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PERSPECTIVES FOR THE USE OF BIOMASS GENERATED BY SOME MISCANTHUS GENOTYPES IN THE PRODUCTION OF DENSIFIED SOLID BIOFUELS

Nicolae Daraduda*, ORCID: 0000-0001-5683-0431,
Grigore Marian, ORCID: 0000-0002-9975-2522

State Agrarian University of Moldova, 44 Mircesti Str., Chisinau, Republic of Moldova
*Corresponding author: Daraduda Nicolae, *n.daraduda@uasm.md*

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Abstract. Miscanthus is a Poaceae family perennial crop of C4 bioenergy characterized by the multilateral use potential, including the production of biofuels. The paper aimed to study the opportunity to use the biomass generated by two Miscanthus genotypes: *Miscanthus* × *giganteus* and *Miscanthus sinensis* in the production of densified solid biofuels. We quantified the biomass generated by crops that were 5 years old, harvested from both genotypes after the vegetation period, the year 2020. Samples were taken from the experimental lots of the Alexandru Ciubotaru National Botanical Garden (Institute) from the Republic of Moldova in autumn, immediately after the initial onset of senescence and in spring of the following year, before the start of the growing season. The results showed that the above-ground biomass generated by both *Miscanthus* genotypes harvested in spring had had significantly higher quality characteristics compared to the biomass harvested in autumn. Virtually all qualitative indices of the *Miscanthus* × *giganteus* biomass harvested in spring comply with the requirements of the ENPlus international standards for densified solid biofuels. The *Miscanthus sinensis* biomass, both, had lower indices than the *Miscanthus* × *giganteus* biomass from both qualitative and quantitative points of view and the former can be used as a filler in various mixtures of raw material for the production of solid biofuels.

Keywords: *energy crops, Miscanthus x giganteus Titan, Miscanthus sinensis, biomass properties*

Rezumat. Miscanthus este o cultură perenă din familia Poaceae de bioenergie C4, caracterizată prin potențial de utilizare multilaterală, inclusiv în producția de biocombustibili. Lucrarea își propune să analizeze oportunitatea utilizării biomasei generate de două genotipuri de Miscanthus: *Miscanthus* × *giganteus* și *Miscanthus sinensis* în producția de biocombustibili solizi densificați. A fost cuantificată biomasa generată de culturi vechi de 5 ani, recoltate de la ambele genotipuri după perioada de vegetație, anul 2020. Au fost prelevate probe din loturile experimentale ale Grădinii Naționale Botanice (Institutul) Alexandru Ciubotaru din Republica Moldova toamna, imediat după debutul senescenței și în primăvara anului următor, înainte de începerea sezonului de vegetație. Rezultatele au arătat că biomasa supraterană generată de ambele genotipuri de Miscanthus recoltate primăvara a avut caracteristici de calitate semnificativ mai mari în comparație cu biomasa recoltată toamna. Practic, toți indicii calitativi ai biomasei de *Miscanthus* × *giganteus* recoltați primăvara respectă cerințele standardelor internaționale ENPlus pentru biocombustibili solizi densificați. Biomasa *Miscanthus sinensis*, ambele variante, au avut indici mai mici decât biomasa *Miscanthus* × *giganteus* atât din punct de vedere calitativ cât și cantitativ, iar prima poate fi folosită ca umplutură în diverse amestecuri de materie primă pentru producerea de biocombustibili solizi.

Cuvinte cheie: *culturi energetice, Miscanthus x giganteus Titan, Miscanthus sinensis, proprietăți ale biomasei.*

Introduction

Biomass biofuels are currently considered as one of the main alternative energy sources. However, the use of plant lignocellulosic biomass as a raw material in the production of densified solid biofuels in the Republic of Moldova has only been flourishing for the last two decades. Particular attention in the biomass fuel production chain is focused on identifying certain types of biomass that can provide sufficient quantities to initiate the production of densified solid biofuels that can compete with traditional solid fuels [1]. Therefore, the biomass generated by some perennial energy plants has a special role in the process. The cultivation of perennials is argued by the fact that they present promising prospects for several sectors of the bioeconomy [2], ensuring the production of both a whole range of biomass industrial products and the production of renewable energy [3].

