ENERGY VALUE OF AGRICULTURAL RESIDUES FROM SOME *BRASSICACEAE* AND *POACEAE* SPECIES GROWN IN MOLDOVA
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VALOAREA ENERGETICĂ A RIZIDURILOR AGRICOLE A UNOR SPECII DE BRASSICACEAE ȘI POACEAE CULTIVATE ÎN MOLDOVA

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ABSTRACT
The utilization of phytomass derived from energy crops and agricultural residues for bioenergy production has attracted increasing attention in recent years, particularly in the context of rising fossil fuel prices. This study aimed to evaluate the quality indices of phytomass – agricultural residues remaining after seed harvesting – from several Brassicaceae species (Brassica napus (rapeseed), Bunias orientalis (Turkish warty cabbage), Isatis tinctoria (woad), and Sinapis alba (white mustard)) and Poaceae species (Dactylis glomerata (orchard grass), Lolium perenne (perennial ryegrass), and Zea mays (maize)), cultivated in the experimental sector of the "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, in order to assess their suitability as feedstock for the production of biogas/biomethane, bioethanol, and solid biofuels (pellets). The results showed that the phytomass collected after seed harvesting from the investigated Brassicaceae and Poaceae species contained 36.30–98.80 g/kg crude protein, 51.00–88.00 g/kg acid detergent lignin, 363.00–424.00 g/kg cellulose, 191.00–299.00 g/kg hemicellulose, and 44.00–71.40 g/kg ash. The analysed phytomass substrates exhibited a carbon-to-nitrogen (C/N) ratio ranging from 29 to 73, with a biochemical biomethane potential of 232–314 L/kg of dry organic matter, while the theoretical ethanol production potential varied between 430 and 523 L/t of organic matter. The solid biofuel produced in the form of pellets showed a net calorific value of 14.55–15.70 MJ/kg, a bulk density of 528–832 kg/m³, and a mechanical durability of 90–97%. Overall, the agricultural residues generated after seed harvesting from the examined Brassicaceae and Poaceae species represent a versatile and promising raw material for renewable energy production in the Republic of Moldova.

REZUMAT
Valorificarea fitomasei din culturi energetice și reziduuri agricole în bioenergie a atras o atenție tot mai mare în ultimii ani în contextul creșterii galopante a prețurilor la resursele energetice fosile. Scopul acestei cercetări a fost evaluarea indicilor de calitate ai fitomasei - reziduuri agricole după recoltarea semințelor, de la speciile de Brassicaceae: rapița (Brassica napus), brăbin Bunias orientalis, drobușor Isatis tinctoria, muștarul alb Sinapis alba și de la speciile de Poaceae: golomăț Dactylis glomerata, raigrasul peren Lolium perenne și porumbul Zea mays, cultivate în sectorul experimental al Grădinii Botanice Naționale (Institutul) „Alexandru Ciubotaru" a Universității de Stat din Moldova, ca materie primă pentru producerea de biogaz - biometan, biocombustibil lichid - bioetanol și combustibil solid – peleți, ca energie regenerabilă. S-a stabilit că fitomasa colectată după recoltarea semințelor de la speciile de Brassicaceae și Poaceae investigate are un conținut de 36.30-98.80 g/kg proteină brută, 51.00-88.00 g/kg acid detergent lignin, 363.00-424.00 g/kg celuloză, 191.00-299.00 g/kg hemiceluloză și 44.00-71.40 g/kg cenușă. Substraturile de fitomasă investigate au un raport carbon azot C/N = 29-73 cu un potențialul biochimic de biometan care variază de la 232 până la 314 l/kg materie organică uscată, iar potențialul teoretic de obținere a etanolului variază de la 430 la 523 L/t materie organică. Combustibilul solid preparat în formă de peleți, posedă o valoare calorică netă de 14.55-15.70 MJ/kg, densitate în vrac de 528-832 kg/m³ și durabilitate mecanică de 90-97%. Fitomasa - reziduuri agricole după recoltarea semințelor, de la speciile investigate de Brassicaceae și Poaceae poate fi valorificată ca materie primă cu utilitate multiplă pentru producerea energiei regenerabile în Republica Moldova.

INTRODUCTION

The high volatility in coal, petroleum, and natural gas prices, together with environmental challenges such as climate change associated with their use, has intensified interest in alternative renewable energy feedstocks with broader geographic availability and lower costs. These include waste biomass, agricultural and forestry residues, and dedicated energy crops. The use of agricultural residues remaining after seed harvesting as raw materials in biorefineries represents a promising alternative to fossil resources for the production of energy carriers and chemicals, thereby contributing to climate change mitigation and enhanced energy security. The conversion of agricultural residues into bioenergy has received increasing attention in recent years, particularly because these feedstocks do not compete with food production and support the transition toward a circular bioeconomy. Consequently, this research area continues to attract substantial scientific interest worldwide (*Akter et al. 2024; Andersen et al. 2021; Casau et al. 2022; Cherubini and Ulgiati, 2010; El-Araby, 2024; Greenhalf et. al., 2012 Gudîma, 2017; Habashescu and Cerempei, 2012; Isikgora and Remzi Becer, 2015; Kumar and Murthy, 2011; Maj et. al., 2019; Marian et. al. 2022; Pavlenco. et al. 2018; Stolarski et al., 2019, Stolarski et al., 2024; Ye et al. 2024*).

Brassicaceae is one of the most important plant families, comprising 338 genera and 3,709 species distributed worldwide. In the spontaneous flora of Bessarabia, the *Brassicaceae* family is represented by 49 genera and 97 species. This family includes numerous economically important species, cultivated for edible uses, industrial oilseeds, condiments, fodder, and as vegetables. *Poaceae* is the second-largest monocotyledonous family, comprising more than 11,000 species, some of which have been used as cereal and pasture plants since the Neolithic period. In the "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, various *Brassicaceae* and *Poaceae* species have been studied over the past decades for their potential as food and fodder plants, melliferous resources and energy crops (*Cerempei et. al., 2022, Cerempei et. al., 2023a; Cerempei et. al., 2023b; Cîrlig et. al., 2023, Cîrlig et. al., 2024; Cozari et. al., 2022; Doroftei et. al., 2021; Nazare and Ţîţei, 2025; Ţîţei, 2016, Ţîţei, 2022; Ţîţei, 2025; Țîței and Roșca, 2021*).

The aim of this research was to evaluate the quality indices of phytomass – agricultural residues remaining after seed harvesting – from selected *Brassicaceae* and *Poaceae* species as feedstock for the production of biogas (biomethane), liquid biofuels (bioethanol), and solid biofuels (pellets) as renewable energy sources.

MATERIALS AND METHODS

The *Brassicaceae* species: canola or rapeseed (*Brassica napus)*, Turkish warty-cabbage *Bunias orientalis*, dyer's woad *Isatis tinctoria,* white mustard *Sinapis alba* and *Poaceae* species: orchard grass *Dactylis glomerata*, perennial ryegrass *Lolium perenne* and corn or maize *Zea mays*, cultivated in the experimental plots of the "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University (NGBNI), Chișinău, were selected as the subjects of this research. After seed harvesting, the residual biomass was collected and chopped into small pieces (2–3 cm) using a chopping unit. The chopped biomass was subsequently milled in a beater mill equipped with a sieve having a mesh size of 6 mm. For analysis, samples were oven-dried at 85°C, ground to <1 mm, and homogenized. The biochemical composition of the biomass was evaluated by analysing the following indices: crude protein (CP), crude ash (CA), acid detergent fibre (ADF), neutral detergent fibre (NDF), and acid detergent lignin (ADL). These parameters were determined using near-infrared spectroscopy (NIRS) with the PERTEN DA 7200 analyser at the Research and Development Institute for Grassland, Braşov, Romania. Additional parameters - cellulose content was calculated as ADF minus ADL, and hemicellulose – as NDF minus ADF. The biochemical methane potential (BMP) was calculated following the method described by *Dandikas et al., (2015)*. The Theoretical Ethanol Potential (TEP) was calculated based on the equations proposed by *Goff et al., (2010)*, considering the conversion of cellulose and hemicellulose into hexose (H) and pentose (P) sugars. Elemental composition, specifically, the total carbon (C), hydrogen (H), nitrogen (N), and sulphur (S) content, was determined by dry combustion using a Vario Macro CHNS analyser. Biomass densification was carried out using pelleting equipment MLG 200. The ash and volatile matter content, energy value of both the dry biomass and the resulting pellets, also bulk density and durability of pellets were measured according to standardized protocols at the Scientific Laboratory of Biosolid Fuel, Technical University of Moldova *(Marian, 2016*).

