oleifera*, the dry biomass of *Lavandula angustifolia* exhibited a higher energy concentration, while *Salvia hispanica* and *Coriandrum sativum* showed lower values.

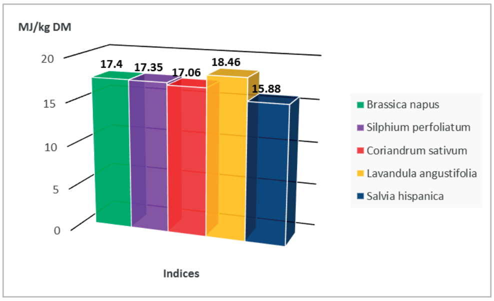

Figure 4. Net calorific value of biomass

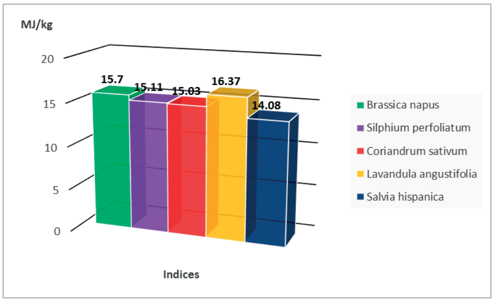

Figure 5. Net calorific value of pellets

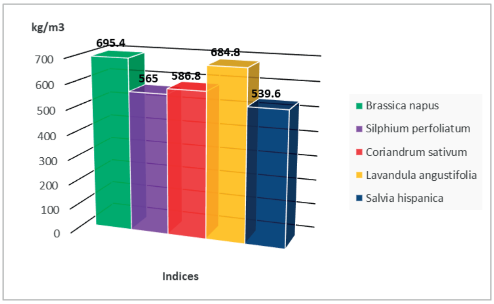

Figure 6. Bulk density of pellets

The pellets produced from *Lavandula angustifolia* biomass were characterized by a high net calorific value, as well as superior bulk density and mechanical durability. In contrast, the net calorific value of pellets made from *Salvia hispanica* and *Coriandrum sativum* was lower than that of pellets from *Brassica napus*. The net calorific value of *Coriandrum sativum* pellets did not differ significantly from that of pellets made from *Silphium perfoliatum*. However, the bulk density and mechanical durability of *Coriandrum sativum* pellets were higher than those from *Silphium perfoliatum*.

Pellets derived from *Salvia hispanica* biomass demonstrated greater mechanical durability compared to those from *Coriandrum sativum* and *Silphium perfoliatum*.

