THE EVALUATION OF THE QUALITY OF THE ENERGY PHYTOMASS FROM INDUSTRIAL HEMP *CANNABIS SATIVA* GROWN IN MOLDOVA

Victor ŢÎŢEI [1]

e-mail: vic.titei@gmail.com

Abstract

Plant biomass, phytomass, is an important source of renewable energy, and its importance has increased in regional and national energy strategies. The goal of this research was to evaluate the quality of energy phytomass from industrial hemp, *Cannabis sativa*, grown in the experimental plot of the National Botanical Garden (Institute), Chişinău, Republic of Moldova, as feedstock for the production of biogas and solid bio-fuel. The analysis of the biochemical composition indicated that the dry matter of the hemp plants harvested in the full flowering period contained 141 g/kg CP, 424 g/kg CF, 457g/kg ADF, 704 g/kg NDF, 82 g/kg ADL, 247g/kg HC, 375 g/kg Cel, 88 g/kg ash, 506.7 g/kg carbon and 22.5 g/kg nitrogen, with biochemical methane potential 280 l/kg. The prepared hemp silage was characterized by specific smell, 14.0 g/kg DM lactic acid, 7.7 g/kg DM acetic acid, 146 g/kg CP, 443 g/kg CF, 468 g/kg ADF, 716 g/kg NDF, 79 g/kg ADL, 248g/kg HC, 389 g/kg Cel, 134 g/kg ash, 481.0 g/kg carbon and 23.4 g/kg nitrogen with biochemical methane potential 286 l/kg. The hemp solid bio-fuel, pellets, was characterized by high net calorific values (17.9 MJ/kg), specific density (1012 kg/m^3), durability (94%) and optimal ash content. Industrial hemp, *Cannabis sativa*, may be use as multi-purpose feedstock for renewable energy production.

Key words: biochemical composition, biochemical methane potential, *Cannabis sativa*, pellets, physical and mechanical properties

The consistent rise in global population and intensive development of the global economy contribute to the rapid growth of consumption of energy. The increasing global dependence on fossil fuels, combined with their increasing cost and gradual depletion, along with environmental pollution and environmental issues such as global warming and water deficit increase people's interest in renewable, sustainable, eco-friendly resources and their applications.

Biomass is the most important renewable energy source in the world, and its importance is increasing as the national energy policy and strategy focus more heavily on the use of renewable sources. Plant biomass – phytomass from energy crops, agricultural and forestry residues is a promising renewable resource to achieve a low carbon bio-economy with the production of biofuels and energy for heat and power, is clean and environmentally safe. Major technologies for the capitalization of biomass are: direct combustion of lignocellulosic biomass, mixed combustion of phytomass and coal, pyrolysis, gasification, densification by pelleting or briquetting, anaerobic digestion for biomethane production, cellulosic ethanol, biodiesel and methanol production. One of the most important tasks in the production of energy crops is the selection of suitable plant species that could thrive in specific soil and environmental conditions of the changing climate, can be used in many areas, and produce a large amount of biomass that is easily converted into energy.

Hemp, *Cannabis sativa* L., family *Cannabaceae*, is one of the oldest crops in the world, dating back to 8,000 B.C. It is an annual short day, C_3 plant, stems growing up to 4 m tall. Leaves are finely hairy, alternate, palmately divided into 3-11 lanceolate toothed leaflets. Male flowers are yellow-green, up to 5 mm in diameter, borne in small panicles; the female plants are darker green, with denser foliage and tightly bunched panicles, the flowers are closely surrounded by tubular bracteoles. The female axillary leafy clusters do not form any compact raceme. The fruiting body is greyish-brown in color and about 4 mm long. *Cannabis sativa* is usually dioecious plant, hermaphroditism occurs in some ecotypes and covarieties, and the breeding programs have resulted in creating some monoecious cultivars. Hemp has a deep, dense root system, which contributes to a good aeration of the

[1] "Alexandru Ciubotaru" National Botanical Garden (Institute), Chişinău, Republic of Moldova

soil and has positive effects on soil structure. It is a relatively fast-growing plant and requires less water compared to plants such as corn and alfalfa. Furthermore hemp requires little to no use of fertilizers and pesticides making it a very sustainable crop. Hemp has historically been used in fiber, food and medicinal production, currently is a valuable crop for the bio-based economy: hemp seed oil has an excellent and unique fatty acid profile, being an interesting pharmaceutical and food supplement, but the extraction residue can be used as a high protein animal feed; the fiber is used in the textile industry, papermaking, for insulation material and biocomposites; the shives, the woody inner core of the stem, are used for animal bedding, construction and feedstock for renewable energy. The results of different studies on agro-biological peculiarities of hemp, breeding cultivars, crop protection, technological cultivation methods, harvesting and processing equipment, quality of seed, fiber and energy biomass are given in the specialized literature (Şandru I. *et al*, 1996; Tabără V., 2005, 2009; Carus M., 2017; Tabără V. and Panda A., 2018; Ţîţei V. *et al*, 2020; Popa L.D. *et al*, 2021)

