48. ACTUAL TASKS ON AGRICULTURAL ENGINEERING

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MISCANTHUS AND MAIZE STALK AS SOURCE FOR GREEN ENERGY PRODUCTION

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ABSTRACT

Rising concerns about fossil energy and its impact on the environment have accelerated the development of bioenergy on a global level since biomass is a long-term renewable and CO_2 neutral. The use of biomass resources for energy purposes will reduce the dependence on fossil fuels and provide a way to mitigate climate change. Miscanthus and maize stalk will be investigated to be used for energy production by direct combustion. Maize stalk as postharvest residues and energy crop Miscanthus x giganteus belong to the second generation biomass (lignocellulosic biomass), but also to C4 plants, and such biomass is a potentially high-value source for green energy production. This study aims to determine the miscanthus and maize stalk biomass energy properties (structural, ultimate and proximate analysis and heating) as feedstock in the process of biofuel production. Namely, the characterization of these components, both qualitative and quantitative, is essential for defining the further processing of biomass into biofuels. Ash with moisture is a fundamental component of the non-combustible matter and 4,40% share for maize stalk and 1,96 for miscanthus is better than the most agricultural biomass., The most significant components of combustible matter are carbon and sulfur, and their values of approx. 47% and 0.2%) indicate good quality of the investigated raw material. The structural composition indicates the potential for use in the production of liquid fuels but also in the production of solid fuels. The lower heating value of maize stalk was 15 $MJkg^{-1}$ while lower heating value of miscanthus biomass was 17 $MJkg^{-1}$. Based on above results it can be concluded that investigated biomass has great potential as raw material for green energy production.

Keywords: *Miscanthus x giganteus, maize stalk, energy properties, biofuel.*

INTRODUCTION

Rising concerns about fossil energy and its impact on the environment have accelerated the development of bioenergy on a global level since biomass is a long-term renewable and CO_2 neutral (Johnson et al., 2007). The substitution of fossil energy by energy obtained from biomass is a promising and multifunctional way to protect and upgrade national energy security and improve rural economy (Zhou and Thomson, 2009). It will also reduce the dependence on fossil fuels and provide a way to mitigate climate change.

Agricultural lignocellulosic biomass has great energy potential because it is obtained from the primary agricultural production residues, as well as from food industry by-products (Krička et al., 2012). Maize stalk as postharvest residues and energy crop Miscanthus x giganteus belong to the second generation biomass (lignocellulosic biomass), but also to C4 plants, and such biomass is a potentially high-value source for green energy production.

By adopting the EU Bioeconomy Strategy, a circular economy for agriculture production is defined through food, feed, fuels, and fiber (4F) strategy. Due to mentioned miscanthus and maize stalk can be also used as fibers source for fiber reinforced composites. During the production process cellulose from the plants is removed and since the obtained residues are rich with lignin, they can be used for energy production by direct combustion.

Thermochemical conversion of biomass is an increasingly viable way to use agricultural residues and energy crops to fulfil energy needs (Tanger et al., 2013). Such biomass can be converted into a variety of energy needs such as electricity, process heat, and engine fuel (Demirbas, 2004). Generally, biomass conversion technologies are considered as environmentally friendly processes (Mladenović et al., 2018; Bilandžija et al., 2018).

Fuel properties data are foundation for valorisation of biomass in the combustion process (Tao et al., 2012). Such information is usually obtained by structural analysis (lignocellulosic composition), ultimate analysis, proximate analysis and heating values (Álvarez-Álvarez et al., 2018).

Considering the above mentioned the aim of this paper is to determine the miscanthus and maize stalk biomass energy properties (structural, ultimate and proximate analysis and heating values) as feedstock in the process of biofuel production.

MATERIALS AND METHODS

The analytical investigation of miscanthus biomass and maize stalk was conducted in the Laboratory for biomass and energy efficiency in agriculture at the University of Zagreb Faculty of Agriculture. All samples, after harvesting, were immediately transported to the laboratory and dried at room temperature in an elementary layer in order to eliminate extrinsic moisture. After drying, samples were ground in a laboratory grinder.

The structural analysis included determination of cellulose, hemicellulose and lignin content by the modified standard method ISO 5351-1:2002 in laboratory conditions.

The proximate analysis included determination of moisture content (HRN EN 18134-2:2015), ash content (HRN EN ISO 18122:2015), fixed carbon and volatile matter content (EN 15148:2009).