RESULTS AND DISCUSSIONS

Plant biomass (phytomass) can be effectively converted into various types of biofuels suitable for transportation, heating, and electricity generation. The biochemical composition of biomass derived from energy crops, as well as forestry and agricultural residues, plays a critical role in determining its suitability as a feedstock for renewable biofuel production. The biochemical composition of the investigated lignocellulosic phytomass samples is summarized in Table 1. Notably, the ash content in *Zea mays* straw was significantly lower than in the other species. The phytomass from *Bunias orientalis*, *Dactylis glomerata*, and *Lolium perenne* exhibited higher levels of both crude protein and ash. The content of fibrous components and lignin varied significantly among species. Lower levels of acid detergent lignin (ADL) were found in *Lolium perenne* and *Dactylis glomerata*, whereas substantially higher ADL concentrations were observed in the *Brassicaceae* species and *Zea mays* biomass. Among the *Brassicaceae* species, *Isatis tinctoria* showed the highest cellulose content, while the other species did not differ significantly. Within the *Poaceae* species, *Dactylis glomerata* had the highest cellulose content, and *Lolium perenne* the lowest. Additionally, the *Poaceae* straws exhibited higher hemicellulose levels compared to the *Brassicaceae* species. Among the *Brassicaceae* species, *Isatis tinctoria* was particularly rich in both cellulose and hemicellulose.

Table 1

Biochemical composition of the dry phytomass from the studied *Brassicaceae* and *Poaceae* species

Indices	*Brassicaceae*				*Poaceae*		
	Brassica napus	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*	*Dactylis glomerata*	*Lolium perenne*	*Zea mays*
Ash, [g/kg DM]	*58.50*	*64.00*	*60.40*	*54.80*	71.40	68.30	44.00
Organic matter, [g/kg DM]	*941.50*	*936.00*	*939.60*	*945.20*	*929.00*	*932.00*	956.00
Crude protein, [g/kg DM]	*58.00*	*76.30*	*38.30*	*98.80*	*64.00*	*63.00*	59.40
Acid detergent fibre, [g/kg DM]	484.00	489.00	512.00	484.00	498.00	414.00	499.00
Neutral detergent fibre, [g/kg DM]	675.00	682.00	738.00	701.00	797.00	681.00	749.00
Acid detergent lignin, [g/kg DM]	83.00	86.00	88.00	83.00	64.00	51.00	87.00
Cellulose, [g/kg DM]	401.00	403.00	424.00	401.00	434.00	363.00	417.00
Hemicellulose, [g/kg DM]	191.00	193.00	226.00	217.00	299.00	267.00	250.00

Multiple studies have provided data on the biochemical composition of the biomass from the examined *Brassicaceae* and *Poaceae* species. According to *Akgül et al., (2018),* canola stalks contain 72.10% holocellulose, 42.55% α-cellulose, 13.15% lignin and 8.2% ash. *Barbash et al., (2011),* mentioned that *Brassica napus* stalks had 3.2% ash, 29.6 % pentosans, 37.7 % cellulose, 26.4% lignin, while *Bunias orientalis* stalks had 5.1% ash, 19.9 % pentosans, 34.3 % cellulose, 22.2% lignin, but *Triticum aestivum* straw had 4.2% ash, 26.4 % pentosans, 46.2 % cellulose, 18.6% lignin. *Bohnert et al., (2011),* remarked that crude protein concentration in perennial ryegrass straw was 6.0%, but in orchardgrass straw – only 4.8%. *Cerempei et al., (2022),* reported that straw collected from the studied cultivars of *Festuca species* contained 28-83 g/kg CP, 417-562 g/kg CF, 469-595 g/kg ADF, 720-889 g/kg NDF, 60-91 g/kg ADL, 0-60 g/kg TSS, 251-294g/kg HC, 406-504 g/kg Cel, while oat straw - 62 g/kg CP, 487 g/kg CF, 82 g/kg ash, 499 g/kg ADF, 800 g/kg NDF, 56 g/kg ADL, 443 g/kg Cel, 301 g/kg HC, 161 g/kg TSS, respectively. *Chen et al., (2018),* reported that rapeseed biomass after the seeds had been collected had 51.15 g/kg CP, 114.48 g/kg WSC, 33.07 g/kg ADF, 47.34 g/kg NDF. *Comlekcioglu et al., (2018),* remarked that stalks from *Isatis tinctoria* had 4.9% ash, 67.1 % holocellulose, 48.5% α-cellulose, 23.9 % lignin and 4.9% extractives, while from *Isatis buschiana* – 11.1% ash, 70.1 % holocellulose, 32.9% α-cellulose, 19.9 % lignin and 4.1% extractives. *Dell'Omo, (2025),* reported that corn stover had 487 g/kg ADF, 794g/kg NDF, 89 g/kg ADL. *Doroftei et al., (2021)*, mentioned that the biochemical composition of grass straws included the following: 36-83 g/kg CP, 400-555 g/kg CF, 46-98 g/kg ash, 647-918 g/kg NDF, 424-604 g/kg ADF, 53-86 g/kg ADL, 371-518 g/kg Cel, 223-314 g/kg HC, but wheat straw – 37 g/kg CP, 488 g/kg CF, 498 g/kg ADF, 775 g/kg NDF, 68 g/kg ADL, 430 g/kg Cel, 277 g/kg HC, 45 g/kg ash, and 13 g/kg TSS. *Dukarska et al., (2011),* reported that the chemical composition of white mustard straw consisted of 36.70% cellulose, 21.10% lignin, 3.46% extractive substances, and 5.60% mineral substances. *Fisher, (2004),* stated that perennial ryegrass straw contained 4.6% CP, 63.0% NDF, and 33.0% ADF. *Greenhalf et al., (2012),* found that rapeseed straw comprised 37.55% cellulose, 31.37% hemicellulose, 21.30% lignin, 3.76% solubles, and 6.02% ash. *Hajj Obeid et al., (2022),* reported that the chemical composition of rapeseed straw ranged between 51.40–55.20% cellulose, 9.30–15.00% hemicellulose, 8.40–10.90% lignin, 20.90–29.90% solubles, and 0.40–0.90% inorganic materials. *Hejduk and Macháč, (2019),* noted that nutrient concentrations in perennial ryegrass straw were 71.3 g/kg ash, 81.4 g/kg CP, 382 g/kg CF, 629 g/kg NDF, 412 g/kg ADF, and 217 g/kg HC. In comparison, Italian ryegrass straw contained 68.3 g/kg ash, 64.1 g/kg CP, 399 g/kg CF, 656 g/kg NDF, 442 g/kg ADF, and 215 g/kg HC. *Isikgora and Remzi Becer, (2015),* observed that the chemical composition of grass straw generally consisted of 25.0–40.0% cellulose, 25.0–50.0% hemicellulose, and 10.0–30.0% lignin. For wheat straw, the corresponding values were 35.0–39.0% cellulose, 23.0–30.0% hemicellulose, and 12.0–16.0% lignin. *Khan et al., (2024),* reported that maize stalks contained 41.43% cellulose, 26.10% hemicellulose, and 8.13% lignin. *Kiro, (2015),* revealed that rapeseed straw was composed of 72.28% holocellulose, 45.39% α-cellulose, 19.43% lignin, 3.32% solubles, and 4.27% ash. In contrast, wheat straw contained 73.75% holocellulose, 39.17% α-cellulose, 21.65% lignin, 4.57% solubles, and 5.53% ash. *Li et al., (2014),* found that maize stover had a dry matter content of 933.8 g/kg, with 95.16% OM, 4.05% CP, 1.31% EE, 71.93% NDF, 41.36% ADF, and 6.16% ADL. *Nasir and Kamaruddin, (2023),* determined that kernel corn stalk dry matter contained 4.09% CP, 0.47% fat, 2.22% ash, 27.23% CF, and 60.99% nitrogen-free extract (NFE). For sweet corn stalks, the composition was 10.47% CP, 1.32% fat, 4.56% ash, 27.05% CF, and 51.42% NFE. *Petersson et al., (2007),* found that oilseed rape straw had 907 g/kg DM, with a chemical composition of 27.3% glucan, 15.0% xylan, 2.7% galactan, 2.0% mannan, 2.2% arabinan, 14.2% Klason lignin, 9.6% ash, 10.1% extractives, and 17.0% residual material. *Potucek et al., (2014),* reported that rapeseed stalks contained 4.45% ash, 76.15% holocellulose, 33.90% cellulose, 28.83% α-cellulose, and 21.35% lignin. The valves of siliques contained 7.83% ash, 71.59% holocellulose, 28.35% cellulose, 25.73% α-cellulose, and 14.14% lignin. *Stanisavljević et al., (2009),* reported that, depending on mineral fertilizer application and plant spacing, the straw yield of *Dactylis glomerata* ranged from 1.24 to 3.09 t/ha DM, with 1.81–5.27% CP, 81.58–94.86% NDF, and 44.94–55.29% ADF. *Viel et al., (2018),* indicated that the chemical composition of rapeseed straw was 53.06% cellulose, 18.13% hemicellulose, 9.63% lignin, 17.68% solubles, and 0.79% ash. *Wattanaklang et al., (2016),* stated that maize stover contained 5.8% CP, 27.38% CF, 1.90% EE, and 20.8% ash. *Witaszek et al*., *(2025),* noted that *Brassica napus* straw contained 49.22–66.52% ADF and 59.52–80.99% NDF, while *Triticum aestivum* straw contained 45.95–52.84% ADF and 77.07–87.09% NDF. *Youngberg and Vough, (1977),* reported that perennial ryegrass straw contained 2.5–7.2% CP, 72.1% NDF, and 41.7–52.6% ADF. Orchardgrass straw had 3.1–7.2% CP, 79.0% NDF, and 44.0–53.8% ADF. Wheat straw contained 1.8–3.7% CP and 52.1–56.9% ADF. *Zhou et al., (2019),* found that sweet corn stover contained 72.3 g/kg CP, 18.1 g/kg EE, 134.1 g/kg WSC, 667.8 g/kg NDF, 426.3 g/kg ADF, and 80.8 g/kg starch.