The main purpose of producing renewable energy from biomass is to replace fossil energy resources with biological ones [4]. It should be noted that the production of bioenergy is one of the nine objectives of the European Parliament's proposal on agricultural policy for 2021-2027 [5], which is particularly focused on the ongoing development of renewable energy sources.

This study emphasizes the qualitative estimation of the biomass generated by some perennials, which are suitable for cultivation under the conditions of the Republic of Moldova in terms of comparing their characteristics with those imposed by EN Plus 3 European standards.

Biomass quality is one of the most important factors that affect the performance of the final product and serves as an argument to start a business that would produce densified solid biofuels in the given geographical area [6,7]. The most important characteristics of the biomass used for energy purposes refer to the combustion power expressed by the calorific value, the content of moisture, ash and volatiles, the content of C, O, S, N and Cl.

It is also interesting to establish the content of the most important carbohydrate components of the biomass (lignin, hemicellulose and cellulose), the components that directly affect the quality of densified solid biofuels and the technological capacity to process and modify some properties by means of various thermochemical processes [1 pp. 26-28; 8]. The need for this study also derives from several researchers’ statements about the dependence of the properties and productivity of energy crops on the region where they are grown, their genotype and agricultural management [9, 10-12].

The paper aims to consider and experimentally verify the opportunity to use the biomass generated by the *Miscanthus* × *giganteus (M.* x *giganteus)* and *Miscanthus sinensis* (*M. sinensis*) genotypes as a raw material for the production of densified solid biofuels in the form of pellets and briquettes.

The *Miscanthus* biomass samples taken from the experimental fields of the Alexandru Ciubotaru National Botanical Garden (Institute) from the Republic of Moldova in 2020 and 2021 served as the object of the research.

The study was conducted within the SAUM Solid Biofuels Laboratory using standard methods testing densified solid biofuels. As a result of the speciality literature review and experimental results on the use of the *Miscanthus biomass* as a raw material in the production of pellets and briquettes, it has been noted that this energy crop is a safe source of raw material for the production of densified solid biofuels, as well as has some other uses in bio-economy.

Materials and methods

Biomass selection, sampling and sample preparation. The biomass and densified solid biofuels in the form of pellets and briquettes from two *Miscanthus* genotypes: *M.* x *giganteus Titan* and *M. sinensis* were studied. Both types of biomass were taken from the experimental fields of the Alexandru Ciubotaru National Botanical Garden (Institute) of the Republic of Moldova. The samples were taken from the plantations, established in 2015.

The biomass for this study was taken from the harvest of 2020, i.e. in the fifth year of vegetation. Biomass samples were harvested from several randomly selected middle cuttings using manual cutters (see Figure 1). The surface of the cuts was set at 2 m^2, and the cutting height of approx. 5 cm. The samples were collected in two periods: in November, immediately after the initial onset of senescence and at the beginning of March of the following year (2021), before the start of the vegetation period.

The biomass harvested in autumn was dried by the forced conversion method in the SAUM Solid Biofuels Laboratory Dryer, and the spring harvest was naturally dried right in the field. The moisture at harvest was determined for both types of samples.

Figure 1. The process of harvesting the Miscanthus × giganteus biomass on the experimental field of the Alexandru Ciubotaru National Botanical Garden (Institute) from the Republic of Moldova in the spring of 2021.

Samples were taken at random from whole reeds, per about 200 kg during both harvest periods. Both the samples taken in autumn and those taken in spring were initially coarsely ground with the help of the ROJEK 517 50 branch shredder, produced in the Czech Republic. Chip sizes after shredding ranged from 50 to 100 mm.

