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EVALUATION OF TECHNOLOGICAL AND ENVIRONMENTAL PARAMETERS OF *ARTEMISIA DUBIA* PLANT BIOMASS UTILIZATION FOR ENERGY CONVERSION

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The studies of growing and harvesting large-stemmed plants *Artemisia dubia* (wormwood) have been carried out at Vėžaičiai Branch LAMMC. There were determined the influence of growing conditions, nitrogen application level and harvesting time to the *Artemisia dubia* productivity. The article also provides the results of research on processing and use of *Artemisia dubia* biomass for energy conversion. At the beginning harvested plants were chopped, milled and pressed into the pellets, and were determined pellet physical, technical, chemical and environmental parameters, such as moisture content, density, elemental composition, ash content, calorific value, emissions after biofuel burning. Research results showed, that the production and burning process of this type of biofuel is characterized by sufficiently high quality, efficient combustion and permissible emissions into the environment. Research results of determined physical properties, combustion and emissions after burning of *Artemisia dubia* pellets show, that they can be used for production and usage for pressed biofuel.

Keywords: *large-stemmed plants, wormwood, harvesting time, pressed biofuel, pellets, properties, density, combustion, emissions.*

INTRODUCTION

There are good conditions for cultivation and use of various energy plants for energy purposes in Lithuania, such as forest wood, agricultural and various herbaceous and woody energy plants. A few years ago, the main source of solid fuel was wood from forests, despite this in recent years various plant biomass is increasingly used for energy purposes. There is a lot of vacant uncultivated and cultivated lands in Lithuania, where it would be possible to grow Willow, Elephant grass, Sida and other herbaceous energy plants, and it would be possible to obtain high-quality and high-calorific biofuel. The biomass of various plants emits low greenhouse gases and helps create additional places for jobs, increases energy independence, and is also beneficial for rural development (Šiaudinis et al., 2015; Stolarski et al., 2015).

Cultivation of energy plants and their rational and ecological use in energy has been carried out for a long time in Lithuania and other European Union countries (Ibitoye et al., 2021; Wang et al., 2020). In order to preserve the environment and the nature around us as much as possible, it is important for everyone to participate as actively as possible in preserving the natural environment and preserve it for future generations. One of the most important aspects of environmental conservation is sustainability and ecology. This can be achieved by the widest possible use of various renewable energy sources and the industrial cultivation of energy plantations. It would be appropriate to use the chips obtained after chopping woody energy plants in energy companies, and to process the herbaceous plants into granular biofuel and use them for household purposes (Cui et al., 2021).

Tall herbaceous plants have a plenty of benefits: it has a high potential for uptake and conversion of sunlight energy, can produce a large yield of plant biomass during the photosynthesis process. A great advantage of elephant grass is that it can grow in low-fertility and arid soils unsuitable for other crops. Due to its high lignin content, Elephant grass

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biomass can be used to produce cellulose and it is also environmentally friendly, because these plants emit low levels of nitrogen oxides (Jasinskas et al., 2020).

For growing of Elephant grass plantations, it is important to select such an area of land that requires minimal costs for mechanized tillage, crop maintenance and ingathering (Clifton-Brown et al., 2001). The calorific value of these plants can to reach 17 MJ energy for 1 kg of dry weight, Elephant grass also store a not big amount of minerals as in colder weather it accumulates in the rhizomes (Lewandowski et al., 2003). It is not necessary to fertilize a lot Elephant grass, as it provides most of the necessary nutrients on its own. These plants also have a disadvantage, as they are not resistant to cold, which is especially noticeable in newly planted plants (Iglinski et al., 2011).

Sida is another promising plant used for energy purposes. These plants grow well in areas with high rainfall, these plants can grow up to 3–4 m tall and reproduce by seeds. Sida biomass yield can reach 8–20 t ha^{-1} dry mass (Lessa et al., 2021). The calorific value of these plants is also big and can reach until 18 MJ kg^{-1}, it comparable to the calorific value of Spruce or Pine. However, compared to growing wood, Sida can provide twice as much energy per unit area per year. Farmers do not need additional machinery to harvest these plants, because they can use the same machinery which they use to harvest other tall crops such as Corn, Jerusalem artichokes, etc. (Iglinski et al., 2011). Interest in these plants is constantly increasing, they are studied by scientists from Poland, Germany and other countries (Bilandžija et al., 2018). In the overall energy balance, a large part of heat energy production is not only wood and wood waste, but also straw and various other types of energetic plants, for which new combustion technologies are increasingly used in bioelectric plants and households (Sumalan et al., 2020).

