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BIOMASS QUALITY OF SOME *Poaceae* SPECIES AND POSSIBLE USE FOR RENEWABLE ENERGY PRODUCTION IN MOLDOVA

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Abstract

Biomass makes a major contribution to the world and nation's renewable energy portfolio. Plant biomass represents stored energy that may be drawn upon on demand, can be converted into energy by combustion, producing cellulosic ethanol and biogas. Domestication of new species as dedicated energy crops may be necessary. Currently Poaceae species are the most commonly utilized herbaceous plants as raw material for the production heat energy by direct combustion process in Moldova. The objective of this research was to evaluate some physical and mechanical properties of dry biomass of the new Poaceae species: Miscanthus giganteus and Sorghum almum collected from the experimental land of the Botanical Garden (Institute), control variants - wheat straw, Triticum aestivum and corn stalks, Zea mays. The physical and mechanical properties of dry biomass were determined according to European Standards in the State Agrarian University of Moldova, the production of solid fuels - by the equipment developed in the Institute of Agricultural Technique „Mecagro" Chisinau. In the field it has been established that Miscanthus giganteus stems defoliated faster than Zea mays, the stems of Sorghum almum dehydrated rapidly. The bulk density of the milled chaffs by sieve 10 mm and 6 mm of the tested energy crops was 90-167 kg/m^3 and 163-198 kg/m^3, respectively. The specific density of briquettes reached 740-923 kg/m^3, but the specific density333 of pellets – 1007-1262 kg/m^3. The Miscanthus giganteus was distinguished by high density, gross calorific value (19.3 MJ/kg) and low ash content (2.23%); Sorghum almum biomass moderately gross calorific value (18.6 MJ/kg) and ash content (3.71%); Zea mays high specific density of solid fuel (923 and 1124 kg/m^3); wheat straw lowest bulk density and calorific value, and high ash content (4.93%).

Miscanthus giganteus and Sorghum almum are promising energy crops for the production solid biofuel in Moldova.

***Key words**: biomass quality, briquettes, Miscanthus giganteus, pellets, Sorghum almum.*

INTRODUCTION

In the face of fluctuating petroleum costs and a growing demand for energy, the need for an alternative and sustainable energy source has increased. Energy generation from renewable supplies is also important from social and economic standpoint; it also can reduce greenhouse gas emissions. Biomass makes a major contribution to the world and nation's renewable energy portfolio (Hăbăşescu, 2011). In the context of fuel conversion, biomass is commonly sourced from plants, either as a by-product of harvesting, as a dedicated energy crop, or as an excess waste product after processing. Plant biomass represents stored energy that may be drawn upon on demand, can be converted into energy by combustion, producing cellulosic ethanol and biogas. Due to its high moisture content, irregular shape and size and low bulk density, biomass is very difficult to handle, transport, store and utilize in its original form. Densification of biomass into durable compacts (pellets, briquettes) is an effective solution to these problems and it can increase the bulk density of collected biomass 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, colour, 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 (Plíštil et. al., 2005; Lisowski et. al., 2010; Hăbăşescu, 2011; Lam, Sokhansanj, 2014; Jackson, 2015; Marian, 2016).

Currently, cereal straw is the most commonly utilized raw material for the production of heat energy by direct combustion process in Moldova. Cereal straw is sometimes used as feed and bedding for animals, as a soil amendment and incorporated into the ploughed layer or used as mulch. The annual area sown with corn crop is about 433 thousand ha, which constitute 29% of the total area (Marian et al. 2013) therefore, it is a widely available biomass resource in Moldova. It has been estimated that approximately 100,000 dry tons of corn stover are available annually to support the biomass industry, but at present the degree of their utilization in the production of solid biofuels is very low.

