MULTI-CROP BIOMASS UTILIZATION FOR BIOENERGY PURPOSSES AND EVALUATION OF PRESSED BIOFUEL PROPERTIES

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Abstract
The article focuses on the evaluation of the suitability of multi-crop biomass to produce solid biofuels. For this purpose, three species of plants were investigated and studied: field bean, maize, and fibrous hemp, grown as a binary (3 samples) and trinomial (1 sample) crops. The object of this research was the biomass of three grown and harvested multi-crop plants (a total of 4 different options), which was processed and utilized for pressed biofuel production. At the beginning, the harvested plant biomass was chopped and milled, and later pressed biofuel (cylindrical 6 mm diameter granules) was produced. The granules were produced using a granulator with a horizontal matrix. Determined fractional composition of the flour in all four samples was optimal to produce biofuel pellets: 65-78% of flour particle size was 2.0 mm, 1.0 mm or 0.63 mm. Determined length of the produced granules ranged from 23.4 to 26.4 mm and the diameter was sufficiently stable and varied from 6.1 to 6.2 mm. The density of the granules produced in all investigated samples reached more than 1100 kg m^{-3} (DM). The moisture content of pellets ranged from 4.4% to 8.8%, and ash content ranged from 4.5 to 6.8%. Determined lower calorific value of pellets varied from 16.8 to 17.0 MJ kg^{-1}. Harmful emissions from the combustion of all binary and trinomial crop pellets were sufficiently low and did not exceed the legal allowed values.

Key words: *multi-crop plants; biofuel pellets; physical-mechanical properties; harmful emissions.*

INTRODUCTION

Ensuring energy independence and use of renewable energy sources for biofuels is becoming increasingly important on a daily basis. Scientists have conducted numerous studies to substantiate the suitability of herbaceous plants for solid biofuels. Sustainable produced biofuel can be seen as a renewable energy source and burning them can help combat the negative effects on climate change (*Pierrehumbert, 2022*). However, to date there are no comprehensive studies to support the use of multi-crop biomass for the production of solid biofuels pellets.

The cultivation of multicultural crops is a good practice that meets the requirements of the European Green Course; so it is important to increase knowledge about their suitability for solid biofuels. Studies have shown multi-cropping stabilized gas concentrations and emissions from the soil. The share of microstructures in the upper soil layers was also found to decrease (*Romaneckas et al., 2022*). When several different crops are grown on the same area of land, not only are resources used more efficiently, but higher yields can be obtained (*Wu et al., 2021; Tumuluru et al., 2020*). Co-cultivation of legumes with non-legumes ensures better nitrogen accumulation and facilitates disease and pest control (*Jensen et al., 2020*). Cannabis is worth growing in multi-crops. Fibber hemp is suitable for multi-crop plants growing. It grows large amounts of biomass, is resistant to diseases and pests, and its biomass is suitable for biofuels, among other uses (*Ahmed et al., 2022*). *Li et al., (2021)* experiment showed that growing maize together with field beans produced more biomass compared to monoculture. Maize also has a high yield. In 2017, they were cultivated on 7.246 million hectares worldwide (*Supasri et al., 2020*).

The use of biomass to produce densified solid biofuels is projected to increase by 56% in 2040 compared to 2010 (*Bajwa, et al., 2018*). The production of pellets from plant biomass ensures their higher density and better energy properties (*Artemio, et al., 2018*). Granulation of biomass ensures uniform shape, size, easy transport, storage and use (*Mock, et al., 2021*). Due to the great diversity of biomass feedstocks, granular biofuels are produced in very different qualities (*Cui, et al., 2021a*). Research by *Cui et al., (2021b)* shows that the quality of pellet fuel can be improved by pelletizing different biomass feedstocks. The aim of this study is to evaluate the suitability of multi-crop (binary and ternary) biomass for the production of solid biofuel pellets.