The utilization of biomass as a fuel source for energy production necessitates the characterization of its elemental chemical components. The elemental composition of biomass is a critical factor that influences its energy content, environmental impact, and overall efficiency in energy conversion processes. It also provides essential parameters for the design and assessment of various thermochemical conversion systems and projects. The primary elemental constituents of dry biomass are carbon (C), oxygen (O), and hydrogen (H). During combustion, the oxidation of carbon and hydrogen releases energy, with carbon contributing most significantly to the overall heating value. Additionally, a higher hydrogen content is associated with an increased net calorific value. In contrast, the presence of nitrogen (N), sulphur (S), and chlorine (Cl) in biomass is undesirable due to their role in generating air pollutants during combustion. Elevated concentrations of these elements typically result in higher emissions of harmful compounds. The energy released during combustion is positively correlated with the carbon and hydrogen content, while high levels of oxygen and nitrogen generally lead to a reduction in calorific value. The elemental composition of the dry phytomass from the studied species is presented in Table 2. Our findings indicate that carbon and hydrogen concentrations did not vary significantly among the samples, although relatively higher levels were observed in *Brassica napus*, *Bunias orientalis*, *Sinapis alba*, and *Dactylis glomerata* compared to *Zea mays*, *Isatis tinctoria*, and *Lolium perenne*. Phytomass from *Bunias orientalis* and *Sinapis alba* exhibited particularly high concentrations of nitrogen and sulphur. Additionally, a notably high sulphur content was detected in *Zea mays* straw biomass.

Table 2

The elemental composition of the dry phytomass from the studied *Brassicaceae* and Poaceae species

Indices	*Brassicaceae*				*Poaceae*		
	Brassica napus	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*	*Dactylis glomerata*	*Lolium perenne*	*Zea mays*
Carbon, [% DM]	45.60	45.24	44.36	45.64	45.18	44.86	44.06
Nitrogen, [% DM]	0.92	1.22	0.61	1.58	1.02	1.01	0.95

Indices	*Brassicaceae*				*Poaceae*		
	Brassica napus	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*	*Dactylis glomerata*	*Lolium perenne*	*Zea mays*
Hydrogen, [% DM]	5.14	5.17	4.99	5.12	5.02	4.98	5.65
Sulphur, [% DM]	0.07	0.19	0.13	0.23	0.09	0.11	0.21
Oxygen, [% DM]	48.30	48.18	49.91	47.43	48.69	49.04	49.13

Several authors have reported varying results concerning the elemental indices of biomass. *Cástková et al., (2018),* found that unmodified rapeseed straw contained 1,340 mg/kg of sulphur, whereas modified straw contained between 323 and 436 mg/kg. *Gao et al., (2017),* reported that rapeseed stalk consisted of 47.47% C, 5.96% H, 41.09% O, 0.47% N, and 0.22% S. *Greenhalf et al., (2012),* indicated that rapeseed straw contained 48.35% C, 5.80% H, 1.15% N, and 44.70% O. Similarly, *Stolarski et al., (2019),* found that rapeseed straw contained 46.89% C, 5.46% H, 1.26% N, 0.315% S, and 0.418% Cl. *Kachel et al., (2020),* reported that rapeseed straw pellets had a composition of 47.42% C, 5.38% H, 1.15% N, 0.78% S, and 0.84% Cl. *Stolarski et al., (2024),* determined that rapeseed straw contained 43.41–45.70% C, 5.12–5.61% H, 0.97–1.18% N, 0.193–0.394% S, and 0.233–0.425% Cl. According to *Stolarski et al., (2025)*, rapeseed biomass pellets were characterized by 48.38% C, 6.04% H, 0.84% N, 0.19% S, and 0.071% Cl.

Organic compounds from renewable raw materials like plant biomass (phytomass) are increasingly central to research in renewable energy and the circular economy. Phytomass serves as a key feedstock for bioconversion, with microorganisms converting organic compounds proteins, cellulose, hemicellulose, and lignin into bio-based products such as biomethane, bioethanol, butanol, and acetone.

One such promising renewable energy sources is the generation of biogas through anaerobic fermentation. This process is increasingly recognized as a sustainable energy solution with a wide array of environmental and socio-economic benefits. Biogas production plays a significant role in reducing greenhouse gas emissions, thereby contributing to climate change mitigation. Additionally, it aids in the destruction of harmful pathogens, promotes the recycling of nutrients, and can stimulate economic growth at both regional and local levels by creating jobs and supporting agricultural development. In biogas reactors, organic material derived from various sources, such as biomass, agricultural residues, organic waste, or wastewater, is biologically broken down in the absence of oxygen. This anaerobic digestion process results in the formation of biomethane (the primary energy component of biogas), along with carbon dioxide and other by-products such as hydrogen sulphide, ammonia, and digestate. While biomethane serves as a clean and renewable energy source, the resulting digestate is rich in nutrients and can be utilized as a valuable organic fertilizer in agriculture, further closing the loop in sustainable resource use.

The carbon-to-nitrogen (C/N) ratio and biomethane potential of the biomass substrates from the studied species are presented in Figures 1–3.