Biomass sampling for testing was performed after manual biomass homogenization in accordance with the requirements of SM EN ISO 18135: 2017. The biomass samples and final products in the form of pellets and briquettes were prepared according to the requirements of EN ISO 14780: 2017. Thus, five samples were prepared for each sample group. The samples had been shredded beforehand in the SV 7 shredder with a 6 mm mesh screen.

Proximity analysis of the biomass. In order to be able to forecast the costs related to the biomass transportation and storage as well as to determine the biomass energy density, the bulk density of coarsely crushed biomass was determined immediately after harvest and estimated while the moisture content was 10% (reference moisture content for densified solid biofuels).

The bulk density was determined according to the SM EN ISO 17828: 2017 standard using the 50-litre container. The size of the biomass after shredding ranged from 35 to 100 mm.

The bulk density of the biomass at harvest was determined by means of the following relation:

$$BD_{ar} = \frac{m_2 - m_1}{V}, \tag{1}$$

where m_1 is the mass of the empty container, kg; m_2 is the mass of the container with the studied biomass sample, kg.

The bulk density of the dry base was determined by the relation:

$$BD_d = BD_{ar} \cdot \frac{100 - M_{ar}}{100}, \tag{2}$$

The bulk density for the given moisture content of the biomass was calculated as follows:

$$BD_{M\%} = BD_d \cdot \frac{100}{100 - M_{ar}} \tag{3}$$

where M is the moisture content at harvest,%

The moisture content was measured immediately after harvest by drying in accordance with the requirements of the standard SM EN ISO 18134-3: 2017. Drying was performed by keeping the temperature stable (105 ± 2) °C in the German oven Memmert UNB 100 until the dry samples obtained the same mass. Before drying, the samples were shredded in the SM 100 cutting mill, produced by the German company Retsch with a 1 mm mesh screen.

The ash content was determined by thermogravimetric testing in accordance with the requirements of the standard SM EN ISO 18122: 2017. The samples to be tested were previously ground in the SM 100 cutting mill with a 1 mm mesh screen. Next, the crushed mass with a grain size of up to 1 mm was dried in the Memmert heat-adjustable oven to zero humidity, according to the SM EN ISO 18134-3: 2017 standard. Calcination of the samples had been done in the oven with an LH 05/13 socket for 6 hours at the temperature of 550 °C.

The percentage of ash resulting from calcination was calculated using the following equations:

$$A_d = \frac{(m_3 - m_1)}{(m_2 - m_1)} \cdot 100, \tag{4}$$

$$A_M = A_d \cdot \left(\frac{100}{100 - W}\right), \tag{5}$$

where A_d is the dry ash content; A_M is the ash content with the moisture content of the biomass M %; m_1 is the mass of the empty crucible, g; m_2 the mass of the crucible plus the mass of the sample subjected to testing with 0% moisture, g; m_3 is the mass of the crucible plus the mass of ash, g; W is the moisture of the analyzed sample,%.

