ASSESSMENT OF ENERGY PROPERTIES OF MAIZE AND MULTI-CROP PELLETS AND ENVIRONMENTAL IMPACT OF THEIR COMBUSTION

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Abstract. Biomass resources are very important raw materials for energy purposes in many countries of the world, and these renewable local sources of energy can replace fossil fuels, whose resources are decreasing and they have a negative impact on the environment. The presented paper provides new research results of multi-crop plants, such as herbaceous, fibrous and leguminous plants growing, harvesting and utilization for energy purposes. Maize biomass can be used not only for the production of fodder or biogas, but also for the production of solid biofuels. In this work were investigated these plants: maize, which is grown as a high-biomass perennial herbaceous plant, together with field beans, accumulating nitrogen in the roots and soil, and the third multi-crop plant was fibrous hemp, which overgrows weeds and contributes significantly to the reduction of CO_2 in the environment. At the beginning plants were harvested and biofuel was prepared by drying, chopping, milling and production of biofuel pellets. The most important properties of pellets made from multi-crop plants and their mixtures, which are influencing the preparation and use of biofuels for energy, were investigated and determined. Investigations were carried out in the fields and laboratories of the Vytautas Magnus University Agriculture Academy and in the Lithuanian Energy Institute. After investigation of biomass pellet qualitative properties, it was determined that the density of all investigated sorts of pellets varied from 1106.5 to 1161.3 kg m^{-3} dry matter (DM), and pellet moisture content reached 6.9 ± 1.6%. A lower heat value (LHV) was sufficiently high and varied from varied from 16.8 to 17.0 MJ kg^{-1}. Additionally, there were investigated the harmful emissions of gases CO_2, CO, NO_x and C_xH_y when these pellets were burned. All these results are in accordance with the requirements of standards.

Keywords: multi-crop plants, maize, field beans, fibrous hemp, pellets, biofuel properties, environmental impact.

Introduction

Various types of biomass are assigned to the important alternative energy sources, and can be used for biofuel production [1]. The use of biofuels helps reduce greenhouse gas emissions, in addition, biofuels produced from local plant biomass stimulate the local economy [2]. For this purpose can be grown and used for biofuel production multi-crop plants, which consist of different species of plants grown in one field. Growing multi-crop plants can help increase biodiversity and reduce the amount of synthetic nitrogen fertilizers. Mixed crops are particularly suitable for growing on less fertile land [3].

Maize, hemp, field beans and other plants used for food, forage and other purposes can be grown in a single plantation as multi-crops. Maize biomass can be used not only for food, forage but also to produce solid biofuels and biogas [4; 5]. Maize produces a large amount of green biomass – the dry matter yield can reach more than 15-20 t·ha^{-1} [5]. Studies in China show that the use of granular biofuels from corn stalks instead of fossil fuels in rural areas, can significantly reduce life cycle greenhouse gas emissions by eliminating 90.5% of GHG emissions [6].

Field beans (Faba beans) have the ability to accumulate nitrogen from the atmosphere. After harvesting, a large amount of field bean biomass remains in the fields, so this residue of green mass can be used for energy production [7]. Other researchers determined that growing maize in combination with field beans, in plants and soil increases the nutrient content, intensifies photosynthesis, increases biomass production and increases the plant yield compared with the monocropping [8]. It has also been observed that less land is needed to grow different crops. A study carried out for Rezaei-Chianeh et al. showed that in order to grow the same grain yield in monocultures, 97% more land was needed compared to the area where two crops were grown [9].

Fibrous hemp is a plant suitable for growing of polynomial crop (multi-crop). Fibrous hemp produces a large amount of biomass and is highly energy efficient. Cannabis competes very well with weeds, requires almost no pesticides and is suitable for crop rotations [10]. Cannabis grows large amounts of biomass (12 t·ha^{-1} DM), the calorific value of hemp is similar to some sorts of wood [11]. Cannabis is receiving increasing attention as a renewable resource due to its short rotation, low cultivation costs, resistance to diseases and pests, and also it has an ability to absorb carbon dioxide, so it has wide and universal use and other competitive advantages [12]. One of the most important elements for cannabis growth is nitrogen, which cannabis needs from the beginning of growth [13].