The goal of this research was to evaluate the quality of energy phytomass from industrial hemp, *Cannabis sativa*, and the prospects of its use as substrate for biomethane production and as feedstock for the production solid biofuel – pellets.

MATERIALS AND METHODS

The Romanian cultivar of industrial hemp, *Cannabis sativa* "ARMANCA", created at the Agricultural Research and Development Station Lovrin, which was cultivated in the experimental sector of the "Alexandru Ciubotaru" National Botanical Garden (Institute), Chişinău, latitude 46°58′25.7″N and longitude 28°52′57.8″E, served as subject of the research, and triticale, *Triticosecale* and corn, *Zea mays*, were used as controls. Hemp seeds were sown in middle May, 200 viable seeds per m^2, in eroded chernozem soil. The hemp green mass samples were collected in full flowering stage, triticale – in early flowering stage, but corn – in kernel milk-wax stage. For ensiling, green mass was chopped into 1.5-2.0 cm pieces by using a forage chopping unit, and then it was shredded and compressed in well-sealed glass containers. For chemical analysis, plant samples were dried in a forced air oven at 60°C, milled in a beater mill. The quality of the substrate biomass was evaluated by analyzing such indices as: crude protein (CP), crude fiber (CF), crude ash (CA, acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL), which have been determined by near infrared spectroscopy (NIRS) technique PERTEN DA 7200 of the Research and Development Institute for Grassland Braşov, Romania. The concentration of hemicellulose (HC) and cellulose (Cel) were calculated according to standard procedures. The carbon content of the substrates was determined according to Badger C.M. *et al,* 1979, the methane potential – according to Dandikas V. *et al,* 2014. Hemp dry stalks were collected in February, chopped and disintegrated by knife mill with a sieve with the mesh size of 1 mm. The total carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) amounts were determined by dry combustion in a Vario Macro CHNS analyzer. The pelleting was carried by the equipment developed at the Institute of Agricultural Technique "Mecagro", Chişinău. The physical and mechanical properties of dry biomass and pellets were determined according to the national standards (Marian G., 2016).

RESULTS AND DISCUSSIONS

In the recent decades, important research has been conducted on the technologies for converting raw materials into biogas. The use of phytomass substrates for biogas production has recently become of major interest in Europe. The biogas resulted from anaerobic digestion processes, consisting of methane, carbon dioxide and small quantities of other gases is used to produce heat and electricity. The digestate represents the anaerobically decomposed substrate, rich is macro and micro nutrients and therefore it can be used as fertilizer for plants. Phytomass substrates may be used in biogas generators as fresh mass and as ensiled mass. Analyzing the results of the assessment of bio-morphological peculiarities of the studied crops, it can be noted that the harvested hemp whole plants contained 27.9 % dry matter, triticale – 21.2 % dry matter and corn 32.6 % dry matter; their biochemical composition is presented in table 1. We would like to mention that hemp whole plant substrate was characterized by higher content of crude protein, minerals and cell wall fractions (NDF, ADF, ADL). Triticale green mass substrate contained higher amounts of hemicellulose, reduced amount of crude protein, minerals and much lower amount of acid detergent lignin than hemp substrate. The lowest levels of crude protein and cell wall fractions were found in corn green mass substrate. It is a commonly known fact that methanogenic bacteria need a suitable ratio of carbon to nitrogen for their metabolic processes, ratios higher than 30:1 were found to be unsuitable for optimal digestion, and ratios lower than 10:1 were found to be inhibitory, due to low pH, poor buffering capacity and high concentrations of ammonia in the substrate. The nitrogen content in the studied green mass substrates ranged from 13.44 to 22.56 g/kg, the estimated content of carbon – from 506.67 to 526.67 g/kg, the C/N ratio varied from 22.5 to 37.5. The C/N ratio in hemp green mass substrate was optimal. The biochemical methane potential of the studied substrates varied from 280 l/kg VS to 347 l/kg VS. The hemp green mass substrate contained high level of acid detergent lignin (82 g/kg), which influenced negatively the activity of bacteria and decomposition processes, thus, the biochemical methane potential was 280 l/kg VS.

