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BIOMASS QUALITY OF HEMP, *Cannabis sativa* L., AND PROSPECTS OF ITS USE FOR VARIOUS ENERGY PURPOSES

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Abstract

Plant biomass is an important renewable energy source in the world, and its importance has increased in regional and national energy strategies. The main objective of this research has been to evaluate the dry biomass quality of hemp, Cannabis sativa L., collected from the experimental field of the National Botanical Garden (Institute), Chişinău *as feedstock for the production cellulosic ethanol and solid bio fuel, namely briquettes. Corn stalks, Zea mays, were considered as control. The analysis of the chemical composition suggested that the dry matter of the whole hemp plants contained 556 g/kg cellulose, 309 g/kg hemicellulose and 105 g/kg acid detergent lignin, but corn stalks - 417 g/kg cellulose, 250 g/kg hemicelluloses and 82 g/kg acid detergent lignin. The theoretical ethanol yield from structural carbohydrates averaged 628 L/t in hemp substrates, as compared with 485 L/t in corn substrates. The bulk density of the milled chaffs of tested biomass, varied from 100 to132 kg/*m^3*, the gross calorific value - from 17.8 to 19.0 MJ/kg, the ash content - from 2.1 to 4.4%. The Cannabis sativa biomass was characterised by high gross calorific values and low ash content. The specific density of hemp briquettes reached 867 kg/*m^3*. Hemp, Cannabis sativa, may serve as multi-purpose feedstock for renewable energy production.*

Key words: biomass quality, briquettes, *Cannabis sativa*, *calorific values, theoretical ethanol yield.*

INTRODUCTION

The interest in alternative energy sources has increased in recent years due to the higher awareness of the negative impacts of climate change and the depletion of fossil fuel reserves. Hydro, bio, geothermal and solar energies are among these alternative energy sources. Biomass is the most developed renewable energy source with a large number of applications starting with direct heating for industrial or domestic purposes and ending with electricity generation or production of gaseous and liquid fuels. The flexibility of biomass as an energy carrier has led to the development of a wide range of biomass conversion technologies and growing biomass share within the global energy balance. According to Eurostat, bioenergy makes up over two thirds of the European Union's renewable energy production.

Since the time humans discovered fire, plant biomass has been a primary source of fuel. Plant biomass is an important renewable energy source in the world, and its importance has increased in regional and national energy strategies. Energy crops are a part of the modern biomass production and can be converted into various types of fuels or energy. The target of an intensified use of agricultural crops as renewable sources of energy thus represents an important question and challenge in the intersection between energy, environmental, agricultural, research and economic policy (Roman et al., 2016).

The combustion of solid biomass represents a direct conversion of biogenic primary energy sources. The densification of plant biomass into pellets and briquettes, contributes to improving its energy efficiency as a fuel, which makes it suitable for use by small households and by industrial consumers.

Ethanol is one of the most appealing fuels in the transportation sector, because it can be blended with petrol or used in its pure form in modified engines. Most of the bioethanol is produced from cereals or sugar cane, but the share of cellulosic bioethanol is rapidly increasing. The advantage of the cellulosic bioethanol, compared to traditional grain/sugar ethanol, is the fact that it is possible to use entire above-ground biomass of a plant for bioethanol production, thus enabling better efficiency and land use. Using lignocellulosic agricultural residues and energy crops as raw materials for the production of ethanol fuel will also minimize the potential conflict between food and fuel production.

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, C3 plant, stems growing up to 4 m tall, leaves are finely hairy with alternate leaves, 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 a 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 strobilus. The fruiting body is greyish-brown in colour and about 4 mm long. The deep (1.0-1.5 m), tap root system of hemp contributes to a good aeration of the soil and optimum air/water conditions. It also loosens the soil and allows the plant to use water from deeper layers of the soil. Hemp is a crop producing big amounts of biomass, which, when ploughed down, contributes to the fast restoration of the biologically active soil layer on degraded land. Furthermore hemp requires little to no use of fertilizers and pesticides making it a very sustainable crop. Hemp has historically been used in fibre, food and medicinal production. The cultivation, possession and use of hemp were strictly forbidden in most countries of the world during the 20 century. Today hemp is a niche crop, cultivated on more than 33,000 ha in the European Union. Fibrous hemp is a plant that easily adapts to new conditions of vegetation and is characterized by a rich diversity of forms. Hemp stem, depending on the cultivars, consists of approximately 20-40% of fibre, which is outside of the stem, and 60-80% of wood (hurds). It is a phytosanitary plant which makes possible its introduction into a variety of crop rotations. In Lithuania, hemp produced 16.2-22.6 t/ha of dry biomass (Jankauskienė and Gruzdevienė, 2010).