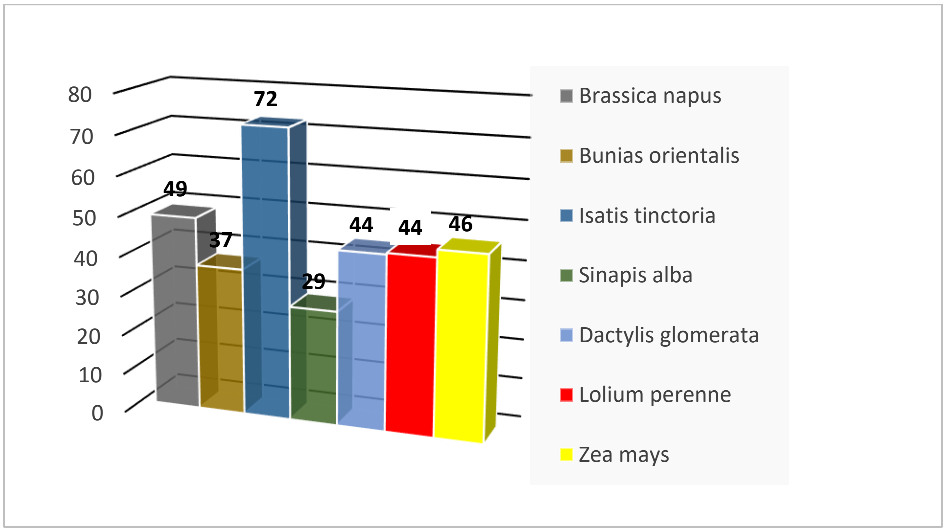

Fig. 1 - Carbon/ Nitrogen ratio

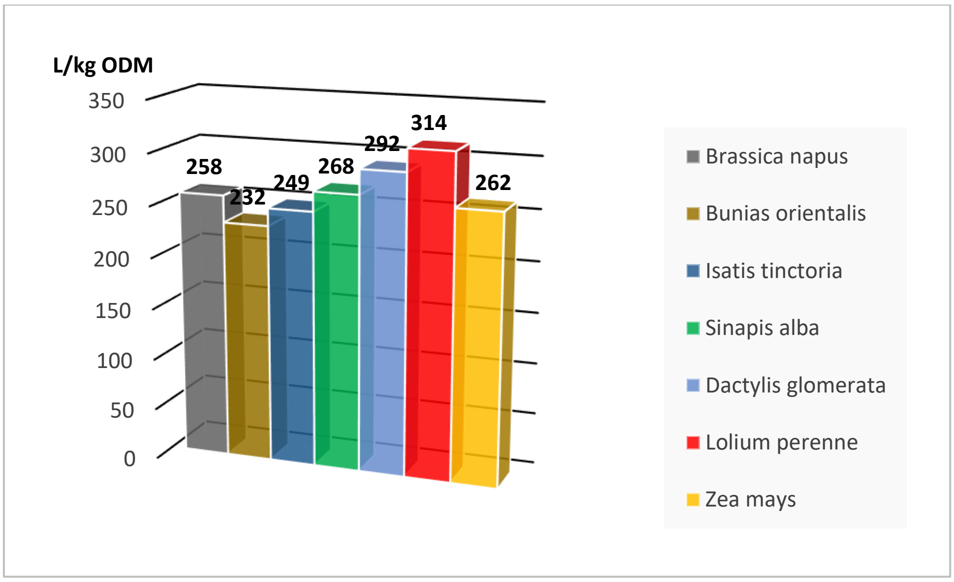

Fig. 2 - Biomethane potential, L/kg ODM

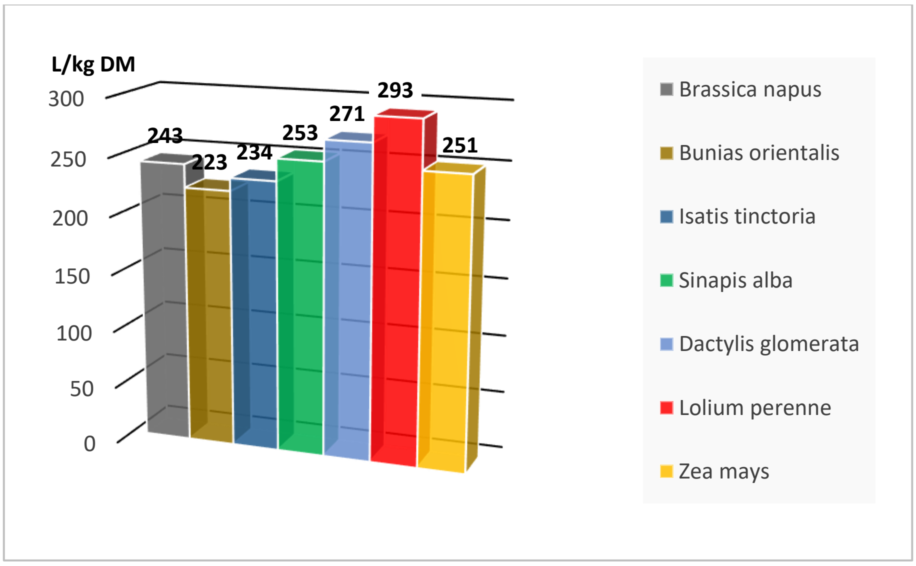

Fig. 3 - Biomethane potential, L/kg DM

The C/N ratio in the investigated biomass substrates ranged from 29.98 to 72.72 in Brassicaceae species and from 44.12 to 46.38 in Poaceae species. Substrates from *Sinapis alba* and *Bunias orientalis* exhibited an optimal C/N ratio, while the substrate from *Isatis tinctoria* showed a significantly higher value. The biochemical methane potential (BMP) of the substrates ranged from 232 to 314 L/kg ODM and from 223 to 293 L/kg DM. Notably, the BMP of *Dactylis glomerata* and *Lolium perenne* substrates was significantly higher compared to those of the *Brassicaceae* species and *Zea mays*, likely due to their higher hemicellulose content and lower lignin levels.

Several studies have reported data on the biomethane production potential of straw-based substrates. *Carchesio et al., (2014),* observed that substrates derived from *Isatis tinctoria* achieved a net methane yield of 153.1 L/kg VS during anaerobic digestion, with an estimated conversion degree of 33%. *Dell'Omo, (2025),* found that methane yield and biogas composition of corn stover raw material was 199.6 m^3/t VS and 52.0%, but from corn stover pretreated material respectively 219.8 m^3/t VS and 51.1%. *Doroftei et al., (2021),* reported that grass straw substrates used for anaerobic digestion exhibited C/N ratios ranging from 37 to 92, with biochemical methane potentials between 254 and 313 L/kg ODM; for wheat straw, a BMP of 282 L/kg ODM was recorded. *Gaballah et al., (2020),* found that combined pre-treatment of rapeseed straw resulted in a methane yield of 305.7 L/kg VS, representing a 77.84% increase compared to untreated rapeseed straw. *Guo and Liang, (2025),* noted that, under optimal conditions, the methane yield of rapeseed straw can reach up to 365 L/kg VS. *Mazurkiewicz et al., (2019),* reported that the methane productivity of maize straw substrates ranged from 201 to 207 m³/t. *Petersson et al., (2007),* found that biogas yields from oilseed rape straw, winter rye straw, and faba bean straw were 420 L/kg VS, 360 L/kg VS, and 440 L/kg VS, respectively. In our previous works (*Ţîţei, 2016; Ţîţei, 2021; Ţîţei, 2022a; Ţîţei, 2022b*), it was established that the biochemical biomethane production potential of the fresh or ensiled substrates from *Isatis tinctoria* varied from 242 to 251/kg VS L/kg organic matter, from *Brassica napus* – 303-324 L/kg, and from *Sinapis alba,* it reached 273-330 L/kg organic matter. *Vishnevskaya, (2017),* noted that the substrates derived from *Dactylis glomerata* achieved methane yields 237-241 l/kg VS. *Witaszek et al., (2025),* reported that straw substrates derived from *Triticum aestivium* had 45.95-52.84% ADF, 77.07-87.09% NDF and methane yields varied from 200.8 to 272.08L/kg VS, while from *Brassica napus* methane, yields varied from 86.69 to 202.06 L/kg VS.

Second-generation ethanol produced from lignocellulosic biomass represents a promising alternative to fossil fuels due to its low cost, broad availability, and reduced greenhouse gas emissions. Liquid biofuels – namely, cellulosic bioethanol, biobutanol, and biodiesel – are therefore of significant interest to researchers, industry stakeholders, and governments. Among these, cellulosic bioethanol is considered a particularly viable drop-in fuel capable of replacing gasoline in the transportation sector. Ethanol use in internal combustion engines presents several advantages over gasoline: it has a higher octane number, which improves resistance to engine knocking; it has a lower freezing point; and it generates lower CO_2 emissions. The production of cellulosic ethanol via biological conversion involves three key stages: (1) pretreatment of lignocellulosic biomass, (2) enzymatic hydrolysis of structural polysaccharides (e.g., cellulose and hemicellulose) into sugar monomers (hexoses and pentoses), and (3) fermentation of these sugars into ethanol (*Kumar & Murthy*, *2011*). Ethanol yield and production efficiency depend on multiple factors, including biomass type, plant species, variety, growth conditions, and maturity at harvest. The results of the present study concerning the theoretical bioethanol potential of the examined lignocellulosic substrates are presented in Figures 4-6. The theoretical ethanol yield from hexose sugars ranged from 275 to 328 L/ton organic matter, while that from pentose sugars ranged from 131 to 205 L/ton organic matter. Substrates derived from *Dactylis glomerata*, *Zea mays*, and *Isatis tinctoria* demonstrated the highest theoretical ethanol potential. In contrast, substrates from *Brassica napus* and *Bunias orientalis* exhibited significantly lower potential, with no substantial differences observed between them.

Various authors have reported different results regarding the ethanol potential of lignocellulosic substrates. *Guo and Liang, (2025),* determined that, under optimal conditions, ethanol output from pre-treated rapeseed straw reached 12.2 g/L. *Sveinsson and Hermannsson, (2010),* estimated that ethanol production from *Phleum pratense* (timothy grass) lignocellulosic biomass was approximately 0.27 L/kg DM. *Kumar and Murthy, (2011),* reported an ethanol potential of 360.57 L/ton from *Festuca arundinacea* straw. According to *Orlygsson, (2013)*, timothy grass substrates yielded approximately 4.2 mM ethanol/g DM, equivalent to 0.24 L/kg DM, or an estimated 1200–1700 L/ha. *Hálfdánarson, (2015),* reported ethanol production efficiencies from *Phleum pratense* second-cut biomass at 346 L/t, while third-cut and fourth-cut biomass yielded 298 and 313 L/t DM, respectively. *Tang et al., (2019),* noted that *Pennisetum alopecuroides* straw, which contained 41.8% cellulose, 28.7% hemicellulose, and 17.5% lignin, achieved an ethanol yield of 744 mg/g after alkaline pretreatment. *Goff et al., (2010),* reported that the theoretical ethanol potential of sorghum biomass ranged from 560 to 610 L/t of dry biomass. *Doroftei et al., (2021),* estimated that theoretical ethanol yields from grass straw substrates ranged from 432 to 605 L/t, while wheat straw yielded approximately 513 L/t. Similarly, *Cerempei et al., (2022),* reported that theoretical ethanol potential for *Festuca* species ranged from 477 to 580 L/t DM, and for oat straw, it reached 541 L/t DM.