Compaction is necessary to obtain higher quality of biofuels produced from biomass of herbaceous plants. This can be done by pressing, briquetting and granulation. Compaction results in fuels with higher calorific value and higher bulk density that are easier to transport. Granulation is currently the most important and widely used of the existing methods for biofuel production [14].

The aim of this study is to substantiate the suitability of maize and its mixtures with other agricultural crops for solid biofuels and to evaluate the granulated biofuel properties and effect of pellet burning into the environment.

Materials and methods

The research of preparation and use of granulated biofuels for combustion of multi-crop plants was performed in the laboratories of the Vytautas Magnus University, Academy of Agriculture and the Lithuanian Energy Institute in 2020-2021. Harvested and naturally dried plants were chopped with a drum shredder and milled with a hammer mill to a fraction of 2–3 mm fineness. The flour was compressed into 6 mm diameter granules using a granulator with a horizontal matrix “Peleciarka” (*Polemix*, Poland).

All fulfilled tests were performed using the following types of produced granules:

- maize biomass;
- maize and fibrous hemp mixture biomass;
- maize and field beans mixture biomass;
- maize, field beans and fibrous hemp mixture biomass.

All the groups of plants from which the pellets were made were grown in different field plots (maize plot-1, maize and fibrous hemp plot-2, maize and field beans plot-3, maize, field beans and fibrous hemp plot-4). After cultivation, samples were taken from different mono-, binary and trinomial fields from which biomass pellets were produced. Plants from different fields were not mixed.

The density of the produced biofuel pellets was determined by measuring the length and diameter of the pellets and calculating the pellet volumes. 10 pellets of each sample were tested.

Moisture content, calorific value, ash content and ash melting temperatures of pellets were determined according to the standardized methodology valid in Lithuania and European countries. For these experiments were used these implements and devices:

- the tester of moisture content (standard LST EN 14774-1: 2010);
- the device for determination of calorific value C 2000 calorimeter (*IKA*, Germany) (standard LST EN 14918: 2010);
- the device for determination of ash content (standard LST EN 14775: 2010).

A 5 kW solid fuel boiler for the combustion of pellet biofuels was used to study the combustion quality and harmful emissions of biofuel pellets. Samples of granulated biofuels (5-7 kg each) were prepared and burned in a boiler, and harmful gas emissions to the environment were determined: CO, CO_2, NO_x and C_xH_y. Each sample was burned for 8-10 min. Emissions of harmful gases during combustion were measured with the analyzers of combustion products Datatest 400CEM and VE7, according to the requirements of the standards LST EN 303-5: 2012 and LAND 43-2013.

All experiments were repeated 5 times and the results of the study were evaluated by the analysis of variance and correlation-regression analysis. Arithmetic means, their standard deviations and confidence intervals were determined at the probability level 0.95 according to the *P* criterion [13].

Results and discussion

Based on the results of various studies, the properties and quality of solid biofuels depend on the following key characteristics of the feedstock: plant species, physical properties and chemical composition. The chemical composition of the feedstock is particularly important for its final quality, which affects the biofuel calorific value, ash content and mechanical properties. Moisture content of biofuels affects the mechanical durability, calorific value and combustion efficiency of solid biofuels.

An important indicator is the density of biofuels, which influences the mechanical durability, calorific value, and cost of biofuel production and storage [15].

Chemical composition of the investigated multi-crop biofuel pellets is presented in Figure 1.