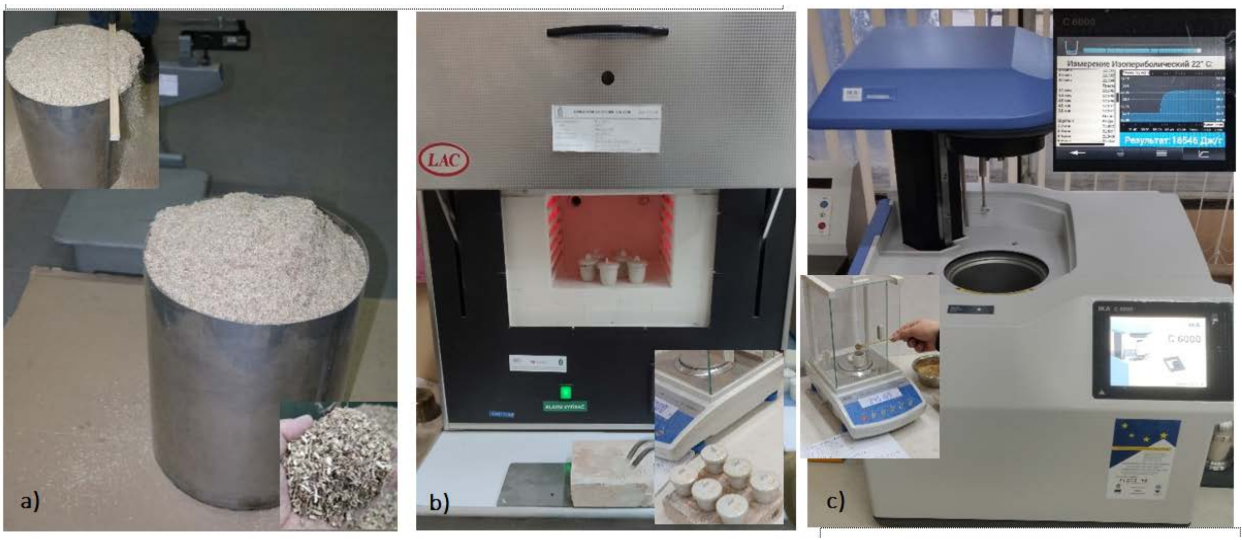

Figure 2. Sequences during miscanthus biomass analysis: *a) bulk density; b) ash content; c) calorific value.*

The content of volatiles for the studied samples V_d, expressed as a percentage, in relation to the mass in the dry base shall be calculated by the following formula:

$$V_d = \left[\frac{100(m_2 - m_3)}{m_2 - m_1} - M_{ad}\right] \cdot \left[\frac{100}{100 - M_{ad}}\right] \quad (6)$$

where m_1 is the mass of the empty ampoule with a lid, g; m_2 is the mass of the ampoule with a lid and the tested sample before drying, g, m_3 is the mass of the ampoule with a lid and non-volatile residues after drying, g; M_{ad} is the moisture content of the analyzed sample in % determined in accordance with the standard SM EN ISO18134-3.

Biomass energy capacity. To determine the possible amount of heat that could be obtained from the burning of the studied biomass, its combustion power was determined by measuring the higher calorific value and calculating the net calorific value and energy density.

The highest calorific value was established in accordance with the requirements of the SM EN ISO 18125: 2017 standard by calcining the samples in the German isoperibolic calorimetric pump IKA C6000.

The net calorific value was calculated for the samples with the moisture of 0 and 10%, tested at constant pressure by means of the following formulas:

$$q_{p,\,net,\,d} = q_{v,\,gr,\,d} - 212.2 \cdot w(H)_d - 0.8 \cdot [w(O)_d + w(N)_d], \quad (7)$$

$$q_{p,\,net,\,M=10\%} = q_{v,\,gr,\,d} - (1 - 0.01M) - 24.43M, \quad (8)$$

where $q_{v,gr,d}$ is the highest calorific value at the constant volume, J/g; $q_{p,net,d}$ is the net calorific value measured for the samples with the moisture content of 0, J/g; $q_{p,net,M=10\%}$ is the net calorific value for the samples with the moisture of 10%, J/g; $w(H)_d$ is the mass participation of hydrogen determined in the dry basis, %; $w(O)_d$ is the mass participation of oxygen determined in the dry basis, %; $w(N)_d$ is the mass share of nitrogen determined in the dry basis, %.

Energy density was determined as the amount of energy stored per unit volume by means of the following relation:

$$Ed_{M=0} = BD_d \cdot q_{p,net,d}. \quad (9)$$

$$Ed_{M=10\%} = BD_{M=10\%} \cdot q_{p,net,M=10}. \quad (10)$$

where $Ed_{M=0}$ is the energy density of the dry base biomass; $Ed_{M=10\%}$ is the energy density of the biomass with the moisture content of 10%.