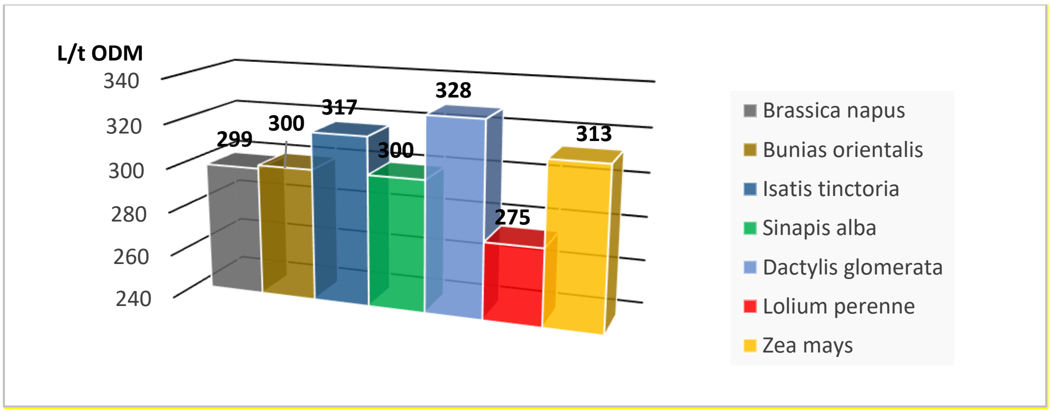

Fig. 4 - Theoretical ethanol potential from hexose sugars, L/t ODM

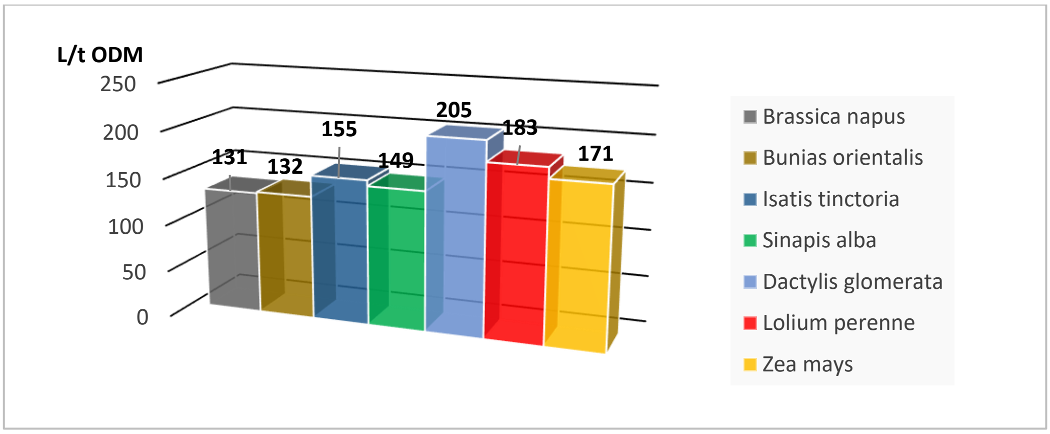

Fig. 5 - Theoretical ethanol potential from pentose sugars, L/t ODM

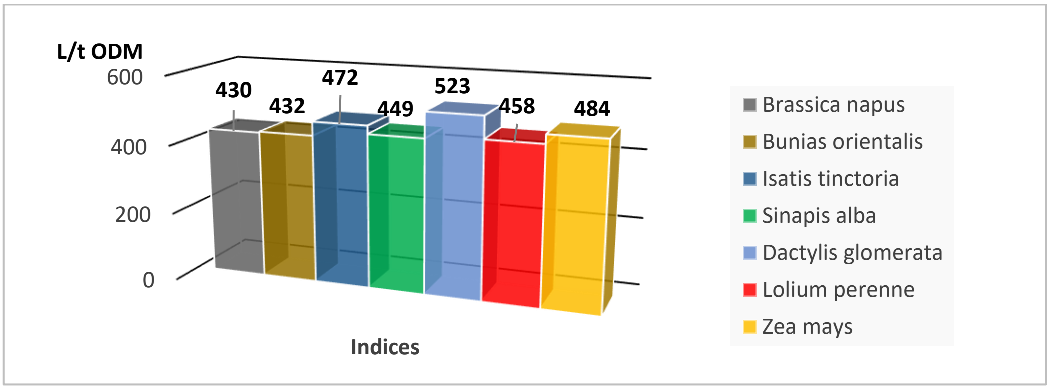

Fig. 6 - Theoretical ethanol potential of biomass, L/t ODM

The valorisation of energy biomass in the form of solid fuels, such as pellets and briquettes, is commonly preferred due to several advantages: it reduces biomass volume, lowers transportation costs, improves handling, and increases energy density per unit of volume. Among the available densification methods, pelletisation is considered one of the most economically advantageous. Densified solid fuels like pellets also offer structural uniformity, making them particularly suitable for use in automated boiler systems in households, schools, kindergartens, and other public institutions. Selected physical and mechanical properties of straw biomass and the resulting pellets are presented in Table 2. Ash content is a critical parameter in determining the quality of solid biofuels, as high ash levels can reduce combustion efficiency, accelerate corrosion, promote clinker formation in combustion chambers, and contribute to wear and physical damage in heating systems. A relatively high ash content, ranging from 6.04% to 7.14%, was observed in the biomass of *Dactylis glomerata*, *Lolium perenne*, *Bunias orientalis* and *Isatis tinctoria*, whereas lower values were recorded in *Sinapis alba* and *Zea mays* biomass (4.40–5.48%). The volatile matter content in the studied straw samples ranged from 76.28% in *Lolium perenne* to 80.04% in *Zea mays*. Pellets produced from *Brassica napus*, *Sinapis alba*, and *Dactylis glomerata* exhibited optimal energy values – higher than those of *Zea mays* and *Lolium perenne* straw pellets, with *Sinapis alba* pellets showing a notably low ash content of 2.1%, significantly lower than that of *Zea mays* and *Lolium perenne*. The bulk density of the pellets ranged from 528 kg/m³ for *Bunias orientalis* to 832 kg/m³ for *Sinapis alba*. Mechanical durability varied from 89.91% for *Bunias orientalis* pellets to 97.33% for *Isatis tinctoria*. The durability of pellets from *Sinapis alba* and *Zea mays* did not differ significantly and was higher than that of pellets produced from *Brassica napus* and *Dactylis glomerata*.

Table 3

Some physical and mechanical properties of biomass and pellets from the studied *Brassicaceae* and *Poaceae* species

Indices	*Brassicaceae*				*Poaceae*		
	Brassica napus	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*	*Dactylis glomerata*	*Lolium perenne*	*Zea mays*
Ash content of biomass, [%]	5.85	6.40	6.04	5.48	7.14	6.83	4.40
Volatile matter, [%]	77.14	78.25	78.61	77.07	78.65	76.28	80.04

Indices	*Brassicaceae*				*Poaceae*		
	Brassica napus	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*	*Dactylis glomerata*	*Lolium perenne*	*Zea mays*
Gross calorific value of biomass, [MJ/kg]	18.60	18.45	18.34	18.57	18.45	18.04	17.84
Net calorific value of biomass, [MJ/kg]	17.40	17.08	17.00	17.20	17.10	16.70	16.19
Bulk density of pellets, [kg/m³]	795.7	528.4	686.6	832.4	595.2	568.7	700.9
Durability of pellets, [%]	94.18	89.91	97.33	96.24	92.86	95.06	96.03
Net calorific value of pellets, [MJ/kg]	17.34	16.98	16.94	17.20	17.10	16.60	16.21
Net calorific value of pellets at 10% moisture [MJ/kg]	15.70	15.04	15.01	15.23	15.10	14.70	14.55

Differences in the quality indices of biomass and densified biofuels from these species are also reported in the literature. *Cástková et al., (2018),* reported that unmodified rape straw contained 95.52% volatile solids and a gross calorific value of 17.79 MJ/kg, while modified rape straw exhibited 94.60–96.97% volatile solids and a calorific value ranging from 17.6 to 18.4 MJ/kg.

Similarly, *Chico-Santamarta et al., (2009),* found an average gross calorific value of 17.4 MJ/kg in canola straw. In a subsequent study, *Chico-Santamarta et al., (2012),* noted that rapeseed stalk pellets had an ash content of 6.74–9.75% and gross calorific values between 16.91 and 17.89 MJ/kg. *Frolov and Rodin, (2019),* noted that rapeseed stalks contained 12.3% moisture, 17.6 MJ/kg calorific value and 82.3 % durability of solid biofuels. *Găgeanu et al., (2018),* reported that rapeseed stalk pellets had a moisture content of 10.54% and an energy value of 3,780.21 kcal/kg (approximately 15.8 MJ/kg). According to *Greenhalf et al., (2012)*, rapeseed straw contained 6.58% ash, 76.9% volatile matter, 11.88% fixed carbon, and a gross calorific value of 18.94 MJ/kg. For comparison, wheat straw had 4.89% ash, 79.92% volatile matter, 15.18% fixed carbon, and a calorific value of 18.69 MJ/kg.

Habășescu and Cerempei, (2012), observed an ash content of 6.20% and a calorific value ranging from 16 to 17 MJ/kg in rapeseed straw. *Heneman and Červinka,* (*2007),* found a gross calorific value of 18.50 MJ/kg for *Isatis tinctoria* biomass and 17.48 MJ/kg for *Brassica napus* straw. *Kachel et al*., *(2020),* reported that rapeseed straw pellets had a mechanical durability of 89.08%, a gross calorific value of 18.45 MJ/kg, a net calorific value of 17.27 MJ/kg, and an ash content of 9.59%. *Jankowski, (2025),* indicated that the lower heating value of white mustard straw ranged from 15.42 to 15.99 MJ/kg. *Karaosmanoğlu et al., (1999),* noted that rapeseed stalks contained 12.64% moisture, 5.87% ash, 75.55% volatile matter, and 18.58% fixed carbon, with a bulk density of 141.17 kg/m³. *Maj et al., (2019),* reported a heat of combustion of 15.55 MJ/kg for white mustard biomass. According to *Maroušek, (2013)*, rapeseed straw pellets had a calorific value of 15.4 MJ/kg and a specific density of 944 kg/m³.

Niedziółka et al., (2015), found that rapeseed straw pellets had a moisture content of 12.3%, a calorific value of 17.3 MJ/kg, and a mechanical durability of 82.4%. *Plíštil et al., (2014),* reported that briquettes made from crambe biomass had a bulk density of 670–800 kg/m³, destruction force of 25–55 N/mm, and compaction pressure of 14–21 MPa. In comparison, briquettes made from rapeseed straw had a bulk density of 800–860 kg/m³, destruction force of 24–40 N/mm, and compaction pressure of 35–40 MPa. *Stasiak et al., (2017),* found that rapeseed straw pellets contained 7.92% ash, had a lower calorific value ranging from 14.3 to 16.5 MJ/kg, and mechanical durability between 40.6% and 54.8%.

