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Energy crops utilization as an alternative agricultural production

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Abstract. Nowadays an increasing attention is given to the production and use of solid biofuels as an alternative to traditional fossil fuels. The common raw material for the production of solid biofuels is a biomass of vegetal origin, which is mainly represented by waste and secondary agricultural products as well as forest or wood residues. Unfortunately, these types of materials do not always meet the quality requirements for the production of biofuels in the form of pellets and briquettes. This is primarily due to the fact that much of the agricultural wastes have low calorific value, high ash content, low density, etc. and at the end all these facts also negatively affects the price of biofuels. In addition, an intensive use of agricultural waste as a raw material for the purpose of biofuels' production could have a negative impact on soil fertility. Based on abovementioned disadvantages of agricultural biomass, there is a big potential in utilization of alternative biomass such as energy crops. Several energy crops from the same biological family *Asteraceae* were selected for the research purposes. The main focus of this article is evaluation and comparison of the main solid biofuels' properties, which were measured according to European and International standards. Assessment of an energy potential of selected crops for the Republic of Moldova is presented here as well.

Key words: energy crops, solid biofuel, briquettes, gross calorific value, ash content.

INTRODUCTION

Supply of mankind with the food and energy remains the central topic of the XXI century. Economic growth and social development of society leads to increased consumption of energy resources, the cost of fossil types of fuels constantly rising and soon they may run short of reserves in general. According to the forecast developed by World Energy Council, consumption of energy in 2050 will double, which, in turn, will lead to increased CO_2 content in the atmosphere and to strengthening of greenhouse effect.

In regard to this, searches for new renewable sources of energy are actively conducted, including development of bioenergy, which gets increasing social demand and now it ranks among the main priorities of innovative development of world economy. The Republic of Moldova imports 95% of energy resources and energy costs per unit of production are three times higher, than on average across Europe. According to Energy strategy of the Republic of Moldova (2013), the total amount of energy produced from renewable sources should be increased to 20% by the year 2020 and 3/4 of this amount will make energy from biomass. Taking into account that forests in Moldova cover less than 8% of the area, it becomes relevant to explore the suitability of using various types of phytoenergy plants (energy crops) as renewable energy sources, and also to develop technologies of their cultivation in order to obtain the maximum yield of technological raw materials for further processing into new types of fuels.

The brief description of selected crops, which seem to be perspective source of energy biomass for Moldova and were object of the present research, is as follow:

According to Shtar et al. (2006) and Teleuta et al. (2012) Jerusalem artichoke was introduced in Moldova at a turn of 17–18 centuries. Silage types of Jerusalem artichoke represent special interest for production of solid biofuel, because these taxa reach 4.2–4.5 m in height and 3.2–4.0 cm in diameter at the plant base.

More than half a century cup plant was studied in Moldova as fodder crop, but in recent years it also became interesting for development of bioenergy field. The plant is propagated by division of a bush, seedling and seeds. Seedling and seeds form only the socket in the first year. In the following years 12–20 shoots develop on one bush. Stem of the plants is straight, well leafy, thick, tetrahedral and by the end of growing season reaches 3.0–3.5 m (Teleuta & Titei, 2012).

By Titei & Teleuta (2011) New York aster was introduced as an ornamental flowering plant. It usually grows as a bush of back pyramidal form. Stems are up to 160 cm height, densely branched and leafy. The plant is propagated by division of a bush (spring), green stems and seeds. New York aster has high frost resistance and it can be used for development of abandoned and eroded lands.

Elecampane is cultivated for medicinal purposes, where rhizomes or leaves are applied, and stems can be used for energy. Propagation of the plant is done by division of a bush, seedling and seeds. In the first year plants form the socket and in the following years develop stems up to 2.3 m height, angular, thick, upright, and furrowed, at the top low-branchy, highly resistant to mechanical damages, steady against precipitations and strong wind during winter period (Halford & Karp, 2010).

The research problem was to evaluate the potential for the Republic of Moldova of solid biofuels produced from four promising energy crops on the basis of determination of their main parameters such as gross and net calorific values as well as ash content and due to calculation of the biomass energy yields.

MATERIALS AND METHODS

Material for research was perennial species of herbaceous plants from the family *Asteraceae*: Jerusalem artichoke (*Helianthus tuberosus* L.), cup plant (*Silphium perfoliatum* L.), New York aster (*Symphyotrichum novi-belgii* or syn. *Aster novi-belgii* L.) and elecampane (*Inula helenium* L.). The selected plants were grown under the same conditions in experimental plots of Chisinau Botanical Garden (Institute) of the Academy of Sciences of the Republic of Moldova (see Fig. 1).