MATERIALS AND METHODS

Plants grown in the test fields of Experimental station of Vytautas Magnus University Agriculture Academy as binary and ternary crops were used for the research. Plants grown in four different fields were studied:

- field 1 – maize and hemp (binary crop, abbreviated below – Sample 1);
- field 2 – hemp and field beans (binary crop, Sample 2);
- field 3 – maize and field beans (binary crop, Sample 3);
- field 4 – maize, hemp and field beans (trinomial crop, Sample 4).

Samples were taken from each field and the plants were naturally dried to 12% moisture. The plants were then crushed and ground. Pellets were made from the obtained flour and their main properties were studied.

The grinding quality is determined using a Retsch AS 200 sieve shaker (Germany). Sieves with holes of different 0.1, 0.25, 0.5, 0.63, 1.0 and 2.0 mm holes in diameter were used.

A low power granulator (200–300 kg h^{-1}) with horizontal matrix with 6 mm holes (Poland) was used for production of pellets.

The main parameters of the pellets were determined according to the standards:

- moisture content – according to the standard LST EN 14774-1: 2010;
- ash content – according to the standard LST EN 14775: 2010;
- lower calorific value – according to the standard LST EN 14918: 2010.

The pellets were burned in a 5 Kw furnace, and harmful emissions were found.

Arithmetic means of the measurement data and their confidence intervals were calculated at the 95% confidence level.

RESULTS AND DISCUSSION

An important parameter for the production of biomass pellets is the fractional composition of the flour. The results of the research show that the largest flour fractional composition was obtained in the ground biomass of Sample 2 and Sample 1. 67%, and 42% of the flour accumulated on the 2 mm sieve, respectively (Fig. 1).

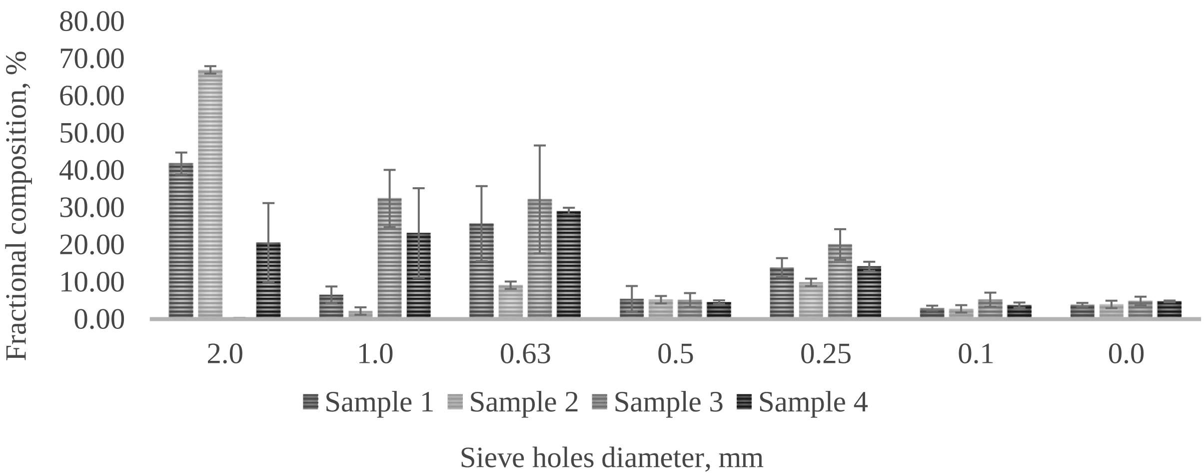

Fig. 1 The mill fraction of multi-crop biomass

In all samples, 65-78% of the flour was distributed on a 2.0 mm, 1.0 mm, or 0.63 mm sieve. It can be stated that the fractional composition of the obtained flour is optimal to produce pellets.