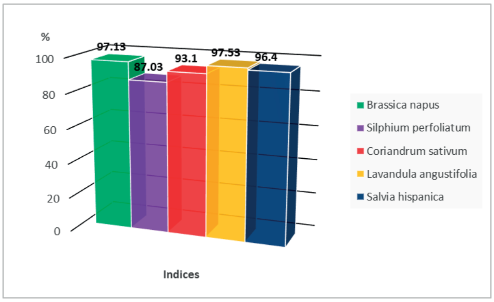

Figure 7. Mechanical durability of pellets

Differences in the quality indices of biomass and densified biofuels from these species are also reported in the literature. According to Plíštil et al. (2005), coriander biomass briquettes had a bulk density of 800-900 kg/m³, a destruction force of 30-50 N/mm, and a compaction pressure of 32-40 MPa, while rapeseed straw briquettes had a bulk density of 800-860 kg/m³, destruction force of 24-40 N/mm, and compaction pressure of 35-40 MPa. Srivastava et al. (2014) reported that coriander stalk and leaf biomass contained 3.47% ash, 78.00% volatile matter, and 18.48% fixed carbon, with a bulk density of 436 kg/m³. The resulting briquettes had a true density of 1319 kg/m³, a bulk density of 747 kg/m³, and a gross calorific value of 13.70 MJ/kg. According to Maroušek (2013), pellets from rapeseed straw had a calorific value of 15.4 MJ/kg and a specific density of 944 kg/m³. Greenhalf et al. (2012) reported that rapeseed straw contained 48.35% carbon, 5.80% hydrogen, 1.15% nitrogen, and 44.70% oxygen. Lesage-Meessenc et al. (2015) found that distilled lavender and lavandin straw contained 48.1% carbon, 5.8% hydrogen, 1.3% nitrogen, 37.8% oxygen, 0.1% sulfur, 0.2% chlorine, and 6.7% ash. Stolarski et al. (2014) reported that *Silphium perfoliatum* harvested in March contained 47.40% carbon, 5.70% hydrogen, and 0.36% sulfur. Chakyrova & Doseva (2021) mentioned that proxymate composition of lavender stalks biomass was 10.2% moisture content, 7.8% ash, 66.7% volatile matter, 15.3% fixed carbon and elemental composition 48.1 % carbon, 5.8 % hydrogen, 1.3 % nitrogen, 37.8% oxygen, 0.1% sulphur, 19.57 MJ/kg gross calorific value. Li et al. (2022) reported that *Lavandula* distilled straws had 2.93% moisture, 80.89 % volatile matter, 8.55% fixed carbon, 7.63% ash, 50.77% carbon, 6.9% hydrogen, 1.28% nitrogen, 41.05% oxygen and 21.43 MJ/kg HHV. Pulidori et al. (2023) revealed that lavender waste had 45.4% carbon, 6.77% hydrogen, 1.79% nitrogen, 45.70% oxygen, 0.112% sulphur, 6.30% ash, 19.20 MJ/kg gross calorific value; rosemary waste - 51.66% carbon, 6. 90% hydrogen, 1.19% nitrogen, 39.2% oxygen, 0.09% sulphur, 3.04% ash, 22.0 MJ/kg gross calorific value; thyme waste 42.55% carbon, 6.66% hydrogen, 1.66 % nitrogen, 46.7 % oxygen, 0.15% sulphur, 4.6% ash, 17.80 MJ/kg gross calorific value, *Artemisia vulgaris* waste contained 44.7% carbon, 6.90% hydrogen, 2.4% nitrogen, 41.8 % oxygen, 0.20% sulphur, 5.8% ash, 19.30 MJ/kg gross calorific value, *Ruta chalepensis* waste included 42.8% carbon, 6.71% hydrogen, 1.84% nitrogen, 45.0% oxygen, 0.15% sulphur, 6.7% ash, and 18.00 MJ/kg gross calorific value.

The production of biogas through anaerobic digestion (biomethanation) of phytomass is gaining increasing importance in the context of renewable energy generation. It is considered both socio-economically cost-effective and environmentally beneficial, primarily due to its potential to reduce greenhouse gas emissions. Phytomass feedstock can be used as a sole substrate for anaerobic digestion or co-digested with two or more additional substrates. Biogas generators produce not only methane for heat and electricity, but also digestate and fugate, which are considered valuable fertilizers in organic farming systems. The use of phytomass for biogas production plays a crucial role in replacing limited fossil energy sources, supporting the transition from a fossil-based to a bio-based economy.

The results concerning the quality indices of biomass substrates from the studied species and their biochemical methane potential are presented in Table 3. In the substrate derived from *Salvia hispanica*, the carbon-to-nitrogen (C/N) ratio was 32.8, the ADL content was 72 g/kg, and the hemicellulose content was 197 g/kg. The biochemical methane potential reached 280 L/kg of organic dry matter, which was significantly higher as compared to *Brassica napus* subsp. *oleifera* and *Silphium perfoliatum*. It was found that the substrates from *Lavandula angustifolia* and *Coriandrum sativum* contained higher levels of acid detergent lignin (117-135 g/kg), which contributed to a lower biochemical methane potential (173-199 L/kg ODM) as compared to the other substrates studied.

Several publications have documented the biochemical composition and biomethane production potential of substrates from the studied species. Gunaseelan (2004) reported that the biochemical methane potential of waste feedstocks from coriander leaves was 0.325 m^3/t DM, while that from coriander stems was 0.309 m^3/t DM. Fardad et al. (2012) found that a substrate from lavender waste contained 48.56% carbon, 1.44% nitrogen, with a C/N ratio of 37.72 and a methane content of 57%. Sahu et al. (2012) observed that the biogas production potential of kitchen waste and sludge in the presence of 50 mg/L coriander waste was 213 L/kg VS, compared to 340 L/kg for kitchen waste alone and 119 L/kg for sludge alone. Ababii et al. (2023) reported that fresh and ensiled biomass substrates of *Salvia hispanica*, based on their C/N ratios (29.2-36.8), acid detergent lignin content (62-72 g/kg) and hemicellulose content (166-199 g/kg), met established standards for anaerobic digestion. The biochemical methane potential of these substrates ranged from 285 to 298 L/kg ODM. According to Sibaoueih et al. (2025), coriander straw contained 898.8 g/kg DM, 6.94% ash, 4.90% CP, 43.39% CF, 73.62% NDF, 53.14% ADF and 8.52% ADL.