Since ancient times, hemp has been grown in our region for fibre, oil and food production, animal bedding and fuel (Tabără, 2009). However, in recent years, there has been increasing interest with regards to using hemp crop to obtain raw material for biorefineries and generation of energy. Due to the crops' high biomass yield and oil content, it can be used as a feedstock for the production of solid biofuels, biogas, biodiesel and cellulosic bioethanol (Alaru et al., 2011; Kreuger et al., 2011; Prade et al., 2011; Tutt et al., 2013; Jasinskas et al., 2014; Kuglarz et al., 2014; Kraszkiewicz et al., 2019). The calorific value of hemp biomass varied from 17.9 to 19.8 MJ/kg depending on the part of the plant (Mankowski et al., 2014).

The main objective of this research was to evaluate the dry biomass quality of hemp, *Cannabis sativa*, as feedstock for the production cellulosic ethanol and solid bio fuel-briquettes.

MATERIALS AND METHODS

Industrial hemp, *Cannabis sativa* cultivar 'Bialobrzeskie' was cultivated at the experimental plot of the National Botanical Garden (Institute) "Alexandru Ciubotaru", Chişinău, latitude 46°58′25.7″N and longitude 28°52′57.8″E, served as subjects of the research, and corn stalks (*Zea mays*) were used as control.

Hemp seeds were sown in middle May, 200 viable seeds m^2. Hemp stalks were collected in the September-February period. Stems and leaves (including fine stems) were separated manually after drying and weighed.

The hemp stalks were chopped and disintegrated by knife mill with a sieve with the mesh size of 1 mm. The content of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were evaluated using the near infrared spectroscopy (NIRS) technique PERTEN DA 7200 at the Research-Development Institute for Grassland Brasov, Romania. The cellulose is ADF minus ADL and hemicelluloses is NDF minus ADF. Theoretical Ethanol Potential (TEP) was calculated according to the equations of Goff et al. (2010) based on conversion of hexoses (H) and pentoses (P) sugars:

$H = [\% \, Cel+(\% \, HC \times 0.07)] \times 172.82$

$P = [\% \, HC \times 0.93] \times 176.87$

$TEP = [H + P] \times 4.17$

For the production of solid biofuel, the harvested hemp stalks were chopped into chaff with the use of a stationary forage chopping unit. The chopped phytomass was milled in a beater mill equipped with a sieve with diameter of openings of 10 mm using the equipment SM 100. The physical and mechanical properties of dry biomass were determined according to the European Standards, at the State Agrarian University of Moldova: the moisture content of the plant material was determined by SM EN ISO 18134 in an automatic hot air oven MEMMERT100-800; the content of ash was determined at 550ºC in a muffle furnace HT40AL according to SM EN ISO 18122; automatic calorimeter LAGET MS-10A with accessories was used for the determination of the calorific value, according to SM EN ISO 18125; the particle size distribution was determined according to SM EN ISO 17827 using standard sieves, the collected particles in each sieve were weighed; the cylindrical containers were used for the determination of the bulk density, calculated by dividing the mass over the container volume according to SM EN ISO 17828, SM EN ISO 18847. The briquetting was carried out by hydraulic piston briquetting press BrikStar model 50-12 (Briklis). The mean compressed (specific) density of the briquettes was determined immediately after removal from the mould as a ratio of measured mass over calculated volume.

RESULTS AND DISCUSSIONS

We could mention that, under the climatic conditions of the Republic of Moldova, the hemp seed emerged in 4 days after sowing and reached growth stage of the first pair of true leaves in 8-9 days after sowing. During the first month after the emergence of seedlings, the root system developed more intensively. The daily growth of the main root during this period was from 1.5 to 1.8 cm, the lateral roots appeared 8-10 days after emergence, when the length of the main root was 11-13 cm. The taproot system of the hemp was strong, well developed, penetrating to a depth of up to 200 cm, developed 25-50 lateral roots, due to which the plants were resistant to flattening and unfavourable weather conditions (heavy rains, wind). They very effectively used the nutrients from the soil, especially below the arable layer. It has been established that at the beginning of June, hemp plants were already 12-14 cm in height, had 3-5 pairs of true leaves. The aboveground part of the plants developed more intensively at the end of June, in the middle of August, the height of hemp plants reached 360-385 cm. The buds emerged at the beginning of July and the first flowering hemp plants appeared only in the second half of July, the mass flowering period lasted 29-36 days. The beginning of maturity of seeds was noticed at the end of August and finished in October.