The effective use of renewable energy resources requires the expansion of new technologies and wide-ranging investigation of the properties of energy plants. Upon completion of analysis of the physical, mechanical, thermal, chemical and other properties of plants and selecting suitable processing and burning equipment, it is possible to produce and supply high-quality fuel to consumers (Ibitoye et al., 2021; Cui et al., 2021).

After the review and analysis of scientific information sources, the aim of this study was formulated – to evaluate the technological-technical parameters of the processing and use of large-stemmed herbaceous plants for energy purposes, to analyse the process of granulated biofuel production, to determine important properties of pellets and to assess the environmental impact of burning pellets produced from big-stemmed plants.

RESEARCH METHODS

Field experiments. The field experiments with *Artemisia dubia* (Wormwood) were conducted in Lithuanian Research Centre for Agriculture and Forestry, Vėžaičiai Branch of Institute of Agriculture in 2021. The research site is located in Western Lithuania, on the eastern edge of the coastal plain (55°430 N, 21°270 E). The study field is naturally acid moraine loam *Bathygleyic Dystric Glossic Retisol* (WRB, 2014) with a clay content (<0.002 mm) of 15.0%. According to the local meteorology, the average annual rainfall is about 915 mm.

The field experiment was conducted according to the principle of two factors. 1st factor – the time of harvesting. *Artemisia dubia* plants were harvested 3 times: 1) at the end of June (PK-1-1); 2) in the middle of August (PK-2-1); 3) at the end of the growing season, that is at the beginning of October (PK-3-1). Harvested area (netto) of all treatments was 3.3 m^2. 2rd factor was nitrogen rates. The seedlings were planted and fertilized by 3 nitrogen levels (0 kg ha^{-1}, 90 kg ha^{-1} and 180 N kg ha^{-1}) (Šiaudinis et al., 2023). But on this article is presented only first experiment, when nitrogen level was 0 kg ha^{-1}. Number of replications – 3.

Fractional composition of mill. In order to determine the suitability of *Artemisia dubia* plants for biofuel production, not only the biometric properties of the pellets, but also the properties of plant mill were determined. The 50 g samples of chopped and milled plant biomass were used for determination of mill fractional composition. For this purpose, were used a sieve shaker Retsch AS 200 with a set of sieves, which worked for 1 minute in 10 second intervals with every sample. The oscillation amplitude of the sieves was 1.0 mm. All tests were repeated 3 times.

Physical-mechanical characteristics of pellets were determined of granulated *Artemisia dubia* plant biomass and control sample, pellets produced of sawdust: pellet moisture content; pellet biometric parameters, density, thermal properties. These research investigations were performed using these presented methods and equipment.

Pellet production. How was mentioned, there were produced three variants of biofuel pellets, produced of *Artemisia dubia* plant biomass and control sample, sawdust pellets. These experiments were fulfilled in the laboratories of Vytautas Magnus University, Agriculture Academy. For biofuel pellets production was used the press with horizontal matrix with 6 mm holes (Jasinskas et al., 2020). After the pellets were pressed and cooled, their biometric parameters etc. dimensions, content of moisture, volume and density were examined.

Pellet moisture content. The moisture content of the pellets was determined according to standard methodology using a drying chamber (Minajeva et al., 2021).

Pellet parameters were determined by measuring it length and diameter using a digital Vernier caliper (accuracy to 0.01 mm). For all experimental trials were randomly selected 10 pellets. Pellet weight was estimated by scales KERN ABJ (accuracy to 0.001 g). The average mass values of the measured three types of granules were calculated.

Pellet density. Pellet volume was calculated by measuring the length and diameter of the pellets. After determining the mass and volume of the pellets, it density was calculated according standard methodology (Jasinskas et all, 2020).

Analysis of LCV and harmful emissions of burning biofuel pellets. The experiments were carried out at the Lithuanian Energy Institute (LEI), Thermal Equipment Research and Testing Laboratory according to the standard methodology valid in Lithuania and other European countries. A calorimeter IKA C 5000 with a calorimeter bomb

IKA C 5012 was used to determine the Lower calorific value (LCV) of the investigated plant pellets. At the Lithuanian Energy Institute, the above-mentioned methodology was also used to determine not only calorific value, but also the amount of chlorine, elemental composition and ash content.

