Influence of a dry year on the Virginia mallow energy properties

Anamarija Gudelj - Velaga, Nikola Bilandžija, Mateja Grubor, Josip Leto, Tajana Krička

University of Zagreb Faculty of Agriculture, Svetošimunska cesta 25, Zagreb, Croatia (agvelaga@agr.hr)

Abstract

This paper is based on the energy characteristics of Virginia mallow (*Sida hermaphrodita* L. Rusby) with the correlation of harvest time and dry year. Virginia mallow attracts attention as an energy crop due to the additional benefits it brings with it, such as: possibility of conversion into different forms of energy, highly attractive for pollinators due to the long flowering season, improvement of soil quality, phytoremediation and according to some research there is a small possibility of invasiveness. Since the natural habitat of Virginia mallow is wet habitats, there is possible sensitivity to drought. Virginia mallow is interesting because as a crop it can be vital from 10 to even 20 years. In addition to its versatility, it also offers valuable energy properties as a permanent crop. Average higher heating value of Virginia mallow obtained by research was 18.06 MJ/kg. There is a valuable possibility that should be taken, in form of good possibility for energy utilization combined with preservation of the ecosystem. The aim of this paper is to determine the energy properties (proximate and ultimate analysis and calorific value) of Virginia mallow in a dry year.

Keywords: *Sida hermaphrodita*, energy crop, energy utilisation, biomass, dry year

Introduction

Europe as a union and a continent depends on renewable energy development. One of the main goals of EU is to become climate neutral continent by 2050, and to cut gas emissions by 55% by 2030 (EU targets). The United Nation climate change summit in Paris 2016 set a goal to limit global warming by 2 °C, preferably 1.5 °C compared to pre-industrial levels (UN climate change). For better understanding, because of combustion of fossil fuels that accumulate greenhouse gases in atmosphere the climate change occurs (Sathre, 2014). Therefore, there are two types of energy, fossil fuels that are non-renewable and includes petroleum, coal, gas etc. and green energy that includes wind power, solar power, and biomass (Midilli et al., 2006). Renewable energy is sustainable, safe, and cost effective it encourages energy independence and diversity while reducing carbon emission (Chum and Overend, 2001). Regarding biomass for renewable energy sources, some of the main resources are wood, energy crops, forestry waste and agricultural waste. All together they can be transformed to liquid, gaseous of solid fuel. Main processes for energy utilisation of biomass are pyrolysis, gasification, and combustion. Pyrolysis converts biomass to bio-oil, gasification is used to get fuel gas and combustion is for heat (Bridgwater, 2003). Another reason why using biomass for energy production is good is its storage potential and use on demand (Jablonowski et al., 2017).

Virginia mallow is a perennial crop from the *Malvaceae* family, and its binomial name is *Sida hermaphrodita* L. Rusby. This species originates from North America, from where it was introduced to Europe primarily to Poland and Russia (Cumplindo-Marin et al., 2020). As for the physical characteristics, Virginia mallow can grow from 1 to 3 m, the leaf has 3 to 7 toothed and elongated leaflets, especially the middle one is the most elongated, and they grow alternately on the stem. Virginia mallow has a characteristic white flower (of 5 petals) that blooms from August to October or until the first frost (Kasprzyk et al., 2013; COSEWIC, 2010). The young stem of Virginia mallow has hairs that fall off completely in the mature stage of the plant. As for growth, Virginia mallow spreads by rhizomes, and in the first year only one shoot emerges, while in the following years more and more emerge, thus Virginia forms a dense assembly of 20 to 30 shoots and can last up to 20 years as a crop (COSEWIC, 2010; Franzaring, 2015).

Effects of drought on Virginia mallow

Virginia mallow tolerates winter conditions and low temperatures as low as -35 °C, but shows sensitivity to drought, some research show that in dry years the yield decreases by 30 % (School et al., 2017; Nahm and Mohart, 2018; Borkowska et al., 2016). The needs of Virginia mallow for precipitation range from a minimum of 500-600 mm, but it tolerates a minimum of 400 mm of precipitation (Borkowska et al., 2009; Borkowska and Molas, 2012; Cumplindo-Marin et al., 2020). Although it shows sensitivity to drought conditions and is more sensitive to drought conditions than other non-wood energy crops, its water requirements are still almost half that of short rotation woody crops (Borkowska and Molas, 2012; Jankowski et al., 2016). In the research conducted by Siwek et al. (2019), it was shown that the biogas yield from Virginia mallow in a dry year is almost half as much as in a year with relatively normal conditions. According to Siwek et al. (2019) biogas yield in 2017 with normal conditions was 7.246 m^3ha^{-1}, and in 2018, which was characterized as a dry year, biogas yield was 3.232 m^3ha^{-1}.