Stolarski et al., (2019), reported that rapeseed straw had a moisture content of 27.98%, a gross calorific value of 18.93 MJ/kg, a net calorific value of 12.95 MJ/kg, 20.69% fixed carbon, 73.84% volatile matter, and 5.47% ash. *Stolarski et al., (2024),* found that rapeseed straw contained 15.85–25.09% moisture, 17.97–19.95% fixed carbon, 72.48–74.69% volatile matter, a gross calorific value of 17.97–18.42 MJ/kg, and a net calorific value of 12.14–14.35 MJ/kg. In a more recent study, *Stolarski M.J. et al., (2025),* noted that rapeseed biomass pellets had a moisture content of 8.19%, 19.65% fixed carbon, 75.35% volatile matter, a bulk density of 607.85 kg/m³, a gross calorific value of 18.91 MJ/kg, a net calorific value of 16.03 MJ/kg, and an ash content ranging from 5.95% to 7.56%.

Vergun et al., (2021), reported that the ash content of *Bunias orientalis* phytomass ranged from 6.79% to 9.2%, with an energy value between 3,337 and 3,498 cal/g (approximately 13.97–14.63 MJ/kg). *Zabaniotou et al., (2008),* found that rapeseed residues had 3.95% ash, 71.01% volatile matter, 23.04% fixed carbon, a gross calorific value of 16.8 MJ/kg, and a net calorific value of 16.37 MJ/kg.

CONCLUSIONS

The results indicate that phytomass substrates from *Lolium perenne*, *Dactylis glomerata*, and *Sinapis alba* exhibited a higher biochemical methane potential than those from *Zea mays*, *Isatis tinctoria*, *Brassica napus*, and *Bunias orientalis*, likely due to their elevated hemicellulose content and lower lignin levels.

Substrates derived from the phytomass of *Dactylis glomerata*, *Zea mays*, and *Isatis tinctoria* demonstrated the highest theoretical ethanol yields, in contrast to those from *Brassica napus*, *Bunias orientalis*, *Sinapis alba*, and *Lolium perenne*.

Pellets produced from *Brassica napus* and *Sinapis alba* phytomass showed favourable energy characteristics and bulk density, exceeding the corresponding values of pellets made from *Zea mays* and *Lolium perenne* straw.

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REFERENCES

[1] Abbasi-Riyakhuni M., Hashemi S.S., Denayer J.F., Aghbashlo M., Tabatabaei M., Karimi K. (2025). Integrated biorefining of rapeseed straw for ethanol, biogas, and mycoprotein production. *Fuel*, 382, 133751. *https://doi.org/10.1016/j.fuel.2024.133751*

[2] Akgül M., Erdönmez I., Çiçekler M., Tutus A. (2018). The investigations on pulp and paper production with modified kraft pulping method from canola (Brassica napus L.) stalks. *Kastamonu University Journal of Forestry Faculty,* 8 (3), 357-365.

[3] Akter M.M., Surovy I.Z., Sultana N., Faruk M.O., Gilroyed B.H., Tijing L., Kabir M. M. (2024). Techno-economics and environmental sustainability of agricultural biomass-based energy potential. *Applied Energy,* 359, 122662. *DOI: 10.1016/j.apenergy.2024.122662*

[4] Andersen S.P., Allen B., Domingo G.C. (2021). *Biomass in the EU Green Deal: Towards consensus on the use of biomass for EU bioenergy. Policy report, Institute for European Environmental Policy (IEEP,*69. *https://ieep.eu/uploads/articles/attachments/a14e272d-c8a7-48ab-89bc-31141693c4f6/Biomass%20in%20the%20EU%20Green%20Deal.pdf?v=63804370211*

[5] Barbash V., Poyda V., Deykin I. (2011). Peracetic acid pulp from annual plants. *Cellulose Chemistry and Technology*, 45 (9–10), 613–618.

[6] Bohnert D.W., Mehren M., Hunt C.W. (2011). Nutritional considerations of grass seed straw for beef cattle. *Pacific Northwest Animal Nutrition Conference*, 1-18.

[7] Carchesio M., Tatàno F., Lancellotti I., Taurino R., Colombo E., Barbieri L. (2014). Comparison of biomethane production and digestate characterization for selected agricultural substrates in Italy. *Environmental Technology*, 35, 2212-2226.

[8] Cástková T., Hýsek Š., Sikora A., Schönfelder O., Böhm M. (2018). Chemical and physical parameters of different modifications of rape straw (Brassica napus L.). *BioResources*, 13(1), 104-114.

[9] Casau M., Dias M.F., Matias J.C.O., Nunes L.J.R. (2022). Residual biomass: a comprehensive review on the importance, uses and potential in a circular bioeconomy approach. *Resources*, 11, 35. *https://doi.org/10.3390/ resources11040035*

[10] Cerempei V., Țîței V., Blaj V.A., Andreoiu A.C., Marușca T., Mazare V., Doroftei V., Ababii A. (2022). The physical properties of seeds and the biochemical composition of the straw of Romanian cultivars of *Festuca* species grown under the conditions of the Republic of Moldova. Scientific Papers, Agronomy series/*Lucrări Ştiinţifice*, series *Agronomie*, 65(2),75-80.

[11] Cerempei V., Țîței V., Vlăduț V., Cristea O-D. (2023a). The peculiarities of seeds and the quality of the green mass of some non-traditional crops in the Republic of Moldova. *INMATEH - Agricultural Engineering*, 2023, 71(3): 11-24.

[12] Cerempei V., Țîței V., Vlăduț V., Moiceanu G.A. (2023b). A comparative study on the characteristics of seeds and phytomass of new high-potential fodder and energy crops. *Agriculture*, 13, 1112. *https://doi.org/10.3390/agriculture13061112*

[13] Chen S., Wan C., Ma Y., Zhang K., Wang F., Shen S. (2023). Study on the quality of mixed silage of rapeseed with alfalfa or *Myriophyllum*. International *Journal of Environmental Research and Public Health*, 20, 3884. *doi.org/10.3390/ijerph20053884*

[14] Cherubini F., Ulgiati S. (2010). Crop residues as raw materials for biorefinery systems–a LCA case study. *Applied Energy*, 87(1), 47-57.

[15] Chico-Santamarta L., Humphries A.C., White D., Chaney K., Godwin R.J., (2009). Effect of pre- and postpelletisation storage of canola (oilseedrape) straw on the quality and properties of pellets. *ASABE Annual Meeting*, no. 096105. *10.13031/2013.27054.*

[16] Chico-Santamarta L., Chaney K., Godwin R.J., White D.R., Humphries A. (2012). Physical quality changes during the storage of canola (*Brassica napus* L.) straw pellets. *Applied Energy Journal*, 95, 220-226.

[17] Cîrlig N., Guţu A., Iurcu-Străistaru E. (2024). *Isatis tictoria* L.– biological peculiarities and usage as honey plant. Science in the North of the Republic of Moldova: achievements, problems, perspectives/*Ştiinţa în Nordul Republicii Moldova: realizări, probleme, perspective*, Chişinău, 445-449.

[18] Cîrlig N., Ţîţei V., Guţu A. (2023). High-value melliferous plant resources. *Research-based training for a prosperous society*/*Instruire prin cercetare pentru o societate prosperă*, Chişinău, 1, 172-175.

[19] Comlekcioglu N., Tutus A., Çiçekler M., Çanak A., Zengin G. (2016). Investigation of *Isatis tinctoria* and *Isatis buschiana* stalks as raw materials for pulp and paper production. *Drvna Industrija*, 67, 249-255. 10.5552/drind.2016.1542

[20] Cozari S., Ţîţei V., Guțu A., Andreoiu A.C., Coșman S., Coșman V., Mocanu N., Mardari L. (2022). The quality of silage from *Isatis tinctoria*. *The scientific symposium Biology and Sustainable Development.* Bacău, 84-85.

[21] Dandikas V., Heuwinkel H., Lichti F., Drewes J.E., Koch K. (2015). Correlation between biogas yield and chemical composition of grassland plant species. *Energy Fuels*, 29, 11, 7221-7229.

[22] Dell'Omo P.P. (2025). Different susceptibilities of wheat straw and corn stover to mechanical pretreatment for biomethane production. *Methane*, 4(1), 5. *https://doi.org/10.3390/methane4010005*

[23] Doroftei V., Ţiţei V., Ababil A., Blaj V., Cozari S., Andreoiu A.C., Maruşca T., Coşman V., Guţu A. (2021). Evaluation of biomass quality from perennial grass seed plantations and possibilities for utilization/Evaluarea calităţii biomasei din plantațiile semincere de ierburi perene și posibilități de valorificare. Genetics, physiology and plant breeding/*Genetica, fiziologia şi ameliorarea plante*lor, Chişinău, 305-308.

[24] Dukarska D., Bartkowiak M., Stachowiak-Wencek, A. (2015). White mustard straw as an alternative raw material in the manufacture of particleboards resinated with different amounts of urea-formaldehyde resin. *Drewno*, 58, 194, 49-63.

[25] Dukarska D., Łęcka J., Szafoni K. (2011). Straw of white mustard (*Sinapis alba*) as an alternative raw material in the production of particle boards resinated with UF resin. *Acta Scientiarum Polonorum Silvarum Colendarum Ratio et Industria Lignaria*, 10, 1, 19-28.