Emissions of harmful gases were determined in pellet fireplace type stove Astra P–5 (Astra, Lithuania). 5 kg mass of the sample was used for combustion. The power of the boiler was 5 kW, and the average flue gas temperature was 105–200°C. The formed pollutants were measured with the combustion product analysers Datatest 400 CEM and VE7. The burning of each sample lasted for about 10 minutes, and were measured the emissions of harmful substances into the environment by burning biofuel pellets (CO, CO_2, NO_x and C_xH_y). Limit values for harmful emissions of biofuel combustion devices are determined using the standard (LAND 43-2013).

In experiments analysing and evaluating the properties of granular biofuel, the research data were statistically evaluated by performing one-way analysis of variance, correlation, and regression (Raudonius et al., 2009).

RESEARCH RESULTS AND DISCUSSION

Determination of briquette properties. The qualities of the raw material, the employed machinery, the mass fractional composition, and the moisture content all affect briquette making. Figure 2 shows the fractional content of Sosnowsky's hogweed, Giant knotweed and Pine as control milled raw material.

When we compare our results with those of researchers Malatak et al. who burnt biomass from herbal plants to make briquettes, we find that their NO_x values ranged from 59.16 ppm to 199.38 ppm. CO values ranged from 1547.88 ppm to 2339.42 ppm (Malatak et al., 2020).

Elemental composition. It has been examined and determined whether Sosnowsky's hogweed and Giant knotweed are suitable for solid biofuel production (Figures 7 and 8). Although inferior than biomass produced from woody pine, solid biofuels made from invasive herbaceous plants did meet the aforementioned European standards.

The lower calorific value of Sosnowky's hogweed, which was obtained in our research at 15.89 ± 1.01 MJ kg^{-1}, seems to be quite similar to Paramonova's results, coming in at 16.50 MJ kg^{-1}(Paramonova et al., 2021). These measurements demonstrate that the biomass from Sosnowsky's hogweed and Giant knotweed is applicable for production of solid biofuels. From these results it can be gleaned that the most important carbon, hydrogen and oxygen values are similar to traditional biomass fuels and the amount of nitrogen does not exceed standard limits. In the tests of elemental composition of these briquettes there were trace amounts of chlorine and sulphur although their values were less than 0.05 % across all three biomass products. This information indicates that briquettes produced from these invasive herbaceous plants have sufficient carbon hydrogen and oxygen for the combustion process and do not have excess amounts of sulphur and chlorine to produce harmful acidic emissions or contaminate ash that accumulates during the combustion process.

Determination of produced mill properties. At the beginning in the preparation of granular biofuels, the plant stems were chopped with a drum chopper into a 15–20 mm long particles. After that this chopped biomass was ground with a hammer mill using a sieve with round holes 2 mm in diameter. The quality of produced mill fractional composition is presented in Figure 1.