Table 2. Biochemical biomethane production potential of substrates from the studied species

Indices	*Coriandrum sativum*	*Salvia hispanica*	*Lavandula angustifolia*	*Brassica napus*	*Silphium perfoliatum*
Organic dry matter, g/kg	954.00	950.20	962.60	941.50	957.60
Minerals, g/kg DM	46.00	49.80	37.40	58.50	42.40
Crude protein, g/kg DM	26.25	78.75	27.50	57.50	13.75
Nitrogen, g/kg DM	4.20	12.60	4.40	9.20	2.20
Carbon, g/kg DM	443.50	431.30	510.30	456.00	522.00
Ratio carbon/nitrogen	106.00	32.80	116.00	49.57	237.20
Cellulose, g/kg DM	466.00	357.00	504.00	401.00	522.00
Hemicellulose, g/kg DM	248.00	197.00	230.00	191.00	248.00
Acid detergent lignin, g/kg DM	117.00	72.00	135.00	83.00	110.00
Biomethane potential, L/kg ODM	199.13	280.00	172.65	263.37	210.90
Biomethane potential, L/kg DM	190.00	266.63	166.19	247.96	201.96

Table 3. Cell wall composition and theoretical ethanol potential yield of the studied species

Indices	*Brassica napus*	*Silphium perfoliatum*	*Coriandrum sativum*	*Lavandula angustifolia*	*Salvia hispanica*
Acid detergent fibre, g/kg DM	484.00	632.00	583.00	639.00	429.00
Neutral detergent fibre, g/kg DM	675.00	880.00	831.00	869.00	626.00
Acid detergent lignin, g/kg DM	83.00	110.00	117.00	135.00	72.00
Cellulose, g/kg DM	401.00	522.00	466.00	504.00	357.00
Hemicellulose, g/kg DM	191.00	248.00	248.00	230.00	197.00
Theoretical ethanol potential:					
from hexose sugars, L/t ODM	298.62	388.69	348.33	374.80	267.21
from pentose sugars, L/t ODM	131.00	170.11	170.11	157.91	135.13

The bioethanol produced from lignocellulosic biomass is currently promoted as an alternative transportation fuel, because of its antiknock properties, which help increasing octane ratings and improve fuel efficiency. The bioethanol yields are influenced by tissue composition, ratios of cellulose, hemicellulose and lignin.

The composition of cell wall dry matter substrates from the studied species and their theoretical ethanol yields are presented in Table 3 and Figures 7-13. We found that the concentration of structural carbohydrates in substrates from *Lavandula angustifolia* biomass do not differ considerably as compared with control *Silphium perfoliatum* biomass. The substrate from *Coriandrum sativum* stalk biomass showed lower levels of cellulose, hemicellulose, and lignin than *Silphium perfoliatum* biomass, although these levels were still higher than those observed in *Brassica napus* subsp. *oleifera* and *Salvia hispanica* substrates. Among all species, the lowest average concentration of structural carbohydrates was generally observed in *Salvia hispanica* biomass substrates. This lower concentration, particularly of lignin compared to other energy crop substrates, is likely due to the higher content of soluble carbohydrates. The theoretical ethanol yield from hexose sugars averaged 375 L/t in *Lavandula angustifolia*, 349 L/t in *Coriandrum sativum*, 267 L/t in *Salvia hispanica*, 389 L/t in *Silphium perfoliatum* (control), and 299 L/t in *Brassica napus oleifera* substrates. Theoretical ethanol yields from pentose sugars were lower across all species, with values of 170 L/t for *Coriandrum sativum* and *Silphium perfoliatum*, 158 L/t for *Lavandula angustifolia*, 135 L/t for *Salvia hispanica*, and 131 L/t for *Brassica napus oleifera*.