The proportions of C, H, N, S and Cl were analyzed using the elemental analyzer Vario Macro Cube CHNS & Cl, produced by the German company Elementary. The samples with the known mass are completely burned until the formation of gaseous combustion products, which separate on a chromatographic column.

The volatile matter content was determined for the *Miscanthus* samples, previously ground in the SM 100 cutting mill with a 1 mm mesh screen. The dimensions of the studied biomass particles did not exceed 1 mm and their mass was within (1 ± 0,1) g. The samples were kept for (7 ± 0,083) min in the oven with the LH 05/13 socket at the temperature of (900 ± 10) °C in accordance with the requirements of the standard SM EN ISO 18123: 2017.

Results and Discussions

Miscanthus is one of the perennial plants, which is among the most widespread energy crops, which can be potentially used as a raw material in the production of biofuels [13-15]. The energy potential of this crop is widely used in the United States and Europe, especially as a raw material for the production of biofuels [16]. *Miscanthus* is recognized due to its high socio-economic potential, perennial nature, high productivity and low cultivation requirements, since it can be cultivated extensively on soils, which are less suitable for other crops [17, 13]. The plant is resistant to diseases and pests [13; 4]. It is considered an effective plant for combating erosion; its cultivation can be carried out by means of agricultural techniques used in ordinary agrotechnical operations [18]. As it is a perennial crop, *Miscanthus* requires no circulation and can be cultivated for 15-20 years on soils less suitable for other crops [19].

Although *Miscanthus* seems to be a major candidate for the production of raw materials and continuous development of renewable energy sources from biomass, its production in the Republic of Moldova is at the initial stage, playing a minor role in national agriculture.

At the moment there are several registered varieties of *Miscanthus* thanks to the research carried out within the Alexandru Ciubotaru National Botanical Garden (Institute) from the Republic of Moldova. GIANT MISCANT, the Titan variety [20 p. 105] and four varieties of *Miscanthus* x *giganteus (JM Greef & Hodk & Renvoize*) - Aphrodite, Athena, Atropos and Titan (B) are among them [21 p. 92].

The *M.* × *giganteus* is an interspecies triploid hybrid from the natural cross of *M. sinensis* (2n = 2x) diploid and *Miscanthus sacchariflorus* (2n = 4 x) triploid, the Poaceae family, rhizome group C4 native to East Asia, which was introduced to Europe in the early 20th century as an ornamental plant [2, 22]. It has an erect stem, which is 2.5–3.5 m long (it can reach 5 m) with linear leaves that are 50–60 cm long and 2.8–3.3 cm wide, the ligule truncated with hairs, which 2–3 mm long. The inflorescence is a panicle, which is 30–55 cm long with branches of 15–21 cm, the harvest is 18-27 t/ha [23 pp. 36]. Its widespread use for the production of biofuels in Europe was registered at the end of the last century [24, 16].

The *M. sinensis* is a popular perennial herb, especially in warm areas, whose yields increase progressively in the first years of growth [25]. Generally speaking, the *M. sinensis* has characteristics, which are similar to those of the *M. × giganteus* genotype. However, it is an earlier species compared to the *M. × giganteus* and it is more tolerant to water stress. [26]. It has a lower yield than the *M. × giganteus*, with a lower aboveground biomass production [25], therefore the ability to use the *M. sinensis* genotype for energy purposes is less studied.

The following are the results of the biomass quantitative and qualitative study, resulting from the cultivation of the *M.* x *giganteus* genotypes, *Titan* and *M. sinensis* cultivated under the conditions of the Republic of Moldova. Energy capacity, proximal and final analysis are considered the most important parameters for the evaluation of the biomass used in the direct combustion process.

The main properties of the studied biomass are shown in Tables 1, 2 and 3. The values for the parameters presented in these tables represent the average calculated from five repetitions of each experiment and the confidence interval for each average value expressed as a standard deviation (σ) for the confidence level of 95% (α = 0.05) as $\overline{x} = \pm 1{,}96\frac{\sigma}{\sqrt{n}}$.