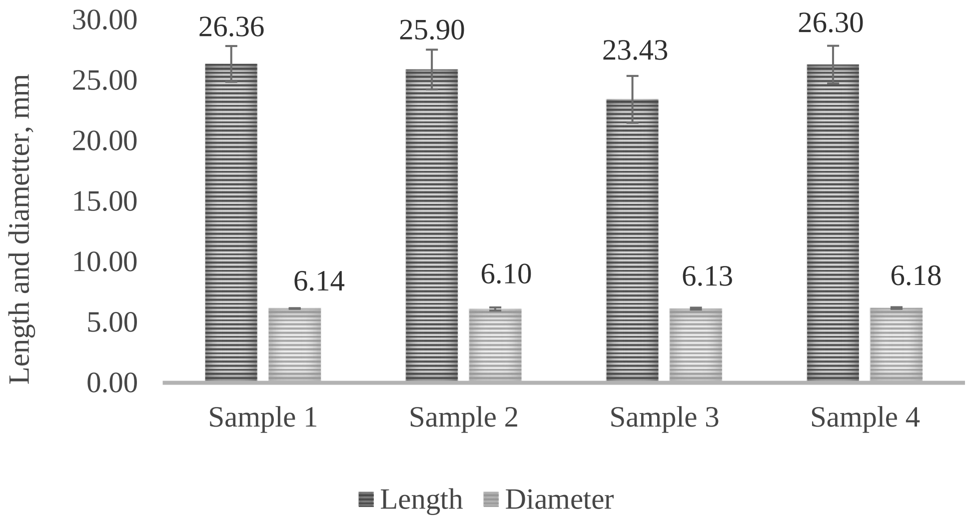

Fig. 2 Biometric properties of multi-crop pellets

The length of the pellets produced in all samples ranged from 23.4 to 26.4 mm and the diameter from 6.1 to 6.2 mm (Fig. 2). The length and diameter of the pellets comply with the standards of ISO17225-6 for solid non-wood biofuels.

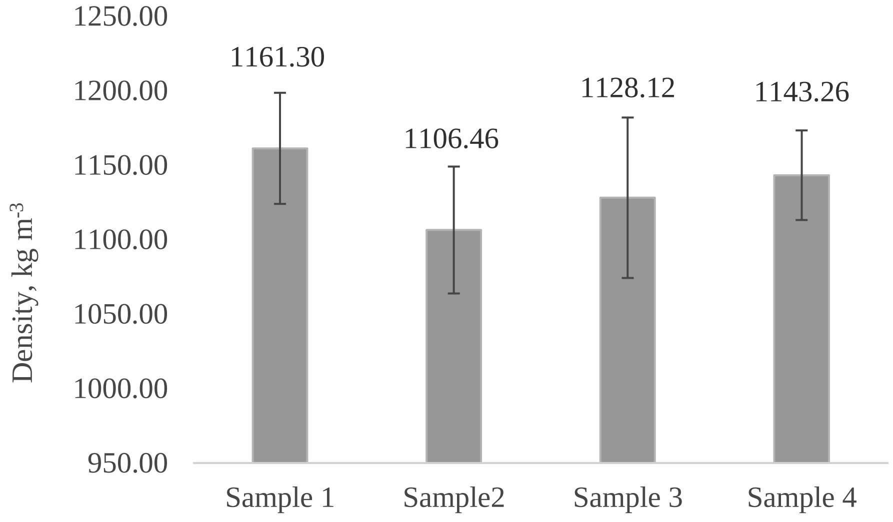

Fig. 3 The density of pellets

The density of the granules produced in all the samples was very similar and amounted to 1100 kg m^{-3} dry mass (Fig. 3). The highest density was of Sample 1 pellets – 1161 kg m^{-3} dry mass. According to this parameter, the granules of these samples meet the requirements of the ISO17225-6 standard for class A pellets (≥ 600 kg m^{-3}).
The elemental composition of the granules was also determined. The three main elements, C, O and H, were found to predominate, accounting for 92.5% to 94.9%.