The ultimate analysis included determination of carbon, hydrogen, nitrogen (HRN EN ISO 16948:2015), and sulphur (HRN EN ISO 16994:2015) content which were determined simultaneously by dry combustion method by using the Vario Macro CHNS analyzer, while the oxygen content was calculated by difference.

The higher heating value (HHV) were determined by the EN 14918:2010 method by using an adiabatic calorimeter, while lower heating value (LHV) is obtained by calculating.

The data were analysed by means of the statistical software package SAS version 9.3 (USA).

RESULTS AND DISCUSSION

For understanding of the feedstock suitability for energy production it is important to determine its energy properties and that can be done through structural properties, ultimative and proximative analysis and heating value.

Miscanthus biomass and maize stalk belong to the second generation of raw materials for the biofuels production and they are included in the raw materials of the so-called lignocellulosic composition. Table 1 shows the structural (lignocellulosic composition) of the studied crops.

Table 1 Crops structural properties

Energy crop	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Miscanthus	53.11b* ± 0.58	13.52a ± 0.21	28.96b ± 0.52
Maize stalk	42.23a ± 0.89	25.74b ± 0.36	24.60a ± 0.33

*Different letters within a column indicate significant differences at the 5% level.

Biomass with a higher content of lignin is more suitable for energy production by the direct combustion process, while during the production of second generation biofuels its lowest share is desirable (Hodgson et al., 2010; Bilandžija et al., 2016). Cellulose has a higher oxygen concentration compared to lignin, so the heating value of cellulose is lower than lignin (Lewandoeski et al., 2003). As a result, a lower cellulose content is desirable for the direct combustion process, and as high as possible in the production of second-generation bioethanol from lignocellulosic biomass. Like cellulose, hemicellulose has a higher oxygen concentration than lignin, so the heating value of hemicellulose is lower than lignin, so a lower proportion of hemicellulose in biomass is also desirable for the combustion process.

The obtained results of lignocellulosic composition indicate the possibility of using the investigated crops in the production of solid and liquid biofuels, and are in accordance with the literature for miscanthus (Bilandžija et al., 2016; Jurišić et al. 2018) and for maize stalk (Antonović et al., 2016; Grubor et al., 2018).

Table 2 shows the proximate analysis of the investigated crops as significant energy parameters during combustion.

Water, as a non-combustible ingredient of the fuel, has a direct effect on the heating value of biomass due to the amount of heat spent on its evaporation (Francescato et al., 2008). The water content in the studied crops was around 5% for miscanthus and 10% for maize stalk.

Table 2 Crops proximate analysis

Energy crop	Moisture (%)	Ash (%)	Coke (%)	Fixed carbon (%)	Volatile matter (%)
Miscanthus	4.85a* ± 0.12	1.96a ± 0.08	11.94a ± 0.14	9.49a ± 0.12	85.71b ± 0.68
Maize stalk	9.70b ± 0.16	4.40b ± 0.10	14.84b ± 0.18	9.95a ± 0.09	75.93a ± 0.73

*Different letters within a column indicate significant differences at the 5% level.

Ash determines the fuel quality, respective the higher ash content decrease the quality. According to Francescato et al. (2008), the ash content in agricultural biomass ranges from 2% to 25%. The ash content in the studied crops ranged around 2% for miscanthus and 4% for maize stalk.

Furthermore, the coke content represents the dry distillation residues and its higher content increase fuel quality (Francescato et al., 2008). The coke content in the studied crops ranged around 12% for miscanthus and 15% for maize stalk.

The fixed carbon content, along with the ash, represents the solid residue after the combustion. The fixed carbon content of both studied cultures was around 10%, which is expected for agricultural biomass.

During the combustion process, biomass decomposes into volatile gases and solid residue. Biomass typically has a high percentage of volatiles, up to 80%, and fuels that have a high volatile content have a lower energy value (Quaak et al., 1999). The volatile matter content in the studied crops ranged around 86% for miscanthus and 76% for maize stalk. From a fuel point of view, high concentrations of volatile matters are not desirable but are as expected for agricultural biomass.

The proximate analysis results of the studied crops are in accordance with the literature (Bilandžija et al., 2016; Matin et al., 2016; Jurišić et al. 2018; Grubor et al., 2018).

Table 3 shows the elemental composition and heating value of the studied crops.