Table 1

The biochemical composition and biomethane production potential of green mass substrates

Indices	*Cannabis sativa*	*Triticale*	*Zea mays*
Crude protein, g/kg DM	141	99	84
Crude fiber, g/kg DM	424	397	248
Minerals, g/kg DM	88	74	52
Acid detergent fiber, g/kg DM	457	416	271
Neutral detergent fiber, g/kg DM	704	691	474
Acid detergent lignin, g/kg DM	82	36	48
Cellulose, g/kg DM	375	370	223
Hemicellulose, g/kg DM	247	275	203
Carbon, g/kg	506.67	514.44	526.67
Nitrogen, g/kg	22.56	15.84	13.44
Ratio carbon/nitrogen	22.5	32.5	39.1
Biomethane potential, L/kg	280	347	321

Table 2.

The biochemical composition and biomethane production potential of ensiled mass substrates

Indices	*Cannabis sativa*	*Triticale*	*Zea mays*
pH index	6.67	4.87	3.77
Organic acids, g/kg DM	20.8	32.0	48.6
Free acetic acid, g/kg DM	0	1.7	5.1
Free butyric acid, g/kg DM	0	1.5	0
Free lactic acid, g/kg DM	0.4	3.8	17.0
Fixed acetic acid, g/kg DM	6.7	4.4	5.2
Fixed butyric acid, g/kg DM	0.1	3.4	0.2
Fixed lactic acid, g/kg DM	13.6	17.0	21.1
Acetic acid, % of total organic acids	32.21	19.06	21.19
Butyric acid, % of total organic acids	0.48	15.31	0.41
Lactic acid, % of total organic acids	67.31	65.63	78.40
Crude protein, g/kg DM	146	113	80
Crude fiber, g/kg DM	443	422	245
Minerals, g/kg DM	134	108	59
Acid detergent fiber, g/kg DM	468	437	258
Neutral detergent fiber, g/kg DM	716	727	469
Acid detergent lignin, g/kg DM	79	28	37
Cellulose, g/kg DM	389	409	221
Hemicellulose, g/kg DM	248	290	211
Carbon, g/kg	481.00	495.56	522.78
Nitrogen, g/kg	23.36	18.08	12.80
Ratio carbon/nitrogen	20.6	27.4	40.8
Biomethane potential, L/kg	286	363	338

The results of the estimation of the quality of hemp green mass substrate and methane yield are given in the specialized literature. Pecenka *et al*, 2007 remarked that the analyzed harvested raw material of hemp was characterized by 220-250 g/kg DM with 38.4-45.5% CF and 1.8-6.5% total sugars. Heiermann M. *et al*, 2011 found that the fresh mass of triticale contained 337-352 g/kg DM, 94.3-95.0% organic matter, 9.3-12.3% CP, 1.4-1.9% EE, 24.0-29.0% CF, 11.5% sugar, C/H=24.4-31.4, methane yields 388-435 l/kg, but hemp fresh mass – 310 g/kg DM, 92.2% organic matter, 13.1% CP, 1.2% EE, 40.9% CF, 10.2% sugar, C/H=28.0, methane yields 301 l/kg, respectively. Pakarinen A. *et al*, 2011 remarked that the methane yield from ground hemp stems was 219 L/kg VS, but – from leaves – was 256 L/kg VS. Iqbal M. *et al*, 2018 reported that the *Cannabis* sps. dry matter was 409.4 g/kg DM with 82.45% organic matter, 28.13% CP, 7.51% EE, 44.29%CF, 44.12% NDF, 19.00% ADF, 0.46% calcium and 0.48% phosphorus. Adamovics A.M. *et al*, 2019 stated that methane yields from fine-chopped hemp were 245-270 l/kg DOM and from leaves – 354-355 l/kg DOM. Gusovius H-J. *et al*, 2019 found that the hemp cultivars harvested in September - October contained 292.5-405.4g/kg DM, 1.16-3.89% sugars, 38.93-60.66% cellulose, 6.24-15.81%

hemicellulose 7.84-11.60% lignin. Matassa S. *et al*, 2020 reported that the biomethane potential was: 239 l/kg in substrate from half of the whole hemp plant, 242 l/kg hemp hurds, 275 l/kg stalks and the highest value – 422l/kg in raw fibers.