Optimal harvest time for Virginia mallow

Harvesting Virginia mallow is characteristic in that the saplings dry out at the end of the growing season, and therefore the moisture level significantly depends on the time of harvest (Borkowska and Molas, 2013; Krička et al., 2017).

Another characteristic of Virginia mallow is that small amounts of nutrients are removed from the field during harvest, because as the mallows dry, the nutrients are located in the rhizome and are returned to the soil through it, or through the fallen leaves that Virginia mallow discards as it approaches the end of its growing season (Krička et al., 2017; Pszczółkowska et al., 2012).

Conventional harvesting methods are applied for harvesting. Compared to short rotation coppice, harvesting Virginia mallow is economically more profitable, requires simpler mechanization and good weather (Vanbeveren et al., 2015; Nahm & Mohart, 2018). Also compared to short rotation coppices, Virginia mallow is dry enough for direct storage or direct combustion (Jablonowski et al., 2017).

Harvest time for Virginia mallow is correlated with calorific value, specifically crude fibers (cellulose, hemicellulose and lignin) are correlated with calorific value. Viriginia mallow has the least crude fibers in the period when it has leaves and when it flowers (Siaudinis et al., 2015; Nahm and Mohart, 2018). The amount of cellulose fibers, hemicellulose and lignin in the period of flowering is 60.2 % of a dry matter, and at the time of autumn harvest from 80 to even 88.1 % according to some studies (Pokoj et al., 2015; Slepetys et al., 2012; Michalska et al., 2015).

According to research conducted by Bury et al. (2019) for biogas production, two harvests of Virginia mallow give a higher dry mass yield than just one annual (winter) harvest. According to research, harvests are carried out in early summer and early autumn (Bury et al., 2019).

Materials and methods

Virginia mallow was harvested in November 2022 at the experimental field of University of Zagreb Faculty of Agriculture. Table 1. gives a detailed information on precipitation on monthly basis for 2021 and 2022 year. During the growing season from April until November average precipitation was 107.7 mm with average temperature 16.51 °C, and it is perceived as a drought year harvest (H 22). The average year that would be compared to drought year is 2021, with harvest also in November (H 21).

Table 1. Precipitation in Zagreb – Maksimir for 2021 and 2022 year

month/year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2021 (mm)	70.2	29.0	36.1	68.7	124.0	13.2	74.5	62.7	34.6	86.2	89.2	83.8
2022 (mm)	24.3	38.5	8.7	82.0	52.5	63.0	57.7	20.03	259.1	21.8	-	-

After drying, the biomass samples in a laboratory dryer at 105 °C (MEMMERT universal dryer) were homogenized and crushed in a laboratory mill (IKA MF 10 basic, Germany).

Proximate analysis determined the moisture content (HRN EN 18134-2:2015) using a laboratory dryer (INKO, Croatia), ash (HRN EN ISO 18122:2015) using a muffle furnace (Nabertherm, USA) and the content of fixed carbon (Cfix) and volatile matter (EN 15148:2009) which were calculated by calculation.

The ultimate analysis determined the total carbon, hydrogen, nitrogen and sulfur which were determined simultaneously by the dry combustion method using the analyser Vario Macro CHNS (Elementar Analysensysteme GmbH, Germany), according to the protocols for carbon, hydrogen and nitrogen (HRN EN ISO 16948:2015) and sulfur (HRN EN ISO 16994:2015) while the oxygen content was calculated from the difference.

Calorific values were determined using the EN 14918:2010 method using an adiabatic calorimeter (C200, IKA Analysentechnik GmbH, Heitersheim, Germany), while the lower calorific value was calculated by computational derivation. The calorific value is expressed in MJ/kg.

Results and discussion

Using various methods, the results for proximate and ultimate analysis and heating value were obtained. Proximate analysis shows values for moisture content, ash, volatile matter, fixed carbon (Cfix), and coke. Ultimate analysis shows values for carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and oxygen (O).

Table 2. Proximate analysis results and higher heating value (HHV)

Sample	MC, %	Ash, % db	VM, % db	Cfix, % db	Coke, % db	HHV, MJ/kg
H 22	50.81	2.68	84.12	9.18	9.63	17.23
H 21	47.62	4.69	82.68	7.01	11.71	18.89
Average	49.21	3.68	83.40	8.09	10,67	18.06

**MC – moisture content (measured at field), VM – volatile matter, C-fix – fixed carbon, % db - % on dry basis, HHV – higher heating value*

Results from proximate analysis in Table 2. shows some differences between a dry year of 2022 and 2021. Moisture content measured directly on the field was 50.81 % which is slightly higher compared to H 21 of 47.62 %. It is visible that a drought year has lower ash content. Volatile matter is slightly higher in drought year than in average year. Fixed carbon and coke also had a bit lower value compared to average year. Considering higher heating value at drought year it was 17.23 MJ/kg which is slightly lower than 18.89 MJ/kg in 2021.