Domestication of new species as dedicated energy crops may be necessary. High potential lies in perennial herbaceous species for biomass, which offer agro ecological benefits not present in annual row crop production such as increased soil organic carbon, reduced soil erosion, reduced input requirements and higher net energy return. Land use change could be minimized in such systems through the utilization of marginal croplands or abandoned grasslands. One of the most commonly used energy crops from the family *Poaceae* is *Miscanthus giganteus* Greef et Deu., a sterile tetraploid hybrid, parental forms: *Miscanthus sinensis* Andersson and *Miscanthus sacchariflorus* (Maxim.) Franch., C_4 photosynthetic pathway plant group, native to tropical and subtropical regions of Africa and Southeast Asia. *Miscanthus giganteus* is propagated asexually, usually by dividing the rhizomes and by tissue culture. It is characterized by rapid growth and development, ultimate height 4.5 metres, produces a large quantity of biomass under low input levels, is tolerant to soil and environmental conditions, being widely used for fuel production of the end last century (Lewandowski et. al., 2000; Havrland et. al., 2013; Jackson, 2015; Ţîţei, 2015).

The genus *Sorghum* Moench, plant group C_4, includes 31 species, is native to Europe, Asia, North and South America along with Australia. It is among the top five cereals and one of the key crops in global food security efforts, grown in drier areas, being able to exploit the salty soils where the cultivation of cereals is more difficult, is utilized for the production of grain, forage, sugar and, more recently, biofuels (Ţîţei and Teleuţă, 1994; 2011; Getachew et. al., 2016.).

Sorghum almum Parodi, also called Columbus grass or almum sorghum is native to South America, it was first developed in Argentina in 1936 as natural hybrid between *Sorghum bicolor* and *Sorghum halepense,* confirmed as species in 1943 by Parodi L.R. It is a robust, tussocky, short-lived perennial plant. It has numerous tillers and thick short rhizomes, reproduces by seed and rhizomes. Culms are thick and solid and can reach up to 4.5 m. *Sorghum almum* tolerates a wide range of soil types and temperatures and it is drought tolerant, reproduces by seed and rhizomes. The species *Sorghum almum* is studied in scientific centres and universities in different regions of the Earth (Rakhmetov and Rakhmetova, 2008; Heuzé et al., 2015). It has been cultivated as forage crop, in the USA, since 1943. In Romania, it has been studied since 1962 in several scientific centres: Fundulea, Caracal, Lovrin (Popescu and Albu, 1970). The green mass productivity of Columbus grass under the conditions of Uzbekistan reached 211 t/ha (Avutkhonov et al., 2016). Depending on the age and the manner of exploitation of the plantation under the conditions of the Republic of Moldova, the biomass productivity of *Sorghum almum* was about 11-15 t/ha (Ţîţei et. al., 2015), in Ukraine, it reached 20 t/ha (Rakhmetov and Rakhmetova, 2008), the maximum yield, 49.5 t/ha, was attested in Gaudiano di Lavello, southern Italy (Corleto et al., 2009).

The objective of this research was to evaluate some biological features, engineering properties of the dry biomass of the non-native *Poaceae* species: *Miscanthus giganteus* and *Sorghum almum*, as well as the quality of solid biofuel.

MATERIALS AND METHODS

The cultivar *Titan* of *Miscanthus giganteus* and the cultivar *Argentina* of *Sorghum almum*, which were cultivated in the experimental plot of the Botanical Garden (Institute), served as subjects of study, control variants - wheat straw, *Triticum aestivum*, and corn stalks, *Zea mays.*

Miscanthus giganteus and *Sorghum almum* were harvested manually in the first days of February. Corn stalks were collected as whole plants after the ears had been removed. Harvestable stems of *Miscanthus giganteus, Sorghum almum* and *Zea mays* and wheat straw bales were chopped into chaff with the use of stationary forage chopping unit. The obtained chaffs of mean dimension from 7 to 35 mm, were milled in a beater mill equipped with a sieve with diameter of openings of 10 mm (for briquettes), and 6 mm (for pellets). Scientific researches on the biomass for the production of solid biofuel were carried out: the moisture content of the plant material was determined by CEN/TS 15414 in an automatic hot air oven MEMMERT100-800; the content of ash was determined at 550ºC in a muffle furnace HT40AL according to CEN/TS 15403; automatic calorimeter LAGET MS-10A with accessories was used for the determination of the calorific value, according to CEN/TS 15400; the particle size distribution was determined 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; the briquetting was carried out by hydraulic piston briquetting press BrikStar model 50-12 and pelleting - by the equipment developed in the Institute of Agricultural Technique „Mecagro"; the mean compressed (specific) density of the briquettes and pellets was determined immediately after removal from the mould as a ratio of measured mass over calculated volume.