Figure 1. Perennial energy crops from the family *Asteraceae.*

Aboveground biomass of the selected energy crops grown for research purposes was harvested in 2012 and the further measurements of biomass and biofuels properties were performed in the Laboratory of solid biofuel of the State Agrarian University of Moldova in accordance with European Union standards for solid biofuel, which were approved and came into force in the Republic of Moldova since 2012.

The gross calorific value (GCV) was determined by bomb calorimeter LAGET MS-10A for the totally dry materials (dry basis) and it was calculated by the following formula (Havrland et al., 2013):

$$GCV = \frac{dTk \cdot Tk - (c1 + c2)}{m} \text{ J g}^{-1} \quad (1)$$

where: *dTk* – temperature jump, °C; Tk – heat capacity of calorimeter, J °C^{-1}; c_1 –repair of benzoic acid, J; c_2 – repair of the heat released by burning spark fine wire, J; m – weight of material sample, g.

The net calorific value (NCV) was then defined as (Marian et al., 2013):

$$NCV = GCV - E_W \cdot (8.9 \cdot H + W),\ \text{J g}^{-1} \quad (2)$$

where: E_W – average value of heat of water evaporation, J g^{-1} (24.42 J g^{-1}); H – hydrogen content in a sample, %; W – moisture content in a sample, %.

Measurement of ash content (A_C) was performed in muffle furnace in accordance with the requirements of SMV EN14775:2012 standard and the following formula was used:

$$A_C = \frac{(m_3 - m_1)}{(m_2 - m_1)} \cdot 100,\ \% \quad (3)$$

where: m_1 – mass of an empty crucible, g; m_2 – mass of crucible with a sample, g; m_3 – mass of crucible with ash residue, g.

The maximum (theoretical) energy potential or biomass gross energy yield (BEY) of energy crops was found due to following calculation (Kolarikova et al., 2014):

$$BEY = GCV \cdot DM,\ \text{GJ ha}^{-1} \quad (4)$$

where DM – productivity of the plant (dry matter yield), t ha^{-1}

RESULTS AND DISCUSSION

Table 1 (below) shows the results of laboratory measurements and calculations regarding to the main fuel properties of selected plants, such as calorific value and ash content. Sunflower like representative of the same family was taken for comparison.

It is evident from Table 1 that New York aster and Jerusalem artichoke have the highest values of gross and net calorific value and the lowest values from all the plants show elecampane. For more probability of the results standard deviations and confidence intervals were found.

Generally, the highest calorific values are typical for biofuels made of wood biomass. According to Jevič et al. (2008) net calorific value of wood ranges between 19.4–20.8 MJ kg^{-1}, which is much higher than net calorific value of presented crops. On the other hand, in accordance with EN 14961–3 the minimum net calorific value determined for the wood briquettes of A1 class should be 15.5 MJ kg^{-1}, which is reached by all the studied plants.

The same as calorific value the best results of ash content (the smallest amount) shows biomass of New York aster, followed by Jerusalem artichoke, and in contrast the highest amount of ash content after the biomass combustion has elecampane. The ash content in selected plants varies from 1.82–4.07%.

Table 1. Main characteristics of energy crops' biomass

Biomass	Parameters of calorific value				Ash content, %
	Calorific value (dry basis), J g^{-1}		Standard deviation	Confidence interval	
	Gross calorific value	Net calorific value			
Jerusalem artichoke (*Helianthus tuberosus* L.)	18,568.85	17,258.96	459.08	6.60	2.26
Cup plant (*Silphium perfoliatum* L.)	17,823.02	16,513.15	653.36	9.59	2.50
New York aster (*Symphyotrichum novi-belgii*)	18,726.84	17,416.95	481.71	6.89	1.82
Elecampane (*Inula helenium L.*)	17,653.07	16,343.18	498.75	7.35	4.07
Sunflower (*Helianthus annuus* L.)	18,437.85	17,127.96	332.17	4.79	2.73

According to the standard for a quality of wood briquettes EN 14961–1 ash content ranges between 0.5–3%. Chosen plants from *Asteraceae* family except from elecampane (including sunflower) fulfill this requirement. As reported by Kotlánová (2010) ash content of herbaceous biomass may reach values up to 10%. For example, ash content of hay (grass) measured by Hutla (2010) is 6.33%, which is much higher comparing to all selected plants. Kim et al. (2000) reported that the low ash content leads to better suitability of fuels for thermal utilization. High ash content causes high dust emission and negatively influences the combustion efficiency.

It is necessary to mention some other important notes and data from the field trials and laboratory measurements concerning the selected crops, e.g. biomass yield as well as bulk density of crushed biomass prepared for transportation and transformation to solid form of fuel.

