Scientific Papers. Series A. Agronomy, Vol. LXII, No. 1, 2019
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

THE QUALITY OF BIOMASS AND FUEL PELLETS FROM JERUSALEM ARTICHOKE STALKS AND WHEAT STRAW

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Abstract

In recent years, the biomass market has constantly increased. The densification of plant biomass would contribute to improving its efficiency as a fuel by increasing its homogeneity and allowing a wider range of lignocellulosic materials to be used as fuel. The eco-friendly solid fuels, such as pellets, have become rapidly a viable alternative to fossil fuels, due to their high energy content, which makes them suitable for use by small households and by industrial consumers. The knowledge of the physical and mechanical properties of biomass is important for the design and efficient operation of equipment for handling, storing and processing such materials. Jerusalem artichoke, Helianthus tuberosus, is native to North America. Its tubers were previously used as raw material, food, folk remedy and animal fodder. Its potential yield and low requirements meant that it could be of interest in the renewable energy sector, tubers can be used for biogas or ethanol production, and the aboveground parts – for pellets and briquettes. The objective of this research was to evaluate some physical and mechanical properties of dry biomass and pellets from Jerusalem artichoke stalks and wheat straw collected from the experimental field of the National Botanical Garden (Institute), Chişinău. The physical and mechanical properties were determined according to the European standards accepted in the Republic of Moldova; the production of solid fuels, pellets – by the equipment developed in the Institute of Agricultural Technique "Mecagro", Chişinău. The pellets were produced from Jerusalem artichoke biomass and mixture of Jerusalem artichoke and wheat straw with a percentage: 0%, 30%, 50%, 70% and 100%. It was determined that the bulk density of the chaffs milled by a 6 mm sieve ranged from 163 to 231 kg/m^3, the ash content – from 2.12 to 4.93%, the gross calorific value - from 17.4 to 19.1 MJ/kg. The biomass of the species Helianthus tuberosus was characterized by high gross calorific value and moderate ash content. The physical and mechanical properties of fuel pellets varied depending on the mixture ratio: the moisture content ranged from 13.8 to 14.1%, the bulk density - from 582 to 685 kg/m^3, the specific density - from 880 to 1008 kg/m^3 and the net calorific value - from 15.6 to 17.71 MJ/kg.

Key words: *biomass, Jerusalem artichoke stalks, pellet, physical and mechanical properties, wheat straw.*

INTRODUCTION

In an era of accelerating change, the imperative to limit climate change and achieve sustainable economic growth is strengthening the momentum of the global energy transformation. The global energy landscape continues to shift toward decarbonisation, digitalization and decentralization in combination with improving energy efficiency. The world's demand for energy grew by 2.1% in 2017, compared with 0.9% in the previous year; a quarter of the rise was met by renewables, according to new data from the International Energy Agency (IEA).
In recent years, the biomass market has constantly increased in the world, and the production of renewable energy has developed at the regional and national levels too. Phytomass, agricultural crop residues along with energy crops, represent a good opportunity, since they can be converted into various types of fuels or energy via thermal, physical and biological processes. Harvested phytomass, because of its irregular shape and size and low bulk density, is very difficult to handle, transport, store and use in its original form. The densification of plant biomass would contribute to improving its efficiency as a fuel by increasing its homogeneity and allowing a wider range of lignocellulosic materials to be used as fuel. Kaliyan & Morey (2009) conducted a broad review of factors affecting the strength and durability of densified biomass products and made recommendations regarding the selection of

processing parameters in the production of agglomerates of acceptable quality and durability. The eco-friendly solid fuels, such as pellets, have become rapidly a viable alternative to fossil fuels, due to their high energy content, which makes them suitable for use by small households and by industrial consumers (Gudîma, 2018).

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, bedding for animals and as a soil amendment, incorporated into the ploughed layer or used as mulch. There are also pellets produced from straw, but they are not so common because such pellets produce more ash than pellets from wood (3-5%), which causes users to clean and service their boilers more frequently (Smaga et al., 2018).