It is known that leaf and moisture contents in the harvested energy biomass influenced the costs of transport, storage, drying and processing. In the middle of August, some of the leaves on the lower part of the stem turned yellow and fell. The results of the assessment of moisture and leaf contents in the in harvested energy biomass of *Cannabis sativa* are shown in Table 1. After taking samples in the first days of September, it was found that the moisture and leaf contents of aboveground parts were 72.8% and 34.1%, respectively. In October-November, the defoliation and dehydration of the hemp stems accelerated, the leaf content in the harvested biomass decreased to 4.0%, and the moisture content lowered to 22.3%, respectively. In winter period, when temperatures below 0°C were recorded, the leaves were falling and the stems were already dry and could be harvested and chopped directly in the field. The yield of harvested hemp stems in February was 9.5 t/ha.

Table 1. Moisture and leaf contents in the harvested energy biomass of *Cannabis sativa*, %

Harvesting Period	*Cannabis sativa*	
	Moisture content	Leaf content
September	72.8	34.1
October	55.0	15.1
November	22.3	4.0
December	17.7	2.7
January	14.3	0.5
February	10.4	0.1

Mankowski and Kolodziej (2008), mentioned that, hemp generates about 10-15 t of biomass per hectare and it has been estimated that 1 ha of hemp absorbs about 2.5 tons CO_2, which results in a significant reduction of the greenhouse effect. The research conducted in the University of Bologna, Italy by Zatta and Venturi (2009), revealed that, depending on the harvest time, the hemp stem dry matter yield varied from 11.2 to 16.5 t/ha. Prade et al. (2011) demonstrated that hemp grown for energy could provide yields of 14.4 t/ha when harvested in autumn and 9.9 t/ha when harvested in spring. Kolarikova et al. (2013) stated that, in the Czech Republic, the hemp yield from autumn harvest was 22.1-25.5 t/ha or 8.6-9.65 t/ha dry matter.

The major components of lignocellulosic biomass are cellulose, hemicellulose and lignin. Cellulose is a crystalline and linear structure made up of units of glucose strongly linked together by β-1-4-glycosidic bonds. These linkages give cellulose very high crystalline structure making it resistant to degradation. It is the most abundant organic polymer on earth. Hemicellulose, on the other hand, consists of linear and highly branched mixture of pentoses (xylose and arabinose) and hexoses (glucose, galactose, and mannose). Lignin is a highly branched polyphenolic polymer, which gives stability to biomass structure. The contents of these components vary significantly depending on the plant species, type of biomass, harvesting period. The possibility of converting lignocellulosic biomass in bioethanol fuel is currently an area of great research interest around the world.

The bioethanol yields are influenced by several factors, including biomass yield and its tissue composition (ratios of cellulose, hemicellulose and lignin). Analyzing the cell wall composition of dehydrated stems, Table 2, we could mention that the concentrations of structural carbohydrates in hemp, *Cannabis sativa*, substrates are much higher in comparison with corn stalks, *Zea mays*, substrates. The analysis of the chemical composition suggested that the dry matter of the whole hemp plants contained 556 g/kg cellulose, 309 g/kg hemicellulose and 105 g/kg acid detergent lignin, but corn stalks - 417 g/kg cellulose, 250 g/kg hemicellulose and 82 g/kg acid detergent lignin. The estimated content of structural sugars in hemp stalks: 85.0 g/kg pentoses and 35.6 g/kg hexoses, but in corn stalks - 75 g/kg and 41 g/kg, respectively. The theoretical ethanol yield from structural carbohydrates averaged 628 L/t in hemp substrates, as compared to 485 L/t in corn substrates.

Table 2. The cell wall composition and theoretical ethanol potential of *Cannabis sativa* dry matter

Indices	*Cannabis sativa*	*Zea mays*
Acid detergent fibre, g/kg	661	499
Neutral detergent fibre, g/kg	970	749
Acid detergent lignin, g/kg	105	87
Cellulose, g/kg	556	417
Hemicellulose, g/kg	309	250
Hexose sugars, g/kg	99.8	75.1
Pentose sugars, g/kg	50.8	41.1
Theoretical ethanol potential,	628	485