Moisture and ash content, volatiles and bulk density are considered as the elements of the proximal analysis. Carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and chlorine (Cl) are considered as final analyses.

Table 1

Proximity analysis of the *Miscanthus* x *giganteus* and *Miscanthus sinensis* biomass

Biomass	M_{rec}	A_d	$A_{r\,(M = 10\%)}$	Vd	BD_{rec}	BD_d	$BD_{M = 10\%}$
	%				kg/m^3		
M. x *giganteus titan (a.h.)*	43.2 ± 6	2.79 ± 0.03	3.1	81.49	182.6 ± 8	103.7	115.2
M.s x *giganteus titan (s.h.)*	18.4 ± 4	1.185 ± 0.1	1.32	83.65	142.4 ± 4	116.2	129.1
M. sinensis (a.h)	49 ± 7	4.07 ± 0.2	4.22	83.44	180.4 ± 7	92.0	102.2
M. sinensis (s.h.)	19 ± 3	2.21 ± 0.2	2.46	83.48	128.0 ± 3	103.6	115.2

<u>Note:</u> M_{rec}. is the moisture content of the biomass at harvest; A_d is the dry ash content; $A_{r\,(M = 10\%)}$ is the ash content calculated for the moisture content of the biomass equal to 10%; Vd is the volatile matter content; BD_{rec} is the bulk biomass density estimated immediately after harvest; BD_d and $BD_{M = 10\%}$ is the bulk biomass density calculated in the dry base and for the moisture of 10% respectively; a.h. stands for „harvested in autumn”; s.h. stands for „harvested in spring”.

Table 1 presents the results of the proximal biomass analysis generated by the two *Miscanthus* genotypes studied in this paper. Based on the analysis of the data from Table 1, it can be concluded that the moisture content of the biomass harvested in autumn, immediately after the initial onset of senescence, is significantly higher than that of the biomass harvested in spring, before the start of the growing season. Thus, the biomass harvested in autumn has a moisture content of approx. 2.5 times higher than the one harvested in spring (it is 45.2 ± 6 and 18.4 ± 4% respectively for the *M.* x *giganteus* and 49 ± 7% and 19 ± 3% respectively for *the M. sinensis*.

Having analyzed the data on the moisture content of the *Miscanthus biomass* studied in this paper, it can be concluded that the biomass harvested in spring can practically be processed directly into densified solid biofuels, without being further dried or by light drying under natural conditions.

It is important to note that the ash content of the biomass harvested in spring is significantly lower than that of the biomass harvested in autumn, with a decrease from 2.79%

to 1.32% for the *M.* x *giganteus* biomass and from 4.07% to 2,21% for the *M. sinensis*. This can be explained by the fact that the spring harvest had fewer leaves than the autumn one, as well as by the increased content of various mineral microparticles in the biomass harvested in autumn.

The volatile matter content is in the range of 81.49% in the *M.* x *giganteus titan (a.h.)* up to 83.65% in the *Ms* x *giganteus titan (s.h.)*. The biomass of the *M. sinensis* practically showed the same volatile matter content of 83.44% for the biomass harvested in autumn and 83.48% for the biomass harvested in spring.

The bulk density of both *M.* x *giganteus titanium* and *M. sinensis* biomass harvested in spring, recalculated in the dry base and at the average processing moisture in solid biofuels (10%) is higher than that of the one harvested in autumn. Thus, the dry bulk density of the *M.* x *giganteus* biomass harvested in spring (116.2 kg/m^3) is 16% higher compared to the biomass harvested in autumn (100.1 kg/m^3). As to the *M. sinensis* biomass, the ratio between the bulk density of the biomass harvested in spring and that harvested in autumn is even higher (approx. 26%), increasing from 82 kg/m^3 to 103.6 kg/m^3.