The identification, mobilisation and cultivation of new species for biomass production depend on the climate and soil conditions, the availability and cost of reproductive material, the market demand for the given type of bio fuel, technological, organizational and economic conditions and other factors. The debate related to agricultural land to be used for food or fuel production in a world that still sees starvation and malnutrition of a part of its population is fierce and the identification and cultivation of species with multiple utility is a subject of topical interest (Roman et al., 2016). One such species is Jerusalem artichoke, otherwise known as topinambour, *Helianthus tuberosus* L., which belongs to the family *Asteraceae*, is native to North America, has strong, vigorous stems, sometimes branched at the base, grows 2.5-3.0 m tall, but can reach even 5 m. Its large leaves reach the length of 20 cm, and are arranged on the opposite sides of the stem, alternately to one another; they are broad ovoid-acute in shape, with dentate edges, covered with rough hair. It produces flower heads with bright yellow petals, which resemble sunflower, with a bunch of small florets (10-20) in the center. The fruit is a hairy achene containing a mottled black or brown seed, 5 mm long x 2 mm wide. In the underground part, there are unevenly shaped tubers, round or elongated, with bumps, ranging in size between 2 and 10 cm, their color can vary from brown to white, red and even purple.

The analysis of literature sources has revealed that Jerusalem artichoke can be useful in many ways. It is interesting because of the high productivity and possibilities of cultivation on marginal land, the ability to absorb carbon from the air and to release oxygen, the suitability for the creation of effective green belts around industrial centers. This species is studied and cultivated in Europe, Asia and America, has many application areas such as: tubers in human nutrition and animal feed, source of inulin for pharmaceutical industry, functional and dietary products, biologically active and food supplements; aboveground parts as green or ensiled forage, raw material for the production of various chemicals etc. (Kays &Nottingham, 2007; Heuze et al., 2015; Ţîţei et al., 2013; Ţîţei & Coşman, 2016). Its potential yield and low requirements mean that it can be of interest in the renewable energy sector (Gunnarsson et al., 2014; Kowalczyk-Juśko et al. 2012; Szostek et al., 2018; Ţîţei, 2015; Zapalowska & Bashutska, 2017).

The growing market demand for renewable fuels has stimulated the search for new biomass types suitable for pelletizing. Biomass materials are frequently mixed to obtain and improve the properties and the quality of pellets (Gageanu et al., 2017; Gudîma, 2018; Lisowski et al., 2018; Miranda et al., 2015). A literature review also points to the need to identify new kinds of fuels by mixing well-known and new materials, and the characteristics of these materials must be established. There is little information in the existing literature regarding the properties of compaction of Jerusalem artichoke stalks in pellet production and the quality characteristics of pellets from mixtures of Jerusalem artichoke and cereal straws.

The objective of this research was to evaluate some physical and mechanical properties of dry biomass and pellets: from Jerusalem artichoke stalks and wheat straw, and their mixtures.

MATERIALS AND METHODS

The cultivar 'Solar' of Jerusalem artichoke, *Helianthus tuberosus,* created in the National Botanical Garden (Institute), registered in

2014, in the Catalogue of Plant Varieties and patented in 2016, by the State Agency on Intellectual Property of the Republic of Moldova patent nr. 205/31.05.2016, served as research subject.

Jerusalem artichoke stalks were collected from the experimental field at the end of January. Stalks and wheat straw bales were chopped. The chopped biomass of pure Jerusalem artichoke stalks and wheat straw and their biomass mixtures (30%, 50%, 70%) were milled in a beater mill equipped with a sieve with diameter of openings of 6 mm using an equipment developed in the Institute of Agricultural Technique "Mecagro", Chişinău. The pellets were produced from Jerusalem artichoke biomass and a mixture of Jerusalem artichoke and wheat straw with a percentage: 0%, 30%, 50%, 70% and 100%. A scientific research on the biomass for the production of solid biofuel was carried out and it included several steps: 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 pelleting was carried by the equipment developed in the Institute of Agricultural Technique "Mecagro"; the mean compressed (specific) density of pellets was determined immediately after removal from the mould as a ratio of measured mass over calculated volume.

RESULTS AND DISCUSSIONS

It is known that moisture and leaf share in the biomass harvested to produce solid fuel influence the costs of transport, storage, drying and processing, and the thermophysical properties of 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. The high amount of moisture in 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 (Marian, 2016).