RESULTS AND DISCUSSIONS

We could mention that, in the first year of vegetation, the cultivar *Titan* of *Miscanthus giganteus* developed, in the underground part, the root system and new rhizomes, and the 5-7 shoots grew up to 185 cm tall. In the following years, the growing season for *Miscanthus giganteus* began on 10-17 April; 17-35 shoots grew and, by the end of the growing season, reached 3.3-4.2 m in height, the root system reached 2 m depth and the number of rhizomes increased considerably. Analyzing the biological peculiarities of the cultivar *Argentina* of *Sorghum almum*, we could mention that after sowing (in May), during 5-7 days, the seedlings emerged at the soil surface, the rate of growth and development was intensive and, in July, the formation of the panicle started, the shoots reaching 235 cm high, the seed ripening stage finished in the middle of September. The formation of rhizomes determined the long-term cycle of development of this crop. In the second year, shoots developed from the underground rhizomes formed in the previous year. *Sorghum almum* plants needed a sum of active temperatures higher than *Miscanthus giganteus,* the revival of vegetation was observed at the end of April, the growth and development rate of shoots increased after 25-30 days after the revival of vegetation and, until the end of June, the plants were in the panicle formation stage, growing 270-290 cm tall. We may mention that, in the following years, the panicle formation occurred 25-30 days earlier in comparison with the first year of vegetation.

It is known that moisture and leaf share in harvested biomass influence the costs of transport, storage, drying and processing, and the thermophysical properties of solid biofuel reduce the final usable energy and thus the efficiency of the energy system, contributing at the same time to the increased emission of pollutants. There is a practical limit of autogenous combustion at about 67% moisture. High moisture content biomass decreases the heating value of fuel, which in turn reduces the conversion efficiency as a large amount of energy would be used for the initial drying step during the conversion processes.

The results of moisture and leaf contents in harvested biomass of the tested *Poaceae* species are shown in Table 1. It was found that, at the end of the growing season, the stems of all the species contained a lot of moisture 52.1-53.9%, but the leaf and panicle share in the biomass of the tested species varied significantly from 27.9%, *Sorghum almum*, to 47.0%, *Zea mays.*

Under the climatic conditions with temperatures above 0°C and rain in the period October-January, the dehydration of the stems in all studied species was very slow, but the rain and the wind also affected the defoliation rate. Thus, leaf and panicle contents in *Miscanthus giganteus* decreased from 39.0% to 16.4%, in *Sorghum almum* from 27.9% to 11.9% and in *Zea mays* from 47.9% to 29.9%. After the establishment of temperatures below -

12°C in early February, the studied species differed in the pace of dehydration of tissues, *Miscanthus giganteus* in the field dehydrated faster than *Zea mays*. Similar results were presented by other authors, for example, in Poland, the moisture content of *Miscanthus giganteus* plants in November-April decreased from 58.36% to 23.23% (Stolarski et. al., 2014).

Biomass particle size and its distribution is an important parameter used for handling, storage, conversion, dust control systems and the combustion behaviour of biomass fuels.