It should be noted that the bulk density of the *Miscanthus* biomass at harvest is inversely related to that previously established in the dry basis and for the moisture content of 10%. This is explained by the significantly higher moisture content at harvest of the biomass harvested in autumn compared to the biomass harvested in spring. This finding is an additional argument in favour of the autumn harvest of the *Miscanthus* biomass used in the production of densified solid biofuels. It should be also added that the biomass estimated directly after harvest, generated by the *M. x giganteus* has a bulk density of approx. 10% higher than that generated by the *M. sinensis*.

Table 2 shows the energy capacity of the biomass generated by the studied *Miscanthus* genotypes expressed by both the calorific value and energy density. The term calorific value refers to the amount of heat released by the complete and perfect combustion of a unit mass of particles and the cooling of the flue gas to 25 °C. [1 p. 56]. It is necessary to estimate the combustion power of the biomass by means of the highest and lowest calorific values.

Table 2

The calorific value and energy density of the biomass generated by the *M.* x *giganteus* and *M. sinensis* varieties

Biomass	$q_{V, gr, d}$	$q_{p, net, d}$	$q_{p, net, M=10\%}$	$Ed_{M=0}$	$Ed_{M=10\%}$
		J/g		**MJ/m^3**	
M. x giganteus titan (a.h.)	18812.3 ± 245	17496.0 ± 252	15502.1 ± 124	1750.73	1723.57
M.s x giganteus titan (s.h.)	19688 ± 198	18409.1 ± 201	16578.3 ± 142	2139.1	2107.56
M. sinensis (a.h)	18685.2 ± 90.5	17552.8 ± 112	15553.2 ± 99	1615.11	1590.13
M. sinensis (s.h.)	19285.1 ± 175	18140.7 ± 176	16082.3 ± 156	1880.24	1852.10

Note: $q_{v,gr,d}$ is the highest calorific value at the constant volume; $q_{p,net,d}$ is the net calorific value in the dry base; $q_{p, net, M = 10\%}$ is the net calorific value for the samples with the moisture of 10%; $Ed_{M = 0}$ is the energy density of the biomass in the dry base; $Ed_{M = 10\%}$ is the energy density of the biomass with the moisture content of 10%.

The highest calorific value is the total amount of heat that can be obtained from the combustion of a unit mass, including that from the condensation and transformation of vapours into water. However, under real combustion conditions, the water resulting from combustion is removed in the form of vapours together with the combustion products, without yielding the combustion heat hidden in the condensate. Therefore, our study presents the highest and lowest calorific values in the dry base, i.e. for the zero moisture, and the lowest value for the moisture of 10%, considering the average humidity at the reception of densified solid biofuels. [1 p. 46-53]. The calorific value of the biomass is closely related to the variation of the chemical composition and ash content, which can be traced by synchronizing the data in Table 1 with those in Table 2. Similarly, having analyzed the data in Table 2, we can state that the biomass harvested in spring had a slightly higher combustion power than that harvested in autumn and dried by means of the method of forced conversion. Thus, the biomass of the *Ms x giganteus titan (s.h.)* and *M. sinensis (s.h.)*, harvested in spring, showed higher calorific values of 19,688 ± 198 J/g and 19,285.1 ± 175 J/g respectively as compared to 18,812.3 ± 245 J/g and 18,685.2 ± 90.5 J/g for the biomass harvested in autumn.

Taking into account the difference in moisture content of the biomass harvested in spring compared to the one harvested in autumn, it can be deduced that harvesting biomass in spring is more advantageous for a number of economic reasons because in such a case the moisture conditioning of raw material before densification can be partially or completely excluded. Another important conclusion, which results from the analysis of the data in Table 2, is the possibility of obtaining densified solid biofuels with the combustion power at reception that corresponds to ENplus requirements, i.e. $q_r \geqslant 15.5$ MJ/kg - for briquettes and $q_r \geqslant 16$ Mj/kg - for pellets [27].