Table 3 Crops ultimate analysis and heating value

Energy crop	Carbon (%)	Sulphur (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	HHV (MJ kg^{-1})	LHV (MJ kg^{-1})
Miscan-thus	47,48b* ± 0.38	0,15a ± 0.02	5,60a ± 0.12	46,25a ± 0.38	0,52a ± 0.06	18,36b ± 0.26	17,17b ± 0.26
Maize stalk	46,03a ± 0.64	0,19a ± 0.05	5,59a ± 0.09	47,47b ± 0.24	0,88b ± 0.08	16,12a ± 0.33	15,01 a ± 0.33

*Different letters within a column indicate significant differences at the 5% level.

Carbon and hydrogen, as elements that increase the heating value of biomass, ranged around 47% and 6% for miscanthus, while for maize stalk they ranged around 46% and 6%.

Nitrogen does not participate in the combustion process, but it reduces the heating value of biomass. Except from the energy aspect, its lowest possible share is also important from the ecological aspect, because its combustion leads to the formation of nitrogen oxides (NOx)

(Van Loo and Koppejan, 2008; Vassilev et al., 2010). In the studied crops nitrogen content was around 0.5% for miscanthus, while it was around 0.9% for maize stalk.

The content of sulphur, a harmful element in the biomass ranged from 0.15% for miscanthus and 0.19% for maize stalk.

Oxygen binds carbon and hydrogen to itself and thus reduces the heating value of biomass, and in miscanthus it was about 46%, while in maize stalk it was about 47%.

The ultimate analysis results of the studied crops are in accordance with the literature (Krička et al., 2012; Bilandžija et al., 2016; Jurišić et al. 2018; Grubor et al., 2018).

All of the above parameters have an impact on the biomass heating value as a measure for determining the fuel energy content (Jenkins et al., 1998) and in miscanthus it was around 17 MJ kg^{-1}, while in maize stalk it was around 15 MJ kg^{-1}. which is in accordance with the literature (Bilandžija et al., 2012; Bilandžija et al., 2016; Jurišić et al. 2018; Grubor et al., 2018).

CONCLUSION

The analyzed biomass of Mischantus x giganteus and maize stalk showed quality properties from the direct combustion aspect, i.e. for the production of green energy. Namely, the ash that determines the quality of the fuel, and the fuel with a higher ash content is of poorer quality, was relatively low in the investigated crops in relation to other agricultural biomass. The elemental composition also shows good energy properties. Namely, carbon and hydrogen, as elements that increase the biomass heating value, occur in a high percentage and the amount of sulphur as a source of harmful elements was relatively low. The ratio of cellulose, hemicellulose and lignin indicates an increased content of cellulose and hemicellulose, but also the quality content of lignin, which results in the proposal that the studied crops can be used for the solid as well as liquid biofuels production. Also, the lower heating value in maize stalk was around 15 MJ kg^{-1}, which is within the expected range for agricultural biomass, while in miscanthus it was relatively high around 17 MJ kg^{-1}, and overall the miscanthus biomass proved to be a slightly better raw material for direct combustion process.

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REFERENCES

Álvarez-Álvarez, P., Pizarro, C., Barrio-Anta, M., Cámara-Obregón, A., Bueno, J. L. M., Álvarez, A., Burslem, D. F. (2018). Evaluation of tree species for biomass energy production in Northwest Spain. Forests, 9(4), 160.

Antonović, A., Krička, T., Matin, A., Jurišić, V., Bilandžija, N., Voća, N., Stanešić, J. (2016). Biochar quantification and its properties in relation to the raw material. In: Pospišil, M; Vnučec, I. (eds.) Proceedings of 51st Croatian and 11th International Symposium on Agriculture, Opatija, Croatia, 445-449.

Bilandzija, N., Voca, N., Kricka, T., Matin, A., Jurisic, V. (2012). Energy potential of fruit tree pruned biomass in Croatia. Spanish Journal of Agricultural Research, (2), 292-298.

Bilandžija, N., Jurišić, V., Voća, N., Leto, J., Matin, A., Antonović, A., Krička, T. (2016). Lignocelulozni sastav trave Miscanthus x giganteus u odnosu na različite tehnološke i agroekološke uvjete. In: Pospišil, M; Vnučec, I. (eds.) Proceedings of 51st Croatian and 11th International Symposium on Agriculture, Opatija, Croatia, 450-455.