[26] El-Araby R. (2024). Biofuel production: exploring renewable energy solutions for a greener future. *Biotechnology for Biofuels*, 17, 129. *https://doi.org/10.1186/s13068-024-02571-9.*

[27] Fisher M.J., Bohnert D.W., Ackerman C.J., Schauer C. S., DelCurto T., Craig A.M., Vanzant E.S., Harmon D.L., Schrick F.N. (2004). Evaluation of perennial ryegrass straw as a forage source for ruminants. *Journal of Animal Science*, 82, 2175-2184.

[28] Frolov D.I., Rodin M.N. (2019). Use of plant material as solid biofuel. *Innovative Machinery and Technology*, 4 (21). 46–51. [In Russian]

[29] Fuksa P., Hakl J., Brant V. (2013). Energy balance of catch crops production. *Zemdirbyste-Agriculture*, 100, 4, 355–362.

[30] Gaballah E.S., Abomohra A.E.F., Xu C., Elsayed M., Abdelkader T.K., Lin J., Yuan Q. (2020). Enhancement of biogas production from rape straw using different co-pretreatment techniques and anaerobic co-digestion with cattle manure. *Bioresource Technology*, 309. 123311. *10.1016/j.biortech.2020.123311.*

[31] Gao Y., Wang X., Chen Y., Li P., Liu H., Chen H. (2017). Pyrolysis of rapeseed stalk: Influence of temperature on product characteristics and economic costs. *Energy*, 122, 482-491.

[32] Găgeanu I., Cujbescu D., Persu C., Voicu G. (2018). Influence of using additives on quality of pelletized fodder. *Engineering for Rural Development*, 17, 1632-1638.

[33] Goff B.M., Moore K.J., Fales, L., Heaton A. (2010). Double-cropping sorghum for biomass. *Agronomy Journal,* 102, 1586-1592.

[34] Gong X., Yu Y., Hao Y., Wang Q., Ma J., Jiang Y., Lv G., Li L., Qian C. (2022). Characterizing corn-straw-degrading actinomycetes and evaluating application efficiency in straw returning experiments. *Frontiers in Microbiology*, 13, 1003157. *doi: 10.3389/fmicb.2022.1003157*

[35] Greenhalf C.E., Nowakowski D.J., Bridgwater A.V., Titiloye J., Yates N., Riche A., Shield I. (2012). Thermochemical characterisation of straws and high yielding perennial grasses. *Industrial Crops and Products*, 36, 449–459.

[36] Gudîma A. (2017). Evaluation of the use of agricultural residues for energy purposes. Case study for Soroca district, Republic of Moldova / Evaluarea utilizării reziduurilor agricole pentru scopuri energetice. Studiu de caz pentru raionul Soroca, Republica Moldova. *Meridian Ingineresc*, 1, 26-29. [In Romanian]

[37] Guo T.X., Liang K.W. (2025). Bioenergy production from rapeseed straw: a feasibility study. *Journal of Energy Bioscience*, 16(4), 163-171.

[38] Güleç F., Direnc P., Orla W., Lester E. (2022). Predictability of higher heating value of biomass feedstocks via proximate and ultimate analyses - a comprehensive study of artificial neural network applications. *Fuel*, 320, 123944. *10.1016/j.fuel.2022.123944.*

[39] Habashescu I., Cerempel V. (2012). Energetic potential of vegetable mass in agriculture of Republic of Moldova. *Energy of Moldova –Regional Aspects of Development*, 355-359.

[40] Hajj Obeid M., Douzane O., Freitas Dutra L., Promis G., Laidoudi B., Bordet F., Langlet T. (2022). Physical and mechanical properties of rapeseed straw concrete. *Materials*, 15, 23, 8611. *DOI: 10.3390/ma15238611*

[41] Hálfdánarson H.E. (2015). *Ethanol production from timothy* (*Phleum pratense* L.). MS – thesis. Agricultural University of Iceland, 105. *https://skemman.is › bitstream › PDF Ethanol Pro.*

[42] Hejduk S., Macháč R. (2019). Yield and quality of straw of Italian and perennial ryegrass cultivated for seed production. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 67, 4. 915-923.

[43] Heneman P., Červinka J. (2007). Energy crops and bioenergetics in the Czech Republic. *Annals of Warsaw University of Life Sciences – SGGW Agriculture (Agricultural Engineering*), 51, 73-78.

[44] Isikgora F.H., Remzi Becer C. (2015). Lignocellulosic biomass: a sustainable platform for production of bio-based chemicals and polymers. *Polymer Chemistry*, 6(25), 4497-4559.

[45] Jankowski K.J. (2025). White mustard: energy balance at different nitrogen management strategies. *Industrial Crops and Products*, 225, 120420. *https://doi.org/10.1016/j.indcrop.2024.120420*

[46] Kachel M., Kraszkiewicz A., Subr A., Parafiniuk S., Przywara A., Koszel M., Zając G. (2020). Impact of the type of fertilization and the addition of glycerol on the quality of spring rape straw pellets. *Energies*, 13(4), 819. *https://doi.org/10.3390/en13040819*

[47] Karaosmanoglu F., Tetik E., Gollu E. (1999). Biofuel production using slow pyrolysis of the straw and stalk of the rapeseed plant. *Fuel Processing Technology*, 59, 1-12.

[48] Khan A., Mishra A., Patidar R., Pappu A. (2024). Effect of lignocellulosic corn stalk on mechanical, physical, and thermal properties of injection moulded low density polyethylene composites: An approach towards a circular economy. *Heliyon*, 10, 4. *DOI: 10.1016/j.heliyon.2024.e25287*

[49] Kiro M. (2015). Cellulose fibers extracted from agricultural biomass. *Tekstilna Industrija*, 62(4), 15-19.

[50] Kord B., Zare H., Hosseinzadeh A. (2016). Evaluation of the mechanical and physical properties of particleboard manufactured from canola (*Brassica napus*) straws. *Maderas. Ciencia y Tecnología*. 18, 1, 9 - 18. *10.4067/S0718-221X2016005000002*.

[51] Kumar D., Murthy G. (2011). Pretreatments and enzymatic hydrolysis of grass straws for ethanol production in the pacific northwest US. *Biological Engineering*, 3, 97-110. *10.13031/2013.36314.*

[52] Li H.Y., Xu L., Liu W.J., Fang M.Q., Wang N. (2014). Assessment of the nutritive value of whole corn stover and its morphological fractions. *Asian-Australasian Journal of Animal Sciences*, 27, 2, 194-200. *doi: 10.5713/ajas.2013.13446.*

[53] Liang K.W, Yan S.D. (2025). Exploring the potential of rapeseed biomass for renewable energy. *Journal of Energy Bioscience*, 16, 3, 105-116. doi: 10.5376/jeb.2025.16.0011

[54] Lukiwati D.R. (2019). Improvement of maize stover nutrition as ruminant feed with manure plus and inorganic fertilizer. *Journal of Animal Husbandry Sciences and Technics*, 249, 147-152.

[55] Marian G. (2014). Agroforestry biomass management for energy purposes/Managementul biomasei agrosilvice pentru scopuri energetice. Chişinău: 264 p.

[56] Marian G., Ianuş G., Istrate B., Banari A., Nazar B., Munteanu C., Măluțan T., Gudima A., Ciolacu F., Daraduda N., Paleu V. (2022). Evaluation of agricultural residues as organic green energy source based on seabuckthorn, blackberry, and straw blends. *Agronomy*, 9, 12, 1-14. *https://doi.org/10.3390/agronomy12092018*

[57] Maj G., Krzaczek P., Stamirowska-Krzaczek E., Lipińska H., Kornas R. (2019). Assessment of energy and physicochemical biomass properties of selected forecrop plant species. *Renewable Energy*, 143, 520-529.

[58] Maroušek J. (2013). Study on commercial scale steam explosion of winter *Brassica napus* straw. *International Journal of Green Energy*, 10, 944-951.

[59] Mazurkiewicz J., Marczuk A., Pochwatka P., Kujawa S. (2019). Maize straw as a valuable energetic material for biogas plant feeding. *Materials*, 12(23), 3848. *https://doi.org/10.3390/ma12233848*

[60] Morissette R., Savoie P., Villeneuve J. (2011). Combustion of corn stover bales in a small 146-kW boiler. *Energies*, 4(7), 1102-1111. *https://doi.org/10.3390/en4071102*

[61] Nasir A.A.A., Kamaruddin N.A. (2023). Assessing the nutritional composition of sweet corn (*Zea mays* L. var. *saccharata*) stover and kernel corn (*Zea mays* L. var. *indentata*) stover for ruminant feed. *Journal of Asian Scientific Research*, 13(3), 136-148.

[62] Naveed M.H., Nouman M., Khan A., Mukarram M., Raza Naqvi S., Abdullah A., & Ul Haq Z., Ullah, H., Mohamadi H. (2024). Cellulosic biomass fermentation for biofuel production: review of artificial intelligence approaches. *Renewable and Sustainable Energy Reviews*, 189, 113906. *10.1016/j.rser.2023.113906.*

[63] Nazare A-I., Ţîţei V. (2025). Productivity and nutritional value of some *Festuca* species in Moldova. *Romanian Agricultural Research*, 42, 204-214.