It was found that stems of Jerusalem artichoke do not break and fall down and this contributes to high accumulation of aboveground dry biomass of about 26–28 t ha^{-1}. Bulk density of harvested and crushed dry biomass of the plant is 268–276 kg m^{-3}.

Cup plant biomass contains up to 25% of leaves that has impact on decrease of calorific value and bulk density. Bulk density of crushed biomass is 241 kg m^{-3}. But physical density of received briquettes made of cup plant is high (961 kg m^{-3}), this has positive impact on their storage and transportation. Biomass yield is about 16.4 t ha^{-1}.

Within establishing negative temperatures New York aster's shoots quickly dry up and at the beginning of December the moisture of harvested aboveground biomass drops below 10%. Biomass yield reaches 11.7 t ha^{-1}; leaves content is 10–18%. Bulk density of harvested and crushed dry biomass is about 248–256 kg m^{-3}.

Negative temperatures also quickly accelerate drying of elecampane's stems and by beginning of November it is possible to start collecting biomass. Harvested yield of aboveground dry biomass of this plant varies between 9–13 t ha^{-1}.

Very important indicator, which was calculated from the abovementioned results, is energy potential of the crop (see Fig. 2).

It is visible from the Fig. 2 that Jerusalem artichoke reaches almost double energy potential comparing to other crops. Energy potential of cup plant biomass is about 300 GJ ha^{-1} that is equal to about 10 t of fuel equivalent.

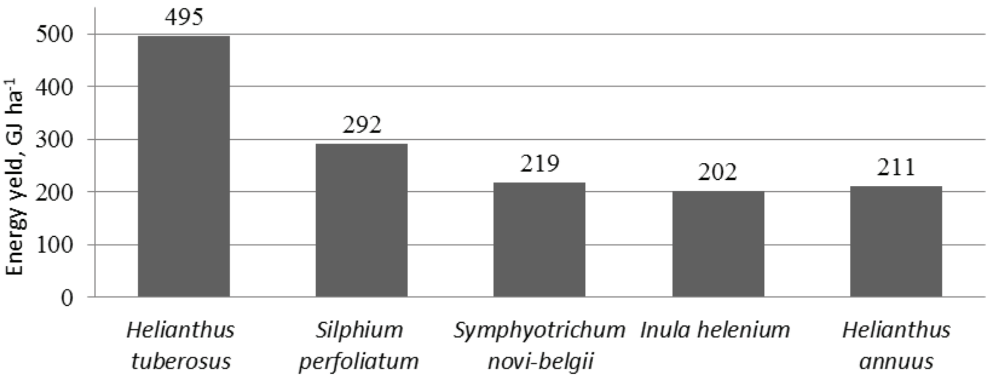

Figure 2. Maximum energy potential of studied plants from the family *Asteraceae.*

Theoretical energy yield of Jerusalem artichoke is approaching the maximum energy yield of *Miscanthus x giganteus*, which belongs to the top energy crop across the Europe. According to Havrland et al. (2013) the energy yield of *Miscanthus x giganteus* is around 531.9 GJ ha^{-1}. In comparison, the energy yield of Jerusalem artichoke is higher than the energy yield of some energy crops like giant reed (*Arundo donax* L.) – 451.6 GJ ha^{-1}, giant knotweed *(Reynoutria x bohemica)* – 387.7 GJ ha^{-1} and *Miscanthus sinensis* – 362.8 GJ ha^{-1}.

The values of energy potentials of New York aster, elecampane and sunflower are seminar and are close to energy yield of annual hemp (*Cannabis sativa* L.) – 213.6 GJ ha^{-1} (Havrland et al., 2013).

The energy potential presented in the study is theoretical maximum energy potential of the crops. It means that losses (post-harvest and combustion losses) were not taken into account; they can vary between 30–50% (Prade et al., 2011).

All of the above mentioned plants were grown under natural conditions without additional inputs in the form of fertilizers, irrigation, etc. It may be expected that some additional inputs will increase biomass yield and subsequently total energy potential of the plant.

CONCLUSIONS

Summarizing the results of calorific values, ash content and energy potential of selected crops, it can be concluded that crops from *Asteraceae* family have positive characteristics, which make them attractive raw materials for production of solid biofuels in the form of briquettes and pellets.

Conducted research demonstrated that Jerusalem artichoke is the most perspective energy crops among the tested plants due to the largest energy yield, followed by cup plant from the viewpoint of energy yield and New York aster with the highest calorific values and lowest ash content.

However for selection of energy crops it is also necessary to do calculations of energy and economical balances (inputs vs. outputs).

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