Several sources in the literature describe the cell wall composition of the studied plant species and their corresponding calculated ethanol yields. Greenhalf et al. (2012) reported that rapeseed straw contained 37.55% cellulose, 31.37% hemicellulose, 21.30% lignin, 3.76% solubles, and 6.02% ash. Srivastava et al. (2014) stated that the biomass of coriander stalks and leaves contained 15.93% cellulose, 11.38% hemicellulose, and 4.51% lignin. Lesage-Meessen et al. (2015) noted that lavandin branch biomass contained 33.6% cellulose, 13.9% hemicellulose, and 25.4% lignin in winter, and 42.7% cellulose, 13.0% hemicellulose, and 23.1% lignin in summer. Tripathi et al. (2017) reported that coriander straw contained 7.43% crude protein, 73.18% NDF, 56.54% ADF, 48.0% cellulose, 8.77% lignin, and 6.64 MJ/kg metabolizable energy. Lesage-Meessen et al. (2018) found that lavandin distilled straw contained 6.85% moisture, 25.64% acid-insoluble lignin, 29.81% hemicelluloses and pectins, 0.36% rhamnose, 1.80% arabinose, 14.20% xylose, 1.06% mannose, 1.32% galactose, 14.51% glucose, 6.58% galacturonic acid, and 16.06% cellulose. In comparison, lavender distilled straw had 7.15% moisture, 24.99% acid-insoluble lignin, 27.82% hemicelluloses and pectins, 0.42% rhamnose, 1.56% arabinose, 13.14% xylose, 1.15% mannose, 1.32% galactose, 3.16% glucose, 7.05% galacturonic acid, and 17.49% cellulose. Ferdous et al. (2020) reported that chia stalk contained 23.2% lignin, 2.73% acid-soluble lignin, 60.5% holocellulose, 30.5% alpha-cellulose, 13.22% pentosane, and 2.58% ash. In contrast, lentil stalk contained 23.8% lignin, 3.57% acid-soluble lignin, 59.9% holocellulose, 23.8% alpha-cellulose, 15.20% pentosane, and 6.78% ash. Angelova et al. (2021) revealed that the proximate composition of lavender straw biomass was 38.16% cellulose, 24.48% lignin, 13.79% non-cellulosic polysaccharides, and 6.59% ash. Uitterhaegen et al. (2020, 2021) reported that coriander straw contained 8.9% moisture. In the dry matter, they determined 52.5% cellulose, 21.2% hemicelluloses, 9.8% lignin, 10.4% hot-water extractives, 4.2% minerals, 3.7% proteins and 0.8% lipids. Pulidori et al. (2023) found that the composition of aromatic plant waste was as follows: lavender waste contained 41% cellulose, 23% hemicellulose, and 16% lignin; rosemary - 32% cellulose, 25% hemicellulose and 26% lignin; thyme - 37% cellulose, 23% hemicellulose and 24% lignin; *Artemisia vulgaris* - 43% cellulose, 21% hemicellulose and 17% lignin; and *Ruta chalepensis* - 35% cellulose, 24% hemicellulose and 22% lignin. Tóth Š. (2023) reported that the lignocellulosic composition of *Silphium perfoliatum* green phytomass was as follows: 31.32-48.94% ADF, 34.94-54.69% NDF, 7.21-12.54% ADL, 24.11-37.30% cellulose and 2.33-5.75% hemicellulose.

CONCLUSIONS

Coriandrum sativum, *Salvia hispanica*, and *Lavandula angustifolia* are characterized by an extended flowering period, providing forage for bees from late May to mid-August, with honey potential ranging from 60 to 330 kg/ha.

The dry biomass of *Lavandula angustifolia* is notable for its very high carbon content, low sulphur content, optimal ash levels, and high energy value, compared to the biomass of *Salvia hispanica* and *Coriandrum sativum*. Pellets produced from *Lavandula angustifolia* biomass exhibited a high net calorific value, along with superior bulk density and mechanical durability.

The biochemical methane potential of substrate derived from *Salvia hispanica* reached 280 L/kg, significantly higher than that of the other substrates studied. The theoretical ethanol yield from hexose and pentose sugars averaged 533 L/t in *Lavandula angustifolia*, 518 L/t in *Coriandrum sativum*, and 398 L/t in *Salvia hispanica*.

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