The quality of ensiled mass depends on the plants species, the growing period at which these plants have been harvested, on the botanical structure of the herbage, on techniques and technology of preparation, on conditions of its storage and on many other factors. As a result of the performed analysis (*table 2*), it was determined that the pH index of the ensiled hemp was 6.67, but in the control variants, corn silage pH=3.77 and triticale silage pH= 4.87. The concentration of total organic acids in ensiled hemp is lower, predominantly in fixed form; in triticale silage a higher content of butyric acid was detected (15.31%). Analyzing the results regarding the biochemical composition of hemp ensiled mass (*table 2*), we would like to mention that the dry matter had higher concentration of crude protein, minerals and cell wall fractions, with a minor decrease in acid detergent lignin content as compared with the initial green mass. The triticale silage is characterized by very high content of hemicellulose, optimal level of crude protein and minerals, low level of acid detergent lignin as compared with corn silage. The nitrogen concentration in the tested ensiled substrates ranged from 12.80 g/kg to 23.36 g/kg, the estimated content of carbon – from 481.00 g/kg to 522.78 %, the C/N ratio varied from 20.6 to 40.8. The higher value of biochemical methane potential was characteristic of the triticale silage substrate (363l/kg VS), but the ensiled hemp substrate contained high level of acid detergent lignin 79g/kg, which influenced negatively the biochemical methane potential (286l/kg VS).

Several studies have evaluated the methane potential of hemp ensiled mass. According to Heiermann M. *et al*, 2011, the hemp ensiled material contained 278g/kg DM, pH= 5.5, 91.9% organic matter, 8.5% CP, 51.0% CF, 2.4% sugar, C/H=35.2, methane yields 259 l/kg; triticale ensiled material contained: 273-412 g/kg DM, 93.1-94.6% organic matter, pH=5.5, 8.8-11.4% CP, 25.6-31.7% CF, 10.5-22.0% sugar, C/H=26.3-34.5, methane yield 467-504 l/kg, but corn silage: 251-370 g/kg DM, pH= 3.7-3.8, 95.3-96.5% organic matter, 8.8-10.2% CP, 18.6-23.2% CF, 2.0-5.3% sugar, C/H=28.8-33.2, methane yield 468-581 l/kg, respectively. Pakarinen A. *et al*, 2011 mentioned that the methane yields from ensiled hemp were 309-379 l /kg VS. Herrmann C. *et al*, 2016 reported that the chemical composition of triticale silage was 273-412 g/kg DM, pH = 4.2-4.5, 8.8-11.4% CP, 2.1-3.0% EE, 25.6-31.7% CF, 5.4-6.9% ash, C/H=26.3-31.7 and methane yields 467-504 l/kgODM; hemp silage – 278 g/kg DM, pH = 5.5 8.5% CP, 1.1% EE, 51.0% CF, 8.1% ash, C/H=35.2 and methane yields 259 l/kg ODM; maize silage – 251-370g/kg DM, pH=3.7-3.8, 8.2-10.2% CP, 18.6-23.2% CF, 3.8-5.0% ash, C/H=28.8-33.2 and methane yields 468-581 l/kgODM, respectively. Gusovius H-J. *et al*, 2019 reported that the wet preserved hemp after 6 months of anaerobic storage without additives contains 272.3 g/kg DM, with pH = 6.30, 17.4 g/kg acetic acid, 15.2 g/kg 3.89% sugar, 44.58% cellulose, 13.04% hemicellulose, 7.84% lignin.

Because of the irregular shape and size and low bulk density, herbaceous phytomass is very difficult to handle, transport, store and utilize in its original form. The densification of biomass into durable compact fuel is an effective solution to these problems and it can increase the bulk density of collected mass from an initial bulk density of 40-200 kg/m^3 to a final compact density of 600-1200 kg/m^3. The knowledge of the engineering properties of biomass, such as bulk density, particle density, particle size, color, moisture content, ash content, heating value and flowability is important for the design and operation of processing facilities for handling, storage, transportation, and conversion to fuels, heat and power. Pelleting is a promising technology which converts the energy of biomass into a more useful form through densification in order to ease handling, storage and transport (Marian G, 2016).

The elemental composition of dry 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 (Lawal A.I. *et al*, 2021).