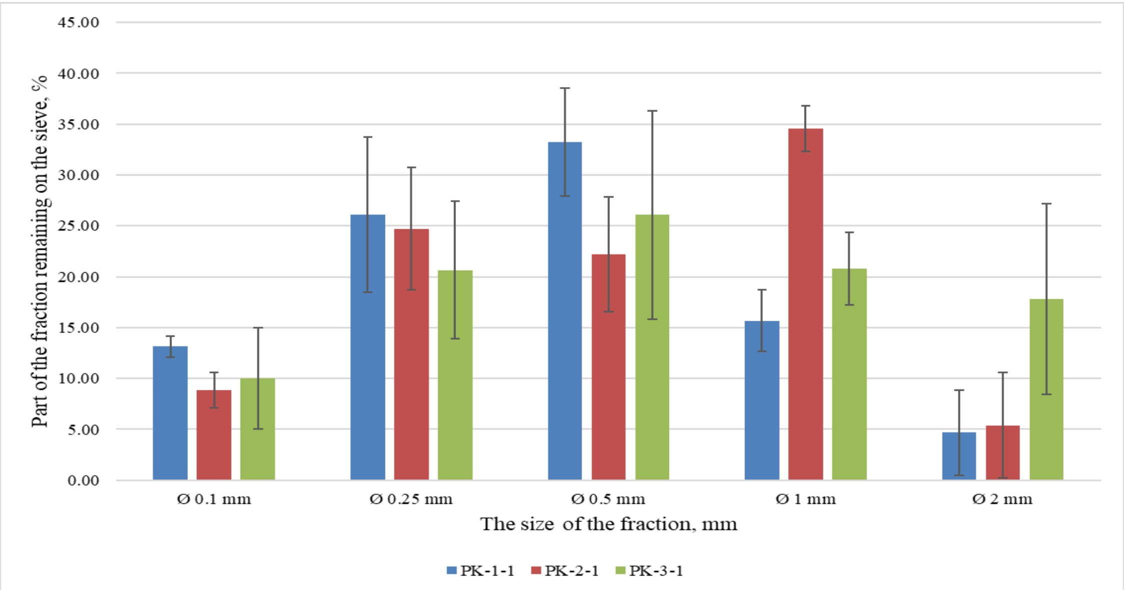


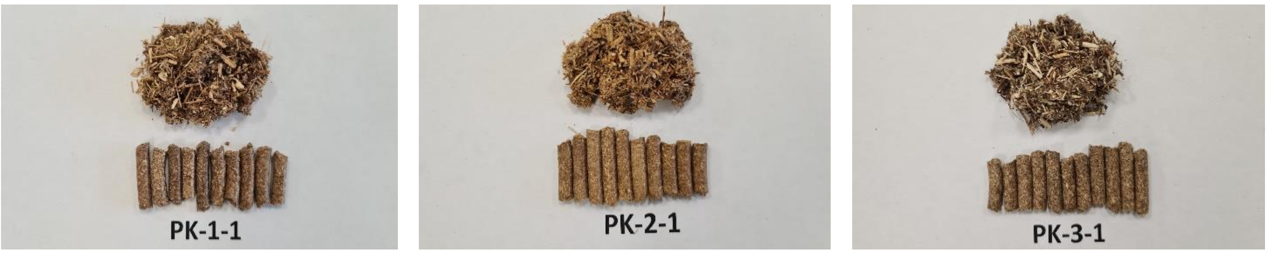
Figure 1. Results of *Artemisia dubia* plant mill fractional composition

When preparing 6 mm diameter pellets, it is recommended that the 1–2 mm mill particles should make up 70–80% (Jasinskas, Zvicevicius, 2008). Summarizing the results of determining the quality and fractional composition of investigated plant mill (Figure 1), it can be stated that using 2 mm sieves for the production of plant biomass mill produces mainly particles of 0.5–1.00 mm size. Most of the fine particles (0.1–0.5 mm) were formed using PK-1-1 plants. The most 1 mm particles remained when crushing PK-2-1 plants, and 2 mm particles in PK-3-1.

It was determined, that moisture content of produced mill varied from 7.4 to 7.8%. So, it can be said that this moisture content is too low for production of granules, therefore the mill was moistened to 13–15% before granules pressing.

Determination of pellets properties. The properties of the produced pellets depend on the granulation equipment used, raw material, mass fractional composition and raw material moisture content.

Biometric properties of produced biofuel pellets using *Artemisia dubia* chopped and milled plant stem biomass (Figure 2) depend on the produced pellet main parameters. It was determined that average diameter of produced *Artemisia dubia* pellet varied from 6.22 mm to 6.39 mm and pellet average length was very similar and varied from 24.66 mm to 25.77 mm. But the length of pine sawdust pellets was bigger and reached 30.73 ± 0.88 mm. (Table 1).



1st harvest 2ond harvest 3rd harvest

Figure 2. Produced biofuel pellets of *Artemisia dubia* plant biomass, which was harvested in different harvest periods

The moisture content has a significant influence on the quality and properties of the pellets. When pellets are very dry, it quickly absorbs moisture from the environment, can swell, decompose and return to its original state, as before granulation. According researches, the raw materials with a moisture content of 15-20% should be used for pellet production (Ungureanu et al., 2018). Other researcher, Greinert et al. (2020) indicated other results and noted, that the optimal pellet moisture content for the burning process is when pellet moisture is about 6-8%. For research was used pellets produced of straw and willow mixture. So, it is important to determine biofuel pellet moisture content. Determined *Artemisia dubia* plant and pine sawdust pellets moisture content and other parameters are presented in Table 1.

Table 1. Main characteristics of produced *Artemisia dubia* plant and pine sawdust pellets

Parameter	PK-1-1	PK-2-1	PK-3-1	Pine sawdust (PS)
Length, mm	25.77	25.79	24.66	30.73 ± 0.88
Diameter, mm	6.22	6.39	6.25	6.09 ± 0.13
Density, kg m^{-3}	1192.44±69.72	1167.06±38.11	1119.86±26.65	1100.9 ±34.0
Moisture content, %	9.98±0.33	9.26±0.37	9.66±0.55	7.50 ± 0.55
Ash content, %	6.35 ± 0.18	5.27 ± 0.02	4.53 ± 0.08	3.46 ± 0.05
LCV, MJ kg^{-1}	17.92 ± 1.01	18.03 ± 0.05	18.14 ± 0.28	18.25 ± 0.59

Research results of determined properties of produced *Artemisia dubia* plant pellets show, that moisture content of investigated pellets was very similar and varied from 9.26±0.37% to 9.98±0.33%, even the moisture content of pine sawdust pellets was lower and reached 7.50 ± 0.55% (Table 1).