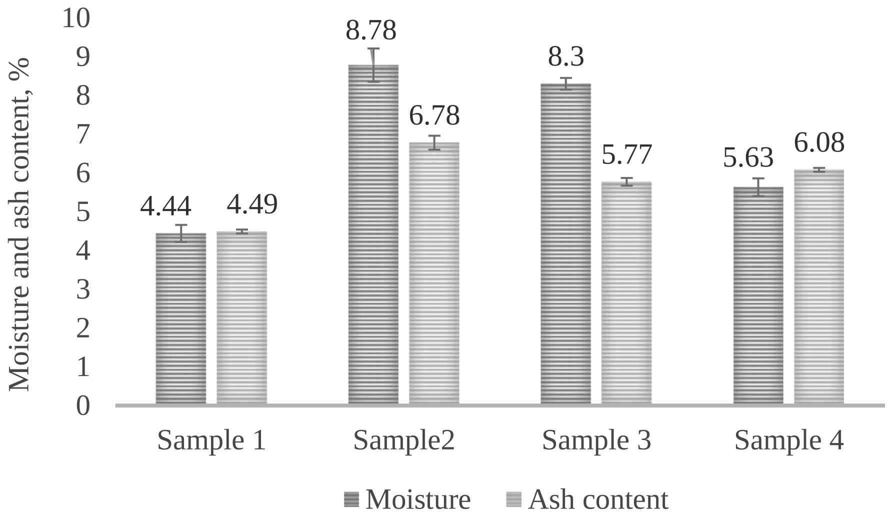

Fig. 4 Pellets moisture and ash content

One of the most important parameters affecting the quality of granulation is the moisture content (*Cui, et al., 2021b*). The other important parameter that defines the quality characteristics of biofuel pellets is ash content. The lowest was the moisture content of Sample 1 granules – 4.4%, and the highest – the moisture content of Sample 2 granules – 8.8% (Fig. 4). (According to the standard, the permissible moisture content of the pellets is ≤ 12% for Class A pellets and ≤ 15% for Class B pellets). The ash content of all 4 samples of pellets ranged from 4.5 to 6.8% and also did not exceed the requirements of the standard (≤ 6% for Class A pellets and ≤ 10% for Class B pellets).

A lower calorific value of produced pellets was also determined. The lower calorific value of all the samples was very similar, and it was about 17 MJ kg^{-1}. The highest calorific value was Sample 3 pellets - 17.02 MJ kg^{-1}, and the lowest – Sample 2 pellets, 16.80 MJ kg^{-1}.

For comparison, *Suleiman et al., (2019)* found that moisture content of corn cob pellets was 3.05%, and ash content was 2.7%. For corn stalk pellets, these parameters were 3.75 and 0.7% respectively.

For comparison according to *Carrillo & Parra et al., (2021)* research data the moisture content of the pellets made from perennial grass, patula pine sawdust and apple firewood was 5.84, 5.62 and 5.58% respectively, and ash content was 9.71, 0.47 and 2.12% respectively.