Table 1. Moisture and leaf contents in the aboveground parts of *Helianthus tuberosus*

Harvesting period	*Helianthus tuberosus*	
	moisture content, %	leaf content, %
September	62.1	23.1
October	35.0	15.1
November	28.0	4.0
December	17.7	0.7
January	14.3	0.5

We could mention that, in the middle of September, when the harvest of tubers started, the moisture and leaf contents of aboveground parts were 62.1% and 23.1%, respectively. Under the climatic conditions with temperatures below 0°C, snow and wind, in October-January, the defoliation and dehydration of the stems intensified, the leaf and capitulum content in *Helianthus tuberosus* aboveground biomass decreased from 15.1% to 0.5%, and the moisture content decreased from 35.0 % to 14.3%, respectively (Table 1). Other authors presented similar results, for example, in Poland, the moisture content of *Helianthus tuberosus* stalks in November-April decreased from 63.49% to 17.93% (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. In the case of pure Jerusalem artichoke milled chaffs, we obtained the highest percentage of particles larger than 4 mm (10.2%), and the lowest values for the particles of 1 mm (6.7%). Moreover, the fractions 1-4 mm were relatively high, in the case of pure milled wheat straw (Table 2). This is probably an effect of the morphological nature of Jerusalem artichoke stalks, the high level of pith microstructures and the moisture content of the used materials, milled chaffs, influences the passage of particles through the sieve meshes.

The mixture of Jerusalem artichoke and wheat straw 50:50 and 70:30 resulted in a reduction in the proportion of longer particles and in an increase in the share of the smallest particles (below 2 mm).

It is known that low ash and moisture contents increase combustibility, high bulk density fuel is convenient to be transported, and high pelletizing percent makes higher yield of the pelletizing process. It was determined that Jerusalem artichoke milled chaffs were characterized by a low ash content (2.12%) and a high moisture content (14.3%), as compared with pure wheat straw. In the prepared mixtures of Jerusalem artichoke with wheat straw, there was a lower ash and higher moisture content than in pure wheat straw (Table 3). Mani et al. (2006), reported that moisture in the material, during the compaction, increases the bonding via Van der Wall's forces, thereby increasing the contact area of particles.

It was established that the bulk density and the gross calorific value of the Jerusalem artichoke milled chaffs constituted 231 kg/m^3 and 19.1 MJ/kg, these indices were the lowest in pure wheat straw milled chaffs: 163 kg/m^3 and 17.4 MJ/kg, respectively. We determined that the ratio of Jerusalem artichoke in mixture makes the bulk density of milled chaffs vary from 178 to 224 kg/m^3 and its gross calorific value - from 18.0 to 18.6 MJ/kg (Table 3).

Table 2. Particle size distribution of milled chaffs, %

Particle size	100% wheat straw	100% Jerusalem artichoke	70% wheat straw +30% Jerusalem artichoke	70% wheat straw +30% Jerusalem artichoke	70% wheat straw +30% Jerusalem artichoke
<5mm	0.1	2.2	0.6	0.7	0.5
4-5mm	2.9	8.0	5.2	4.6	4.7
3-4mm	31.7	27.9	33.2	20.8	19.8
2-3mm	31.8	34.5	29.2	31.9	31.6
1-2mm	20.6	20.6	19.6	26.1	26.9
1mm	12.8	6.7	12.2	15.8	16.5

Table 3. Some physical and mechanical properties of biomass and pellets

Indices	100% wheat straw	100% Jerusalem artichoke	70% wheat straw +30% Jerusalem artichoke	70% wheat straw +30% Jerusalem artichoke	70% wheat straw +30% Jerusalem artichoke
moisture content of milled chaffs,%	11.6	14.3	11.8	13.8	13.0
ash content of milled chaffs,%	4.93	2.12	3.98	3.42	2.93
bulk density of milled chaffs, kg/m^3	163	231	178	197	224
gross calorific value of milled chaffs, MJ/kg	17.4	19.1	18.0	18.3	18.6
moisture content of pellets, %	13.4	12.3	14.1	13.9	14.1
ash content of pellets, %	4.87	2.10	3.94	3.45	2.87
specific density of pellets, kg/m^3	1007	880	1008	947	884
bulk density of pellets, kg/m^3	685	582	636	615	601
net calorific value of pellets, MJ/kg	15.6	17.7	16.2	16.7	17.2

In Poland, Kowalczyk-Jusko et al. (2012) stated that the calorific value of biomass of the examined varieties of Jerusalem artichoke varied within narrow limits 16.10-16.30 MJ/kg, while the ash content was 5.4-5.6%; Stolarski et al. (2014) mentioned that the ash content of *Helianthus tuberosus* stalks, from November to April, decreased from 5.26% to 3.02%, but the gross calorific value grew insignificantly from 18.45 to 18.59 MJ/kg dry matter.