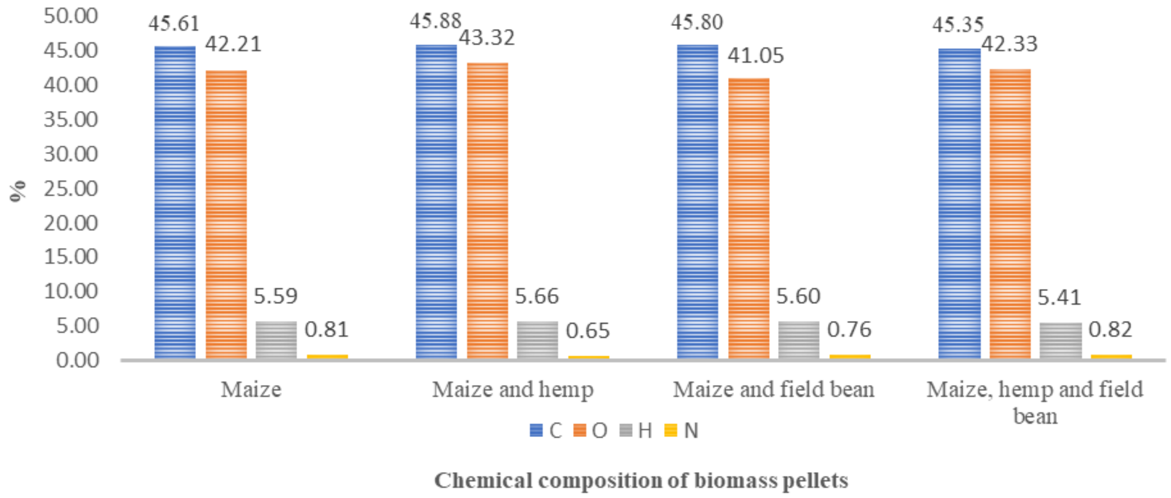

Fig. 1. **Elemental and chemical composition of multi-crop pellets**

There were determined these chemical characteristics of pellets, among which no significant differences were observed: C (varied from 45.35 to 45.88%); O (varied from 41.05 to 43.32%); H (varied from 5.41 to 5.66%); N (varied from 0.65 to 0.82%).

The qualitative properties of the investigated pellets are presented in Table 1.

Table 1

Biomass pellets qualitative properties

Raw material from which the pellets are produced	Moisture content, %	Density, kg·m^{-3} (DM)	Ash quantity, %	Lower calorific value, MJ·kg^{-1}
Maize biomass	4.61 ± 0.59	1159.57 ± 29.08	5.78 ± 0.06	16.87 ± 0.93
Maize and fibrous hemp mixture biomass	4.44 ± 0.22	1161.30 ± 37.30	4.49 ± 0.05	16.99 ± 0.85
Maize and field beans mixture biomass	8.78 ± 0.43	1106.46 ± 42.60	6.78 ± 0.18	16.80 ± 0.35
Maize, field beans and fibrous hemp mixture biomass	5.63 ± 0.23	1143.26 ± 30.08	6.08 ± 0.05	16.92 ± 0.66

The moisture content of the produced pellets was sufficiently low (6.9 ± 1.6%), only pellets produced of maize and field beans mixture biomass were of bigger moisture, which reached 8.78 ± 0.43%. Determined density of all investigated sorts of pellets was sufficiently high and varied from 1106.5 to 1161.3 kg·m^{-3} dry matter (DM). It can be stated that the pellets produced from multi-crop plants were of high density and met the requirements of many national standards, which usually specify a minimum density of 1000 kg·m^{-3} DM. Determined lower heat values (LHV) of all sorts of pellets were sufficiently high and varied from 16.8 to 17.0 MJ·kg^{-1}.

Maize pellets have also been studied by other scientists. Miranda et al. found that the lower calorific value of the pellet biomass produced from maize cobs was 15.68 MJ·kg^{-1} (DM) [14]. Kusek found that the lower calorific value of the maize stem pellets was 17.03 MJ·kg^{-1}, the moisture content of the pellets – 4.17% [16]. Gageanu et al. found that the lower calorific value of the wheat straws and corn cobs mixture pellets was 16.24 MJ·kg^{-1}, the moisture content – 8.37% and the ash content – 3.88% [1]. Jasinskas et al. found that the lower calorific value of three different varieties of cannabis was about 17.4 MJ·kg^{-1} the moisture content varied from 8.2 to 10.0% ant the density varied from 899.3 to 1171.7 MJ·kg^{-1} [13].