Table 1. Biomass moisture and leaf contents of the studied *Poaceae* species

Harvesting period	*Zea mays*		*Miscanthus giganteus*		*Sorghum almum*	
	moisture content, %	leaf content, %	moisture content, %	leaf content, %	moisture content, %	leaf content, %
2 October	53.0	47.0	52.1	39.0	53.9	27.9
6 November	50.5	45.6	49.1	38.6	48.4	26.7
21 November	46.3	40.0	48.0	37.7	45.4	23.7
14 December	45.3	39.0	44.7	31.5	35.5	19.3
3 January	42.3	35.0	43.0	21.3	29.7	17.0
16 January	41.0	33.3	33.6	20.4	28.6	12.0
31 January	31.5	29.9	31.6	16.4	27.6	11.9
5 February	28.8	25.4	23.0	12.2	22.0	11.0

Table 2. Particle size distribution of milled chaffs of the studied *Poaceae* species, %

Particle size	*Triticum aestivum*		*Zea mays*		*Miscanthus giganteus*	*Sorghum almum*	
	sieve10 mm	sieve 6 mm	sieve10 mm	sieve 6 mm	sieve 6 mm	sieve 10 mm	sieve 6 mm
<5mm	31.5	0.1	25.7	0.5	2.1	28.7	2.7
4-5mm	17.3	2.9	19.5	1.4	2.9	15.4	3.7
3-4mm	15.2	31.7	14.9	10.4	11.8	19.8	13.3
2-3mm	17.7	31.8	18.0	34.3	26.3	17.6	26.4
1-2mm	12.4	20.6	17.5	32.0	30.1	17.3	33.0
1mm	6.0	12.8	3.9	21.4	26.7	6.2	20.9

Table 3. Some physical and mechanical properties of biomass and solid biofuel of the studied *Poaceae* species

Indices	*Triticum aestivum*	*Zea mays*	*Miscanthus giganteus*	*Sorghum almum*
ash content of biomass,%	4.93	4.40	2.51	3.71
gross calorific value of biomass, MJ/kg	17.4	17.8	19.3	18.6
bulk density of chopped chaffs 7-35 mm, kg/m^3	79	87	146	89
bulk density of milled chaffs 10 mm, kg/m^3	90	100	167	109
bulk density of milled chaffs 6 mm, kg/m^3	163	165	198	163
specific density of briquettes, kg/m^3	740	923	882	783
bulk density of briquettes, kg/m^3	407	501	488	415
specific density of pellets, kg/m^3	1007	1174	1262	1008
bulk density of pellets, kg/m^3	685	701	700	674

It is commonly known that, for the production durable compacts bio fuel the particle shape and size, the density and moisture content are the most essential properties of the comminuted material (Lisowski et al., 2010). In our study, the moisture content of milled chaffs of tested energy crops differed essentially and ranged from 7.9% *Zea mays*, 11.6% *Triticum aestivum*, 13.3% *Sorghum almum*, to 15.4% *Miscanthus giganteus*.

Data on particle size distribution of milled chaffs of the studied *Poaceae* species are shown in Table 2. Analyzing distribution on particle size in milled chaffs, sieve with diameter of openings of 10 mm, it can be stated that the highest content of particles larger than 5 mm in wheat chaffs and the lowest - in corn chaffs. In samples with *Sorghum almum* chaffs contained 60.9% particle size <4 mm, which has positively influenced the increase bulk density of milled chaffs up to 109 kg/m^3, versus wheat straw 51.3% and 90 kg/m^3, respectively.

It was found that milled chaffs, sieve with diameter of openings of 6 mm, contained 65-88% particle size <3 mm for all speeds, which indicated that these milled materials were suitable for effective pelleting. The biomass of *Miscanthus giganteus*, even if it had the highest moisture content (15.4%), was milled very well - about 26.7% particle size 1 mm. These differences result from biometric features of the plant and diameter of their stems, share of leaves and structure of tissues.

The energy content of biomass is determined by its calorific value, which is influenced by biomass elemental composition, moisture and ash content.

Comparing the obtained results on ash content (Table 3), one can add that the highest average amount is contained by *Triticum aestivum* and *Zea mays* biomass (4.93% and 4.40%). The lowest average ash content was found in *Miscanthus giganteus* biomass (2.51%). The greatest ash level reported in research studies conducted by other authors. The ash content in Czech of wheat straw pellets reached 6.33% (Ivanova et al., 2015), in Poland straw and hay briquettes - 7.1-7.3% (Kaleta et al., 2016), which negatively influenced the combustion efficiency.