Some authors mentioned various findings about the hemp biomass quality. According to Zatta and Venturi (2009), the chemical composition of stems of female hemp plants, harvested at full flowering stage, was: 58-63% cellulose, 13-17% hemicellulose and 9-10% lignin, but hemp stems harvested at beginning of seed maturity - 62-65% cellulose, 12-16% hemicellulose and 9-10% lignin, the calculated bioethanol production varied from 2799 up to 4500 litres/ha. Agbor et al., 2011, mentioned that purified hemp substrates contained 91.30% NDF, 86.36 ADF, 4.94% hemicellulose, 78.94% cellulose, 7.92% lignin with specific ethanol yield 1.99 mMol/g cellulose, but purified wood substrates 95.57% NDF, 93.40% ADF, 2.17% hemicellulose, 91.27% cellulose, 2.13% lignin, specific ethanol yield 1.79 mMol/g cellulose, respectively. Tutt and Olt (2011) stated that hemp contained 5.25% ash, 53.86% cellulose 10.6% hemicellulose, 8.76% lignin; the glucose yield was 312.7 g/kg or 58.06% from possible maximum values. Thygesen et al. (2007) reported the chemical composition of raw hemp fibre was as follows: 55-72% cellulose, 8-19% hemicellulose, 2-5% lignin, <1% wax and 4% minerals; hurds had higher content of lignin (19-21%) and hemicellulose (31-37%), but lower amount of cellulose (36-41%). Wawro et al. (2019) found that the chemical composition of hemp biomass before pre-treatment consisted of 50.82% cellulose, 27.79% hemicellulose and 14.68% lignin, but after alkaline treatment, the cellulose content in biomass increased to 62.70%, lignin to 15.12% and hemicellulose content decreased significantly to 20.16%. In comparison, for sorghum crop, the theoretical ethanol potential ranged from 560 to 610 L/t of dry biomass (Goff et. al., 2010).

Biomass is very difficult to handle, transport, store and utilize in its original form due to factors that can include high moisture content, irregular shape and sizes, and low bulk density. Densification can produce more compact products with uniform shape and sizes that can be more easily handled using existing handling and storage equipment and thereby reduce the costs associated with transportation, handling and storage. Baling, briquetting and pelleting are the most common biomass densification methods used for solid fuel applications. The quality and structural integrity of a briquette is affected by the size of particles, moisture, contents of lignin and cellulose, but also by the cellular structure of plant stems and leaves. It is known that low ash and moisture contents increase combustibility, and high bulk density fuel is convenient to be transported. Physical and mechanical properties of hemp biomass and prepared briquettes are presented in Table 3. The ash content in hemp biomass was lower (2.1%) than in corn stalks (4.4%), hemp has an excellent gross calorific value (19.0 MJ/kg), greater than corn stalks (17.8 MJ/kg), due to the fast defoliation and the stems with higher concentrations of cellulose, hemicellulose and lignin.

Table 3. Some physical and mechanical properties of biomass and solid biofuel

Indices	*Cannabis sativa*	*Zea mays*
Ash content of biomass, %	2.1	4.4
Gross calorific value of biomass, MJ/kg	19.0	17.8
Bulk density of chopped chaffs, kg/m^3	117	87
Bulk density of milled chaffs, kg/m^3	132	100
Specific density of briquettes, kg/m^3	867	923
Net calorific value of briquettes, MJ/kg	15.4	14.0

The bulk density of the hemp chopped chaffs reached 100 kg/m^3 and milled chaffs – 132 kg/m^3. The densified hemp solid fuel-briquettes have optimal specific density (867 kg/m^3), but still lower than corn briquettes (923 kg/m^3), perhaps because of the anatomical structure and the high content of fibre in hemp biomass. The net calorific value of hemp briquettes reached 15.4 MJ/kg and corn stalks 14.0 MJ/kg.

There are different results concerning the physical and mechanical properties of hemp reported in research studies conducted by other authors. Alaru et al. (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, dioecious hemp had 5.3-6.3% ash, 77.0-79.0% volatiles, dry mass calorific value 16.6-16.7 MJ/kg, actual calorific value 15.3-15.4 MJ/kg. Prade et al. (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. According to Poisa 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. Jasinskas et al. (2014) noted that bulk density of seeder hemp chaff was 28.2 kg/m^3 DM and hemp mill 101.0 kg/m^3 DM, the specific density of pellets was 877.8 kg/m^3 and the calorific value – 18.2 MJ/kg. Kakitis 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. Kolarikova 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. Kraszkiewicz et al. (2019) reported that the heat of combustion of hemp biomass was 18.089 MJ/kg and the calorific value 16.636 MJ/kg, the ash content 2.51%, the physical properties of briquettes: the density of briquettes 828 kg/m^3 and the mechanical durability - 98.17%.

CONCLUSIONS

The dry matter of the whole hemp plants contained 556 g/kg cellulose, 309 g/kg hemicellulose and the theoretical ethanol yield from structural carbohydrates averaged 628 L/t. The *Cannabis sativa* biomass was characterized by high gross calorific values (19.0 MJ/kg) and low ash content (2.1%).

The specific density of hemp briquettes reached 867 kg/m^3 and the net calorific value – 15.4 MJ/kg.

Hemp, *Cannabis sativa* may serve as multi-purpose feedstock for renewable energy production.

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