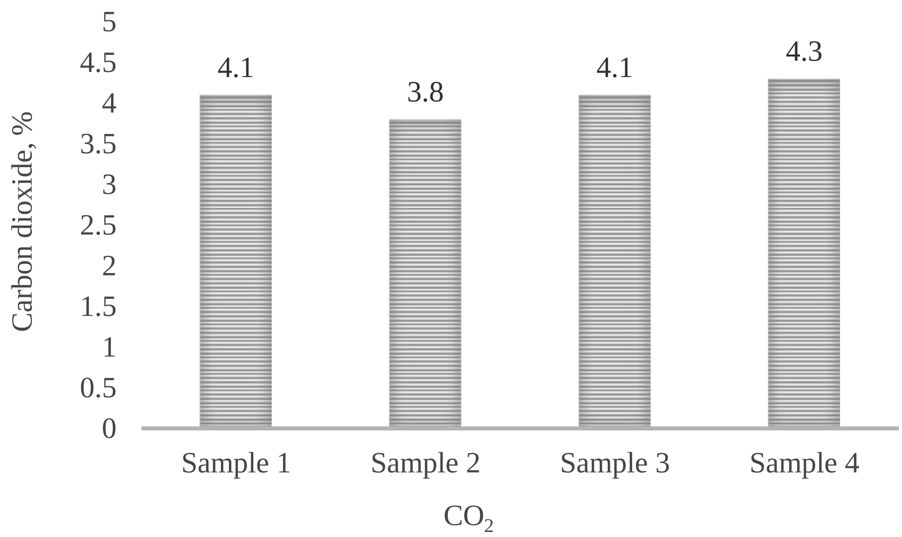

Fig. 5 CO_2 emissions by burning pellets

The quality of a fuel is also determined by the emissions that result from burning fuel. When burning pellets of multi-crop plants, the highest CO_2 concentrations were found when burning Sample 3 pellets – 4.3%, and the lowest – burning Sample 2 pellets – 3.8% (Fig. 5). For comparison, *Jasinskas et al., (2020)* found that CO2 emissions from burning biofuel pellets produced from faba bean waste ranged from 4.1 to 5.0%.

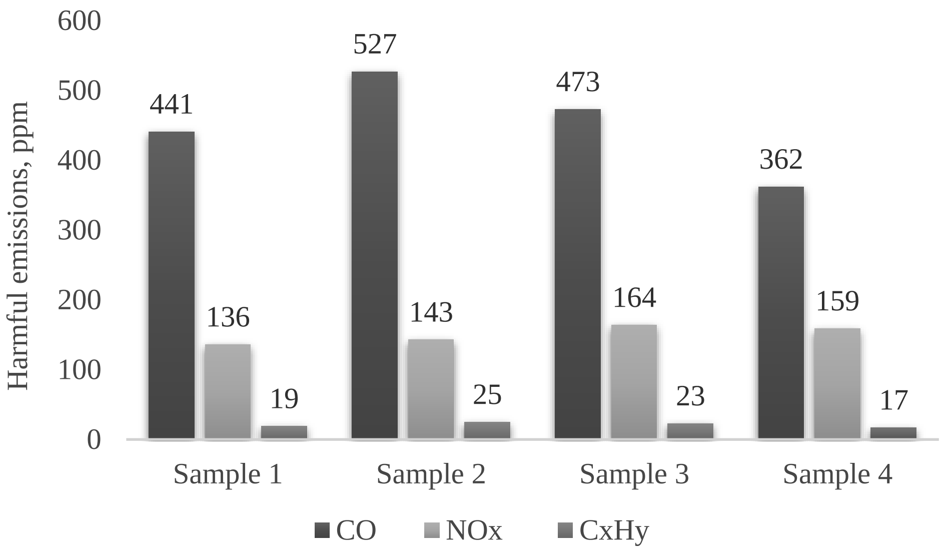

Fig. 6 CO, NO_x and C_xH_y emissions

The highest concentrations of CO and C_xH_y were in the combustion of Sample 4 pellets (527 and 25 ppm, respectively), and the highest concentrations in the incineration of Sample 2 pellets (362 and 17 ppm, respectively). Meanwhile, the lowest NO_x emissions were recorded by burning Sample 1 pellets (136 ppm), and the highest – by burning Sample 3 pellets (164 ppm) (Fig. 6). For comparison, the aforementioned study by *Jasinskas et al., (2020)* showed that burning pellets made from faba bean waste resulted in significantly higher CO emissions and ranged from 1072 to 2785 ppm. The nitrogen oxide emissions was very similar – 133-266 ppm.
The results of the pellet burning and emission studies presented in this article show that harmful emissions do not exceed the legal emission limit values for combustion of biomass pellets in low-power boilers.

CONCLUSIONS

The length of the pellets produced from 4 different biomass blends was 23.4-26.4 mm, and the diameter was 6.1-6.2 mm. The maximum moisture content of the granules did not exceed 8.8%, and the ash content did not exceed 6.8%. Lower calorific values from all four samples were higher than 16.8 MJ kg^{-1}. Biomass pellets made from binary and trinomial crops (maize, hemp and beans) meet the quality requirements for solid biofuels set out in the standard ISO17225-6. Burning of all 4 types of pellets has resulted in harmful emissions that do not exceed the legal limit values. Biomass pellets made from multi-crop plants (maize, beans and hemp grown for fiber) can be used as pressed solid biofuels of high quality.

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