The gross calorific value of biomass varied significantly (17.4-19.3 MJ/kg). The research showed that *Miscanthus giganteus* had high gross calorific values (19.3 MJ/kg), *Sorghum almum* - moderate (18.6 MJ/kg), but wheat straw - very low ones (17.4 MJ/kg), probably because of the high content of ash. Stolarski et al. (2014) investigated the higher heating value of *Miscanthus giganteus* and obtained a value of 19.09 MJ/kg, while Daraban et al. (2015) found a HHV of 17.7-19.6 MJ/kg, which is in line with the results obtained in this research. Similar research was conducted by Havrland et al. (2013), who saw that the gross calorific value of raw material ranged from 19.1 MJ/kg in the biomass of sweet sorghum to 20.3 MJ/kg in *Miscanthus giganteus*, and Heuze et al. (2015), who found that the gross calorific value of Columbus grass reached 17.8 MJ/kg. The lowest average calorific value 15.7-15.8 MJ/kg is characteristic of hay and straw briquettes (Kaleta et al., 2016).

It was established that the bulk density of the chopped material of *Miscanthus giganteus* constituted 146 kg/m^3, the difference between the other tested species wasn't significant, the lowest bulk density was 79-89 kg/m^3 (Table 3).

Differences were found in the bulk density of chaffs that were chopped and milled in a beater mill equipped with a sieve with diameter of openings of 6 mm. These differences amounted to 52 kg/m^3 in *Miscanthus giganteus* biomass and about 80 kg/m^3 in the other species.

We could mention that the briquettes produced from *Miscanthus giganteus* and corn chaffs in our study were observed as very solid and were not cracking, versus wheat straw, its specific density reaching values 882-923 kg/m^3. The specific density of briquettes from *Sorghum almum* was 783 kg/m^3, but wheat straw -740 kg/m^3.

Plíštil et al. (2005), also, reported similar trends of engineering properties for sorghum briquettes 800-870 kg/m^3 and barley straw 650-730 kg/m^3, destruction force 40-60 N/mm and 6-13 N/mm, respectively.

One of the most economically advantageous methods in densification is compression of biomass in pellet, the density increases of 6-8 times and reaches 1100 to 1250 kg/m^3, while the baled straws have only 120 - 150 kg/m^3. This product is simple to use as energy source in corporate and individual boilers (Hăbăşescu, 2011; Marian, 2016). The our investigation showed that *Miscanthus giganteus* and *Zea mays* pellets have high specific density, 1262 and 1124 kg/m^3, respectively, but bulk density similar values.

According to Tumuluru (2014), that specific and bulk density, and durability of the corn pellets range of 813-1180 kg/m^3 and 445-681 kg/m^3, and 76-96%. The pellets bulk density for miscanthus, wheat straw, and corn stover was 580, 490 and 635 kg/m^3, respectively (Jackson, 2015).

CONCLUSIONS

The studied *Poaceae* species differed significantly in the moisture and leaf contents of plant material at the end of the growing season and in the rate of stem defoliation and dehydration after the establishment of temperatures below -12°C. *Miscanthus giganteus* stems defoliated faster than *Zea mays*, the stems of *Sorghum almum* dehydrated rapidly. The specific density of briquettes made from chopped material (7-35 mm) of *Miscanthus giganteus* was low 594 kg/m^3.

The bulk density of the milled chaffs by sieve 10 mm and 6 mm of the tested energy crops was 90-167 kg/m^3 and 163-198 kg/m^3, respectively.

The specific density of briquettes reached 740-923 kg/m^3, but the specific density of pellets – 1007-1262 kg/m^3.

The *Miscanthus giganteus* was distinguished by high density, gross calorific value (19.3 MJ/kg) and low ash content (2.23%); *Sorghum almum* biomass moderately gross calorific value (18.6 MJ/kg) and ash content (3.71%); *Zea mays* high specific density of solid fuel (923 and1124 kg/m^3); wheat straw lowest bulk density and calorific value, and high ash content (4.93%).

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