Comparing average results of H 22 and H 21 with literature findings, average ash content is 3.68 % while in research by Banks et al. (2021) it was 2.11 %, and in Sliz and Wilk (2020) ash value was 1.97 %. Volatile matter on average was 83.40 % and in Banks et al. (2021) results show volatile matter of 79.74 %, while in research obtained by Sliz and Wilk (2020) volatile matter was 85.50 %. In research by Banks et al. (2021) Cfix was 18.15 %, and in research by Sliz and Wilk (2020) Cfix was 5.63%, compared to this average result of 8.09 %, that is much lower than Banks et al. (2021) and closer to Sliz and Wilk (2020). Heating value obtained by Sliz and Wilk (2020) was 17.79 MJ/kg which compared to average value of 18.06 MJ/kg is slightly lower.

Table 3. Ultimate analysis results

Sample	Carbon, % db	Hydrogen, % db	Nitrogen, % db	Sulphur, % db	Oxygen, % db
H 22	45.75	5.64	0.22	0.03	48.01
H 21	44.93	5.59	0.18	0.02	49.09

**% db - % on dry basis*

The results obtained in Table 3. by ultimate analysis shows that drought year did not influence ultimate properties. Compared to literature findings in Sliz and Wilk (2020) values for C was 44.9 %, H 6.02 %, O 46.78 % and N was 0.33 %. In the research from Banks et al. (2021), the values of ultimate analysis were C 47.02 %, H 5.54 %, N 0.47 %, S was not detected, and O was 46.97 %. Ultimate analysis of this research compared to other shows similar results.

Conclusion

The energy analysis shows good values of proximate and ultimate analysis with satisfactory heating value, so Virginia mallow could be and should be used much more as an energy utilisation crop.

The researched biomass of Virginia mallow with a harvest date in November, in comparison with the energy characteristics from harvest year before and the literature, shows satisfactory results of proximate, ultimate analysis and calorific value. The influence of the dry year is visible in the lower ash content but generally it did not influence energy characteristics in a great proportion.

Acknowledgments

The research has received funding from the European Regional Development Fund via K.K.01.1.1.04.0091 project "Design of Advanced Biocomposites from Renewable Energy Sources - BIOCOMPOSITES".

Literature

Banks S.W., Śnieg M., Nowakowski D.J., Stolarski M., Bridgwater A.V. (2021). Potential of Virginia Mallow as an Energy Feedstock. Waste and Biomass Valorization. 12 (5): 2375-2388.

Borkowska H., Styk B., Molas R. (2006). Staude mit Potenzial: Sida als Energie-und Faserpflanze. Energie Pflanzen. 2: 12-13.

Borkowska H., Molas R., Kupczyk A. (2009). Virginia fanpetals (Sida hermaphrodita rusby) cultivated on light soil; height of yield and biomass productivity. Polish Journal of Environmental Studies. 18 (4): 563-568.

Borkowska H., Molas R. (2012). Two extremely different crops, Salix and Sida, as sources of renewable bioenergy. Biomass and Bioenergy. 36: 234-240.

Borkowska H., Molas R. (2013). Yield comparison of four lignocellulosic perennial energy crop species. Biomass and Bioenergy. 51: 145-153.

Bridgwater A.V. (2003). Renewable fuels and chemicals by thermal processing of biomass. Chemical engineering journal. 91 (2-3): 87-102.

Bury M., Facciotto G., Chiocchini F., Cumplido-Marín L., Graves A., Kitczak T., Martens R., Morhart C., Możdżer E., Nahm M., Paris P., Siwek H., Włodarczyk M., Burgess P., Kahle H.P. (2019). Preliminary results regarding yields of Virginia mallow (Sida hermaphrodita (L.) Rusby) and cup plant (Silphium perfoliatum L.) in different condition of Europe. In Biomass Crops and Energy Grasses, Proceedings of the 27th European Biomass Conference and Exhibition, (pp. 27-30). Lisbon, Portugal.

Chum H.L., Overend R.P. (2001). Biomass and renewable fuels. Fuel processing technology. 71 (1-3): 187-195.

Cumplido-Marin L., Graves A.R., Burgess P.J., Morhart C., Paris P., Jablonowski N.D., Facciotto G., Bury M., Martens R., Nahm M. (2020). Two Novel Energy Crops: Sida hermaphrodita (L.) Rusby and Silphium perfoliatum L.—State of Knowledge. Agronomy. 10 (7): 928.