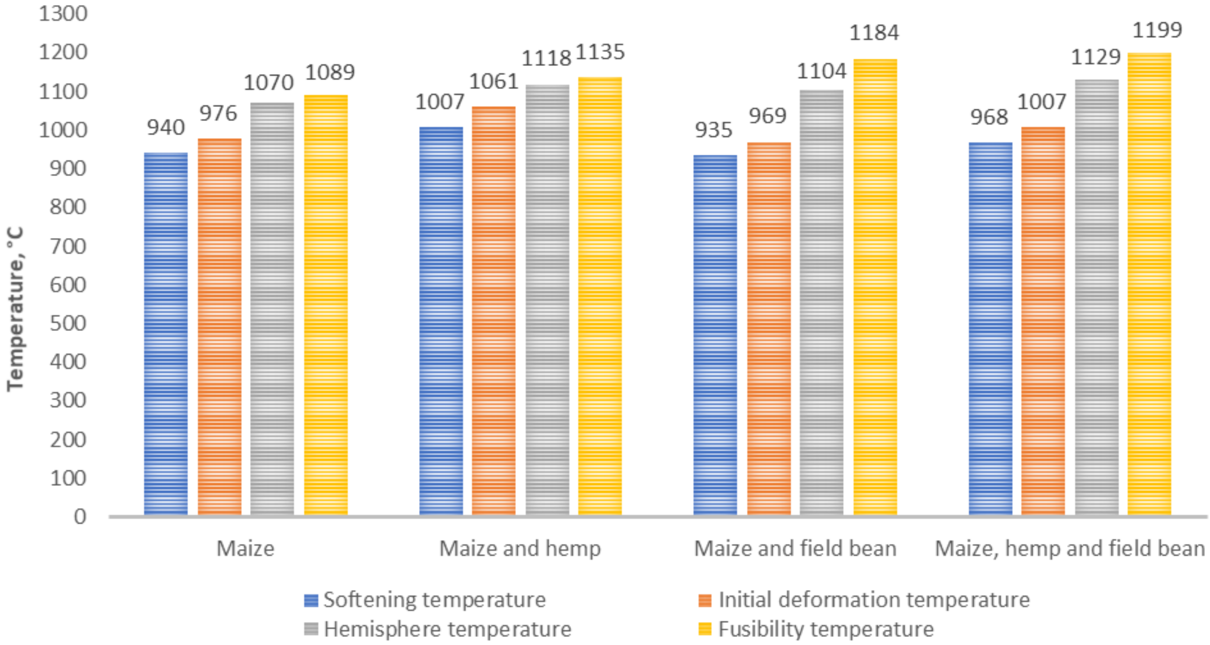

Fig. 2. A**sh melting temperatures of different samples**

Ash melting temperatures were also investigated, and their determined values can be seen in Figure 2. The initial ash deformation temperature (DT) has the greatest effect on the operation of incinerators. DT varied from 976 to 1007 °C. The highest one was that of maize and hemp mixture biomass sample, 1007 °C.

Determined research results of harmful gases emissions from burning pellets produced of maize biomass with other plant mixtures are presented in Table 2.

This presented study shows that mixing of maize biomass with the biomass of field beans and fibrous hemp reduced CO_2 emissions, which varied from 4.1 to 5.0%. This is confirmed by the research conducted by other authors. Dragutinović et al. found that the use of biomass blends in the production of solid biofuel pellets (wood and corn cob pellets) reduces total particulate and CO emissions by 48 to 60% and 64 to 89%, respectively [17].

Table 2

Harmful gases from burning pellets produced of maize biomass with other plant mixtures

Type of pellets	CO_2%	CO ppm	NO_x ppm	C_xH_y ppm
Maize pellets	5.0	525	167	19
Maize and fibrous hemp mixture pellets	4.1	441	136	19
Maize and field beans mixture pellets	4.1	473	164	23
Maize, field beans and fibrous hemp mixture biomass	4.3	362	159	17
Wood pellets	5.2	83	43	12

Finally, it can be stated that after investigation of harmful emissions of gases CO_2, CO, NO_x and C_xH_y when all sorts of pellets were burned, the values of emissions met the requirements of the standards.

Conclusions

1. Solid biofuel pellets produced from maize biomass in mixtures with other crops such as field beans and fibrous hemp grown in one field as multi-crop plants were investigated.
2. Maize and fibrous hemp mixture pellets had lower ash content compared to pellets made only from maize biomass.
3. Determined lower heat values (LHV) of all investigated sorts of pellets were sufficiently high and varied from 16.8 to 17.0 $MJ \cdot kg^{-1}$.
4. Determined density of pellets produced from multi-crop plants varied from 1106.5 to 1161.3 $kg \cdot m^{-3}$ dry matter (DM). These pellets were of high density and met the requirements of standards, which usually specify a minimum density of 1000 $kg \cdot m^{-3}$ DM.
5. In most cases, the use of maize biomass in solid biofuel pellets produced in blends with field biomass and fibrous hemp biomass emits less harmful emissions compared to pellets made only from maize biomass.

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