[64] Niedziółka I., Kachel-Jakubowska M., Kraszkiewicz A., Szpryngiel M., Szymanek M., Zaklika B. (2015). Assessment of quality and energy of solid biofuel production. *Bulgarian Journal of Agricultural Science*, 21, 2, 461–466

[65] Orlygsson J. (2013). Ethanol production from grass by *Thermoanaerobacter* B2 isolated from a hot spring in Iceland. The Role of Grasslands in a Green Future: *Threats and Perspectives in Less Favoured Areas*, 534-536.

[66] Pavlenco A., Marian G., Gudîma A. (2018). The energy potential of agricultural residues: a case study for the Northern development region, Republic of Moldova/Potenţialul energetic al reziduurilor agricole: studiu de caz pentru Regiunea de Dezvoltare Nord, Republica Moldova. *Agricultural Science/Ştiinţa Agricolă*, 2, 141-149.

[67] Petersson A., Thomsen M.H., Hauggaard-Nielsen H., Thomsen A.B. (2007). Potential bioethanol and biogas production using lignocellulosic biomass from winter rye, oilseed rape and faba bean. *Biomass and Bioenergy*, 31, 11–12, 812–819.

[68] Petlickaite R., Jasinskas A., Mieldažys R., Romaneckas K., Praspaliauskas M., Balandaite J. (2022) Investigation of pressed solid biofuel produced from multi-crop biomass. *Sustainability*, 14, 799. *doi.org/10.3390/su14020799*

[69] Plíštil D., Brožek M., Malaák J., Roy A., Hutla P. (2005). Mechanical characteristics of standard fuel briquettes on biomass basis. *Research in Agricultural Engineering*, 51(2), 66-72.

[70] Potucek F., Gurung B., Hájková K. (2014). Soda pulping of rapeseed straw. *Cellulose Chemistry and Technology*, 48, 7-8, 683-691.

[71] Rahim M., Douzane O., Le A.T., Promis G., Langlet T. (2015). Characterization and comparison of hygric properties of rape straw concrete and hemp concrete. *Construction and Building Materials*, 102, 679-687.

[72] Rozenfelde L., Puke M., Vedernikovs N., Scherbaka R., Rapoport A. (2021). Catalytic treatment of rapeseed straw for enhanced production of furfural and glucose for bioethanol production. *Process Biochemistry,* 102, 102-107.

[73] Stanisavljević R., Marković J., Dinić B., Lazarević D., Milenković J., Đokić D., Anđelković B. (2009). Yield and chemical composition of orchard grass harvest remains-straw (*Dactylis glomerata* L.) depending on the vegetation space and application of mineral fertilizers. *Biotechnology in Animal Husbandry*, 25, 5-6, 1233-1239,

[74] Stasiak M., Molenda M., Bańda M., Wiącek J., Parafiniuk P., Gondek E. (2017). Mechanical and combustion properties of sawdust—straw pellets blended in different proportions. *Fuel Processing Technology*, 156, 366-375.

[75] Stolarski M.J., Welenc M., Krzyżaniak M., Olba-Zięty E., Stolarski J., Wierzbicki S. (2024) Characteristics and changes in the properties of cereal and rapeseed straw used as energy feedstock. *Energies*, 17(5), 1243. *https://doi.org/10.3390/en17051243*

[76] Stolarski M.J, Rybczyńska B., Krzyżaniak M., Lajszner W., Graban Ł., Peni D., Bordiean A. (2019). Thermophysical properties and elemental composition of agricultural and forest solid biofuels versus fossil fuels. *Jorunal of Elementology*, 24(4), 1215-1228. *10.5601/jelem.2019.24.1.1819*

[77] Stolarski M. J., Krzyżaniak M., Olba-Zięty E. (2025). Properties of pellets from forest and agricultural biomass and their mixtures. *Energies*, 18(12), 3137. *https://doi.org/10.3390/en18123137*

[78] Sveinsson T., Hermannsson, J. (2010). Biomass production, premises and prospects. *Fræðaþing landbúnaðarins*, 7, 36-45. [In Icelandic].

[79] Ţîţei V. (2016). Agrobiological peculiarities and prospects for valorification of woad, *Isatis tinctoria* L., in Moldova. *Lucrări Ştiinţifice*, series *Agronomie*, 59, 2, 267-272.

[80] Ţîţei V. (2022a). Silage quality from some species of the Brassicaceae family and possibilities for utilization in the Republic of Moldova/Calitatea silozului din unile specii din familia Brassicaceae și posibilități de valorificare în Republica Moldova. Science and innovation in the north of the Republic of Moldova: problems, achievements, prospects/*Știința și inovarea în nordul Republicii Moldova: probleme, realizări, perspective.* Bălți, 277-281.

[81] Ţîţei V. (2021). The quality of fresh and ensiled biomass of *Brassica napus oleifera* and prospects of its use. *Scientific Papers. Series A. Agronomy*, 64(2), 330-335.

[82] Ţîţei V. (2022b). The quality of fresh and ensiled biomass from white mustard, *Sinapis alba*, and its potential uses. *Scientific Papers. Series A. Agronomy*, 65(1), 559-566.

[83] Ţîţei V. (2025). Some agrobiological features and quality indices of the biomass of *Panicum virgatum* and *Panicum miliaceum* grown under the conditions of the Republic of Moldova. *Scientific Papers. Series A. Agronomy*, 68(1), 892-901. *https://agronomyjournal.usamv.ro/pdf/2025/issue_1/Art110.pdf*

[84] Ţîţei V., Roşca I. (2021). Good practices for the use of degraded lands in crop cultivation with a potential of energetic biomass/Bunele practici de utilizare a terenurilor degradate în cultivarea culturilor cu potenţial de biomasă energetică. Chişinău, 80p.

[85] Vergun O., Rakhmetov, D., Shymanska, O., Rakhmetova S., Bondarchuk O., Fishchenko V. (2021). Morphometric and biochemical features of different *Bunias orientalis* L. genotypes in the M. M. Gryshko National Botanical Garden of the NAS of Ukraine. *Plant Varieties Studying and Protection*, 17, 66-72. *10.21498/2518-1017.17.1.2021.228213*.

[86] Viel M., Collet F., Lanos C. (2018). Chemical and multi-physical characterization of agro-resources' by-product as a possible raw building material. *Industrial Crops and Products*, 120, 214–237. *doi: 10.1016/j.indcrop.2018.04.025.*

[87] Vishnevskaya O.V. (2017). Alternative sources of vegetative mass for biofuels in Polissia zone. *Agricultural Science and Practice*. 4(3), 35-42.

[88] Witaszek K., Kupryaniuk K., Kupryaniuk J., Panasiewicz J., Czekała W. (2025). Optimization of straw particle size for enhanced biogas production: a comparative study of wheat and rapeseed straw. *Energies*, 18(7), 1794. *https://doi.org/10.3390/en18071794*

[89] Wattanaklang B., Abrar A., Cherdthong A. (2016). Nutritional value of fermented maize stover as feed for ruminant. *Jurnal Peternakan Sriwijaya*, 5(1), 44-51.

[90] Yang B., Na N., Wu N., Sun L., Li, Z., Qili M., Han H., Xue Y. (2024) Impact of additives and packing density on fermentation weight loss, microbial diversity, and fermentation quality of rape straw silage. *Microorganisms 12,* 1985. *https://doi.org/10.3390/microorganisms12101985*

[91] Yang W., Lv L., Han Y., Li Y., Liu H., Zhu Y., Zhang W., Yang H. (2022). Effect of densification on biomass combustion and particulate matter emission characteristics. *Atmosphere,* 13, 1582. *https://doi.org/10.3390/atmos13101582*

[92] Ye Y., Guo W., Ngo H.H., Wei W., Cheng D., Bui X.T., Hoang N.B., Zhang H. (2024). Biofuel production for circular bioeconomy: Present scenario and future scope. *Science of The Total Environment*, 935, 172863. *doi: 10.1016/j.scitotenv.2024.172863*.

[93] Youngberg H., Vough L. (1977). *A study of the nutritive value of Oregon grass straws*. O.S.U. Extension Service Special Report 473, 14.

[94] Zabaniotou A., Ioannidou O., Skoulou V. (2008). Rapeseed residues utilization for energy and 2-nd generation biofuels. *Fuel*, 87(8-9), 1492-1502.

[95] Zarajczyk J. (2013). *Technical and technology conditions of plant biomass pellets for energy purposes*. Monografi e i rozprawy. Inżynieria Rolnicza, 1 (142), 2-81.

[96] Zelenchuk T.V., Deikun I.M., Barbash V.A. (2017). Obtaining of peracetic cellulose from oat straw for paper manufacturing. *Research Bulletin of the National Technical University of Ukraine*, 5, 123-131.

[97] Zhou X., Ouyang Z., Zhang X., Wei Y., Tang S., Ma Z., Tan Z., Zhu N., Teklebrhan T., Han X. (2019). Sweet corn stalk treated with *Saccharomyces cerevisiae* alone or in combination with *Lactobacillus plantarum*: nutritional composition, fermentation traits and aerobic stability. *Animals,* 9(9), 598. *https://doi.org/10.3390/ani9090598*