In our study, has been established that after pressure agglomeration of the biomass, the average moisture in the pellets changed, thus it decreased by 2%, in pellets from pure Jerusalem artichoke biomass and increased in pellets from pure wheat straw, 30% and 70% mixtures, reaching the absolute values of 13.1-14.1%, the ash content of all prepared pellets did not change essentially as compared with milled chaffs. The specific density of pellets made from pure Jerusalem artichoke biomass and pure wheat straw was 880 kg/m^3 and 1007 kg/m^3, while the bulk density was 582 kg/m^3 and 685 kg/m^3, respectively. It was determined that the specific and bulk densities of pellets were the highest in the products manufactured from Jerusalem artichoke biomass mixture and they attained values of 884-1008 kg/m^3 and 601-636 kg/m^3, respectively. The net calorific value of pellets ranged from 15.6 MJ/kg to 17.7 MJ/kg and decreased with an increase in the proportion of wheat straw in the mixture (Table 3).

There are different results reported in research studies conducted by other authors. Kowalczyk-Jusko et al. (2012) stated that the calorific value of biomass of the examined varieties of Jerusalem artichoke varied within narrow limits 16.10-16.30 MJ/kg, while the ash content was 5.4-5.6%. Zapalowska & Bashutska (2017) noted that Jerusalem artichoke pellets were characterized by lower moisture content (6.81%), moderate ash content (2.04%), higher energy value (18.85 MJ/kg) and resistance to crushing (1024.57 Newton), as compared with pellets made from conifers and deciduous trees. Hăbăşescu (2011) stated that the pellets from sunflower stems had net calorific value of 14.8 MJ/kg and the ash content was 3.78%, the pellets from corn stems were characterized by 14.2 MJ/kg and 5.14%, respectively, and wheat straw - by 14.3 MJ/kg and 6.25%, respectively. According to Ivanova et al. (2015) the ash content in wheat straw pellets reached 6.33% and the calorific value 17.60 MJ/kg. Gageanu et al. (2017) stated that the pellets obtained from wheat straw had 8.0% moisture, 6.03% ash, 15.6 MJ/kg net calorific value and 382.3 kg/m^3 bulk density; from biomass mixture 40% wheat straws and 60% forestry residues - 8.1% moisture, 5.11% ash, 16.9 MJ/kg net calorific value and 456.3 kg/m^3 bulk density, but pellets from 50% wheat straw and 50% corn cobs - 8.37% moisture, 3.88 % ash, 16.2 MJ/kg net calorific value and 386.4 kg/m^3 bulk density.

The results obtained Miranda et al. (2015) for wheat straws pellets were: 9.4 % moisture, 9.10 % ash, 18.25 MJ/kg gross calorific value and 13.73 MJ/kg net calorific value and 620 kg/m^3 bulk density. Swietochowski et al. (2018) determined that the properties of wheat pellets and wood pellets used for tests differed significantly, wheat pellets contained 8.52% moisture, were characterized by 94.66% durability, 13.79 MJ/kg net calorific value, 587.5 kg/m^3 bulk density and 1151 kg/m^3 specific density, but wood pellets - 3.53% moisture, 98.31% durability, 16.79 MJ/kg net calorific value and 671.1 kg/m^3 bulk density and 1213 kg/m^3 specific density, respectively.

The bulk density of pellets made from miscanthus, wheat straw and corn stover was 580, 490 and 635 kg/m^3, respectively (Jackson, 2015). Lisowski et al. (2018) mentioned that the pellets made from hay, straw and their blend at the ratio of 50:50, have moisture content 5.56-5.87%, specific density of 974-1102 kg/m^3, while the bulk density values were 478-514 kg/m^3, the calorific value of pellets was 16.07-17.00 MJ/kg, the highest values were achieved by the pellets made from the blend of biomass.

Kowalczuk et al. (2012) mentioned the following calorific values: pellets from wheat straw 15.960 MJ/kg, rye straw 15.865 MJ/kg and pellets made from maize straw - 15.868 MJ/kg.

CONCLUSIONS

It was determined that the bulk density of the chaffs milled by a 6 mm sieve ranged from 163 to 231 kg/m^3, the ash content - from 2.12 to 4.93%, the gross calorific value - from 17.4 to 19.1 MJ/kg.

The biomass of the species *Helianthus tuberosus* was characterized by high gross calorific value and moderate ash content. The physical and mechanical properties of fuel pellets varied depending on the mixture ratio: the moisture content ranged from 13.8 to 14%, the bulk density - from 582 to 685 kg/m^3, the specific density - from 880 to 1008 kg/m^3 and the net calorific value - from 15.6 to 17.71 MJ/kg.

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