The results of the density test of the produced pellets are presented in Figure 3. Based on the determined data, the average density of granules in kg m^{-3} with a confidence interval was also calculated.

Research results show, that the biggest density had biofuel pellets, produced of *Artemisia dubia* plant (1st harvest), 1192.44±69.72 kg m^{-3}. The lowest density had pellets produced of pine sawdust, 1100.9 ±34.0 kg m^{-3} (Figure 3, Table 1). It could be stated, that all types of produced biofuel pellets had sufficient high density (more than 1000 kg m^{-3}).

The obtained density results of *Artemisia dubia* plant biomass pellets were statistically evaluated according to Student's and Tukey's HSD tests and the essential limit of density difference was calculated. Considering the minimum limit of reliable difference and pellet density, it was found that there is no significant difference between the different types of tested pellets.

If compare our research results with the results of other researchers, they look very similar. Tulumuru et al. (2018) study showed that the density of pellets (8 mm diameter) made from corn stover reached about 1133 kg m^{-3}. Maj et al. (2022) determined, that produced and investigated corn cob pellet density reached 1140 kg m^{-3}, and mixed corn cobs and corn husks pellets density was very similar to our results, and reached 1150 kg m^{-3} (Maj et al., 2022).

The lowest ash content was found in control sample, after burning of pine sawdust pellets – 3.46 ± 0.05%, and the highest was found in a sample of PK-1-1 – 6.35 ± 0.18%. These results show, according to the ash content parameter, that all produced samples did not exceed the requirements of the ISO17225-6:2021 standard.

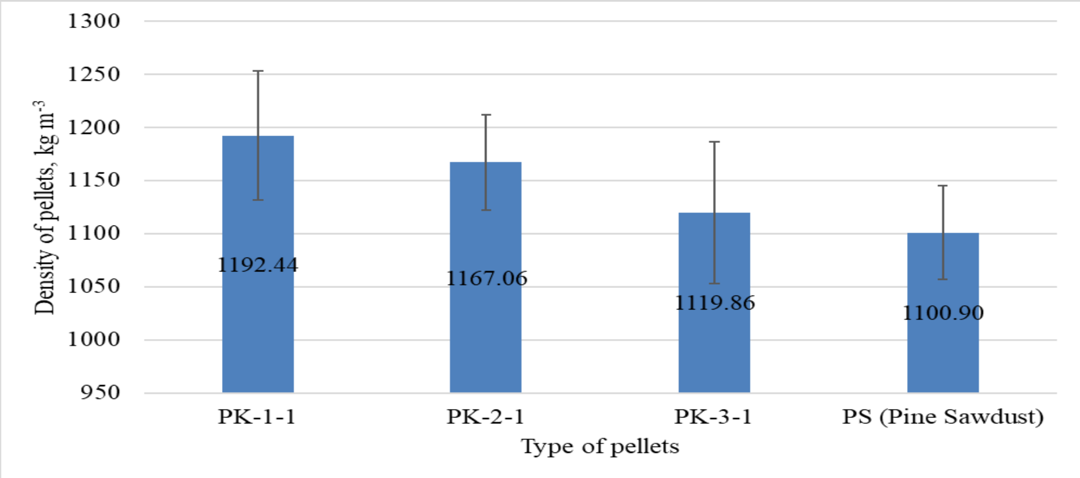


Figure 3. Average means of pellet density

Values of Lower calorific value (LCV) of all produced types of pellets was quite similar and sufficient high, was about 18 MJ kg^{-1} and varied from 17.92 ± 1.01 to 18.25 ± 0.59 MJ kg. The studies of other researchers show, that the lower or net calorific value of biomass and their mixtures can be similar. Ozturk et al. (2019) research showed that higher calorific value (HCV) of maize pellets was with a diameter of 6.26 mm, and a length of 17.28 mm was similar than that of our produced pellets and reached 18.11 MJ kg^{-1}.

Determination of harmful emissions. Determined emissions when burning *Artemisia dubia* plant pellets showing the quality and suitability of produced biofuel. Table 2 show emissions from the burning of pressed coarse-stemmed plants.