EU targets https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en

Franzaring J., Holz I., Kauf Z., Fangmeier A. (2015). Responses of the novel bioenergy plant species Sida hermaphrodita (L.) Rusby and Silphium perfoliatum L. to CO2 fertilization at different temperatures and water supply. Biomass and Bioenergy. 81: 574-583.

Jankowski K.J., Dubis B., Budzyński W.S., Bórawski P., Bułkowska K. (2016). Energy efficiency of crops grown for biogas production in a large-scale farm in Poland. Energy. 109: 277-286.

Jablonowski N.D., Kollmann T., Nabel M., Damm T., Klose H., Müller M., Bläsing M., Seebold S., Krafft S., Kuperjans I., Dahmen M., Schurr U. (2017). Valorization of Sida (Sida hermaphrodita) biomass for multiple energy purposes. GCB Bioenergy. 9: 202-214.

Kasprzyk A., Leszczuk A., Domaciuk M., Szczuka E. (2013). Stem morphology of the Sida hermaphrodita (L.) Rusby (Malva- ceae). Modern Phytomorphology. 4: 25.

Krička T., Matin A., Bilandžija N., Jurišić V., Antonović A., Voća N., Grubor M. (2017). Biomass valorisation of Arundo donax L., Miscanthus× giganteus and Sida hermaphrodita for biofuel production. International agrophysics. 31: 575-581.

Michalska K., Bizukojc M., Ledakowicz S. (2015). Pretreatment of energy crops with sodium hydroxide and cellulolytic enzymes to increase biogas production. Biomass and Bioenergy. 80: 213–221.

Midilli A., Dincer I., Ay M. (2006). Green energy strategies for sustainable development. Energy policy. 34 (18): 3623-3633.

Morhart D.C., Douglas C.G., Dupraz C., Graves R.A., Nahm M., Paris P., Sauter H.U., Sheppard J., Spiecker H. (2014). Alley coppice—a new system with ancient roots. Annals of Forest Science. 71 (5): 527-542.

Nahm, M., Morhart, C. (2018). Virginia mallow (Sida hermaphrodita (L.) Rusby) as perennial multipurpose crop: Biomass yields, energetic valorization, utilization potentials, and management perspectives. Gcb Bioenergy. 10(6): 393-404.

COSEWIC. 2010. COSEWIC assessment and status report on the Virginia Mallow Sida hermaphrodita in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 9 -18 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Pokoj T., Bułkowska K., Gusiatin Z.M., Klimiuk E., Jankowski K.J. (2015). Semi-continuous anaerobic digestion of different silage crops: VFAs formation, methane yield from fiber and non-fiber components and digestate composition. Bioresource Technology. 190: 201–210.

Pszczółkowska A., Romanowska-Duda Z., Pszczółkowski W., Grzesik M., Wysokińska Z, (2012). Biomass production of selected energy plants: Economic analysis and logistic strategies. Comparative Economic Research. Central and Eastern Europe. 15 (3): 77-103.

Sathre R. (2014). Comparing the heat of combustion of fossil fuels to the heat accumulated by their lifecycle greenhouse gases. Fuel. 115: 674-677.

Schoo B., Kage H., Schittenhelm S. (2017). Radiation use efficiency, chemical composition, and methane yield of biogas crops under rainfed and irrigated conditions. European journal of Agronomy. 87: 8-18.

Siaudinis G., Jasinskas A., Sarauskis E., Steponavicius D., Karcauskiene D., Liaudan- _ skiene I. (2015). The assessment of Virginia mallow (Sida hermaphrodita Rusby) and cup plant (Silphium perfoliatum L.) productivity, physico–mechanical properties and energy expenses. Energy. 93: 606–612.

Siwek H., Włodarczyk M., Możdżer E., Bury M., Kitczak T. (2019). Chemical Composition and Biogas Formation potential of Sida hermaphrodita and Silphium perfoliatum. Applied Sciences. 9 (19): 4016.

Slepetys J., Kadziuliene Z., Sarunaite L., Tilvikiene V., Kryzeviciene A. (2012). Biomass potential of plants grown for bioenergy production. In: Renewable Energy and Energy Efficiency. Proceedings of the International Scientific Conference (ed. Rivza P), pp. 66–72. Latvia: University of Agriculture, Jelgava.

Śliz M., Wilk M. (2020). A comprehensive investigation of hydrothermal carbonization: Energy potential of hydrochar derived from Virginia mallow. Renewable Energy. 156: 942-950.

UN climate change https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Vanbeveren S.P.P., Schweier J., Berhongaray G., Ceulemans R. (2015). Operational short rotation woody crop plantations: manual or mechanised harvesting? Biomass and Bioenergy. 72: 8–18.