Bilandžija, N., Krička, T., Matin, A., Leto, J., Grubor, M. (2018). Effect of harvest season on the fuel properties of Sida hermaphrodita (L.) Rusby biomass as solid biofuel. Energies, 11(12), 3398.

Demirbas, A. (2017). Higher heating values of lignin types from wood and non-wood lignocellulosic biomasses. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 39(6), 592-598.

Francescato, V., Antonini, E., Zuccoli Bergomi, L., Metschina, C., Schnedl, C., Krajnc, N., Stranieri, S. (2008). Priručnik o gorivima iz drvne biomase. Regionalna energetska agencija Sjeverozapadne Hrvatske, (eds.) V. Šegon, Zagreb, Hrvatska, 1-84.

Grubor, M., Krička, T., Bilandžija, N., Jurišić, V., Voća, N., Antonović, A., Matin, A. (2018). Kukuruzovina kao energent za proizvodnju krutog goriva. In: Rozman, V.; Antunović, Z. (eds.) Proceedings of 53. Croatian and 13. International Symposium on Agriculture, Vodice, Croatia, 275-279.

Hodgson, E. M., Lister, S. J., Bridgwater, A. V., Clifton-Brown, J., Donnison, I. S. (2010). Genotypic and environmentally derived variation in the cell wall composition of Miscanthus in relation to its use as a biomass feedstock. Biomass and Bioenergy, 34(5), 652-660.

Jenkins, B., Baxter, L. L., Miles Jr, T. R., Miles, T. R. (1998). Combustion properties of biomass. Fuel processing technology, 54(1-3), 17-46.

Johnson, J. M. F., Franzluebbers, A. J., Weyers, S. L., Reicosky, D. C. (2007). Agricultural opportunities to mitigate greenhouse gas emissions. Environmental pollution, 150(1), 107-124.

Jurišić, V., Krička, T., Matin, A., Grubor, M., Antonović, A., Voća, N., Bilandžija, N. (2018). Mogućnost korištenja trave Miscanthus uzgojene na tlima lošije kvalitete kao čvrstog biogoriva. In: Rozman, V.; Antunović, Z. (eds.) Proceedings of 53. Croatian and 13. International Symposium on Agriculture, Vodice, Croatia, 294-298.

Koppejan, J., Van Loo, S. (Eds.). (2012). The handbook of biomass combustion and co-firing. Routledge. London, UK

Kricka, T., Bilandzija, N., Jurisic, V., Voca, N., Matin, A. (2012). Energy analysis of main residual biomass in Croatia. African Journal of Agricultural Research, 7(48), 6383-6388.

Lewandowski, I., Clifton-Brown, J. C., Andersson, B., Basch, G., Christian, D. G., Jørgensen, U., Teixeira, F. (2003). Environment and harvest time affects the combustion qualities of Miscanthus genotypes. Agronomy Journal, 95(5), 1274-1280.

Matin, A., Krička, T., Jurišić, V., Voća, N., Antonović, A., Bilandžija, N., Grubor, M., Miličević, I. (2016). Iskoristivost biomase kukuruza za proizvodnju toplinske energije. In: Pospišil, M; Vnučec, I. (eds.) Proceedings of 51st Croatian and 11th International Symposium on Agriculture, Opatija, Croatia, 489-492.

Mladenović, M., Paprika, M., Marinković, A. (2018). Denitrification techniques for biomass combustion. Renewable and Sustainable Energy Reviews, 82, 3350-3364.

Quaak, P., Knoef, H., & Stassen, H. (1999). Energy from biomass: a review of combustion and gasification technologies. The International Bank for Reconstruction, SAD.

Tanger, P., Field, J. L., Jahn, C. E., DeFoort, M. W., Leach, J. E. (2013). Biomass for thermochemical conversion: targets and challenges. Frontiers in plant science, 4, 218.

Tao, G., Lestander, T. A., Geladi, P., Xiong, S. (2012). Biomass properties in association with plant species and assortments I: A synthesis based on literature data of energy properties. Renewable and Sustainable Energy Reviews, 16(5), 3481-3506.

Vassilev, S. V., Baxter, D., Andersen, L. K., Vassileva, C. G. (2010). An overview of the chemical composition of biomass. Fuel, 89(5), 913-933.

Zhou, A., Thomson, E. (2009). The development of biofuels in Asia. Applied Energy, 86, S11-S20.