Table 3 summarizes the data obtained from the final analysis of the *Miscanthus* biomass. The final biomass analysis is extremely important as it has multiple effects, including the determination of the theoretical air-fuel ratio in thermal conversion systems in order to identify the thermal values and to know the level of environmental pollution.

This study has shown that the carbon content of the *M. x giganteus titan* biomass does not differ much from that of the *M. sinensis* biomass, though the difference is noticeable depending on the terms of harvest. Thus, the biomass harvested in spring has a carbon content of approx. 5 ... 6%. Correspondingly the situation with the oxygen content is opposite, i.e. the biomass harvested in autumn contains more oxygen than that harvested in spring (the difference of about 10%). The nitrogen content does not differ much depending on the harvest season, but the *M. x giganteus titan* biomass has a much higher nitrogen content than the *M. sinensis* biomass. It is necessary to mention that the studied biomass is in line with the ENPlus requirements in terms of this indicator. This moment is extremely important because the increased nitrogen content leads to the formation of nitrogen oxides (NO_x) which favours the formation of acid rain and smog [1 p. 75].

Table 3

Final biomass analysis (mass participation, %)

biomass	C	H	N	S	Cl	O (rest)
M. x giganteus titan (a.h.)	46.51	6.04	0.44	0.04	0.03	44.19
Ms x giganteus titan (s.h.)	49.07	5.86	0.47	0.04	0.04	43.38
M. sinensis (a.h.)	46.01	5.17	0.28	0.06	0.03	44.41
M. sinensis (s.h.)	49.01	5.23	0.27	0.05	0.03	43.02

A slightly increased sulphur content is noticeable for all biomass species. Although sulphur produces a large amount of heat when burned, its content in biofuels is limited to 0.05% because it is considered unfriendly to the environment and has increased corrosive activity. The chlorine content is within the limits of 0.03 … 0.04%, practically within the limits required by the ENPlus standards.

Conclusions

Laboratory analysis of the biomass generated by two energy crops, the *M. x giganteus titan* and *M. sinensis*, show that the biomass harvested in spring before the beginning of the growing season has a moisture content (18.4 ± 4% and 19 ± 3% respectively), which is significantly lower than in the case of the biomass harvested in autumn immediately after the initial onset of senescence (45.2 ± 6% and 49 ± 7% respectively), which allows us to conclude that the biomass harvested in spring can be processed directly into densified solid biofuels without being further additionally dried forcefully or under natural conditions.

The biomass harvested in spring showed other high-quality parameters compared to those specific to the same type of biomass, harvested in autumn: respectively, the ash content for the *M. x giganteus titan* is 2.4 and it is 1.8 times lower for the *M. sinensis*; the calorific value at the moisture level of 10% was respectively 1.07 and 1.03 times higher; the energy density was respectively 1.22 and 1.11 times higher.

The chemical analysis of the studied biomass showed that the chemical composition of the *M. x giganteus titan* biomass does not differ much from that of the *M. sinensis* biomass, but the difference is noticeable depending on the terms of harvest.

The biomass used for the production of densified solid biofuels is recommended to be harvested in spring before the beginning of the growing season.

Virtually all qualitative indices of the *M. × giganteus* biomass harvested in spring comply with the international ENPlus standards on densified solid biofuels, so it can be used as a raw material in the production of pellets and briquettes.

The *M. sinensis* biomass has lower indices than the *M. × giganteus* biomass from both qualitative and quantitative points of view and can be used as a filler in the creation of various mixtures of raw material for the production of densified solid biofuels.

According to the development prospects of renewable energy sources, *Miscanthus* is likely to be one of the important contributors of biomass used as a raw material in the production of densified solid biofuels under the conditions of the Republic of Moldova.

The obtained results can be used by producers of densified solid biofuels as an argument for the use of the Miscanthus biomass as a raw material in the production of pellets and briquettes from plant biomass. Similarly, the results can serve as reference material for the argumentation of raw material mixtures based on Miscanthus.

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