The elemental composition, some physical and mechanical properties of biomass and pellets from dry stalks of hemp and corn is presented in table 3. We found that hemp stalks are characterized by an optimal content of carbon (46.03%) and hydrogen (5.75%), and low content of nitrogen (0.62 %), sulphur (0.03%) and ash (2.23%), as compared with corn stalks. Hemp biomass had excellent gross calorific value (19.68 MJ/kg), which is higher than that of corn biomass (18.34 MJ/kg), due to the total stem defoliation and higher concentrations of cellulose, hemicellulose and lignin. The specific density of the pellets made from milled chaffs of hemp stalks reached 1012 kg/m^3, so, they still had lower density than corn pellets, perhaps because of the anatomical structure of this plant. The net calorific value and durability of hemp pellets was significantly higher than of corn pellets.

Table 3.
Elemental composition, some physical and mechanical properties of biomass and pellets

Indices	*Cannabis sativa*	*Zea mays*
Carbon, %	46.88	44.87
Hydrogen, %	5.75	5.65
Nitrogen, %	0.64	0.83
Sulphur, %	0.03	0.24
Ash, %	2.23	4.04
Gross calorific value, MJ/kg	19.68	18.34
Specific density of pellets, kg/m^3	1012	1150
Durability of pellets, %	94	90
Net calorific value of pellets, MJ/kg	17.91	16.67

There are different results concerning the physical and mechanical properties of hemp biomass reported in research studies conducted by other authors. Alaru M. (2011) determined that the briquettes from dioecious hemp had better quality, because its male plants increased the mean content of lignin in the briquetting material, the dry mass contained: 5.3-6.3 % ash, 77.0-79.0 % volatiles, 16.6-16.7 MJ/kg calorific value. Prade T., 2011 stated that the calorific value of hemp biomass increased from 17.5 MJ/kg in July to 18.4 MJ/kg during the period August-December, to an average of 19.1 MJ/kg during the period January-April. Komlajeva L. *et al*, 2012 reported that the hemp stems are used as a fuel, and their average calorific value was 16.98 MJ/kg and ash content 4.3 %. Kaķītis *et al*, 2011, 2014, mentioned that hemp had gross calorific value of 18.29 MJ/kg and net calorific value of 15.54 MJ/kg, the ash content was 2.97%, the density of briquettes reached 1135 kg/m^3, the splitting force for particles reached 115 N/mm. Kolaříková M. *et al*, 2013 stated that, in Czech Republic, the calorific gross value of hemp was 18.6-19.3 MJ/kg and the net calorific value was 15.8-17.3 MJ/kg. According to Poisa L. *et al*, 2016, in Latvia, for the hemp cultivar 'Bialobrzeskie' the calorific value of stem biomass was 18.68 MJ/kg and of shives – 18.16 MJ/kg, the ash content was 2.16 % in shive biomass and 3.02 % in stem biomass, the ash melting temperature for the hemp stems was 1393.17ºC and for shives – 1368.85ºC. Jankauskiene Z. *et al*, 2017 stated that the fresh hemp biomass contained 336-373 g/kg DM, 44.13- 44.90% C, 0.85-1.20% N, 0.13-0.15% S, 6.54-13.50% ash, 17.50-18.10 MJ/kg calorific value. Streikus D. *et al*, 2017 noted that hemp pellet density reached 979.1-1286.2 kg/m^3 DM, heat value 17.37-17.34 MJ/·kg, ash content varied 3.30-3.89%, pressing force of pellet degradation 854.19-1223.21 N. Voicea I. *et al*, 2017 stated that biomass residues resulted from the processing of hemp stems had 9.66-9.75% moisture, 3.00-4.53-9.75% ash, 75.34-77.87% volatile matter and 17.52-17.98 MJ/kg lower calorific value. Jasinskas A. *et al*, 2020 found that fibrous hemp contained 3.58% ash, 17.37 MJ /kg net calorific value and pellet density reached 1171.7 kg/m^3 DM. Dok M. *et al*, 2021 noted that the studied biomass from cannabis varieties had 4.256-4.589 kcal/kg calorific value, and obtained pellets had 3.76-11.72% ash and 87.57-96.03% durability resistance. Frankowski J. & Sieracka D. 2021 stated that the analyzed hemp biomass was characterized by 41.23% cellulose, 14.12% lignin, 29.76% hemicellulose, 19.42% pentosans, 6.58% ash, 5.66% hydrogen, 0.52% nitrogen, 18.30 MJ/kg high calorific value and 17.10 MJ/kg heat of combustion.

CONCLUSIONS

The investigated industrial hemp, *Cannabis sativa*, may be used as multi-purpose feedstock for renewable energy production; the fresh and ensiled mass can be used as co-substrate in biogas generators for the production of biomethane, and dry stalks – to obtain compact solid fuel – pellets.

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