In accordance with the requirements of LAND 43-2013, there were determined, that the emissions of *Artemisia dubia* plant and sawdust pellets did not exceed the maximum permissible concentrations (only the PK-1-1 sample have too big CO harmful gases concentration – 8303 ppm. The value of C_xH_y gases was also too big – 1109 ppm).

Table 2. Emissions from the burning of pressed coarse-stemmed plants pellets

Plant species	CO_2	CO	NO_x	C_xH_y
	%	ppm	ppm	ppm
PK-1-1	2.5	8303	157	1109
PK-2-1	4.5	2447	169	206
PK-3-1	4.5	702	111	40
Pine sawdust	4.7	188	111	9

The lowest concentrations of CO, NO_x, and C_xH_y harmful gases were obtained by burning control sample, pine sawdust pellets (188 ppm, 111 ppm, and 9 ppm, respectively). High emissions were obtained by burning PK-1-1, only CO_2 emissions were detected very low, only 2.5%. Sulphur dioxide SO_2 emissions were not detected during the combustion of investigated biofuel pellets. In these studies of biofuel pellet combustion and harmful gas emissions, a trend was observed that when later the *Artemisia dubia* plants were harvested, was detected the less harmful environmental impact.

Summarizing research results of *Artemisia dubia* plant pellets combustion and determination of harmful emissions to the environment, it can be stated that these plants grown in Lithuania can be recommended to use for pressed biofuel production. But in order to pollute the environment as little as possible when burning such biofuel pellets, it is recommended to harvest plants for the production of pelletized biofuel as late as possible in autumn.

CONCLUSIONS

1. There were produced and investigated three variants of *Artemisia dubia* plant and pine sawdust biofuel pellets. *Artemisia dubia* plants were harvested 3 times: 1) at the end of June (PK-1-1); 2) in the middle of August (PK-2-1); 3) at the end of the growing season, i.e., beginning of October (PK-3-1).
2. Determined moisture content of investigated three types pellets was very similar and varied from 9.26±0.37% to 9.98±0.33%, even the moisture content of pine sawdust pellets was lower and reached 7.50 ± 0.55%.
3. Investigated biofuel pellets had sufficient high density, it reached more than 1000 kg m^{-3} DM. The biggest density had biofuel pellets, produced of *Artemisia dubia* plant (1st harvest), 1192.44±69.72 kg m^{-3}, and the lowest density – pine sawdust pellets, 1100.9 ±34.0 kg m^{-3}.
4. Results of investigated biofuel pellets burning and determination of harmful emissions to the environment show, that when burning *Artemisia dubia* plant and sawdust pellets, it was not exceeded the maximum permissible concentrations, only the emissions of PK-1-1 have too big CO gases concentration – 8303 ppm., and the value of C_xH_y gases was also too big and reached 1109 ppm.

5. Summarizing research results it can be stated that *Artemisia dubia* plants grown in Lithuania can be recommended to use for pressed biofuel production. But in order to pollute the environment by harmful gases less, for the production of pressed biofuel it is recommended to harvest plants as late as possible in autumn.

REFERENCES

1. Šiaudinis, G.; Jasinskas, A.; Šarauskis, E.; Steponavičius, D.; Karčiauskienė, D.; Liaudanskienė, 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(1), 606. https://doi.org/10.1016/j.energy.2015.09.065
2. Stolarski, M.J.; Krzyzaniak, M.; Warminski, K.; Tworkowski, J.; Szczukowski, S. 2015. Willow biomass energy generation efficiency and greenhouse gas reduction potential. *Polish Journal of Environmental Studies*, 24(6), 2627. https://doi.org/10.15244/pjoes/59333
3. Ibitoye, S.E.; Jen T.Ch.; S.E.; Mahamood, R.M.; Akinlabi, E. T. 2021. Densification of agro-residues for sustainable energy generation: an overview. *Bioresour. Bioprocess*, 8, 75. https://doi.org/10.1186/s40643-021-00427-w
4. Wang Y., Wang J., Zhang X., Grushecky S. 2020. Environmental and Economic Assessments and Uncertainties of Multiple Ligno-cellulosic Biomass Utilization for Bioenergy Products: Case Studies. *Energies*, 13, 6277. https://doi.org/10.3390/en13236277
5. Cui, X.; Yang, J.; Wang Z.; Shi, X. 2021. Better use of bioenergy: A critical review of co-pelletizing for biofuel manufacturing. *Carbon Capture Science & Technology*, 1, 100005. https://doi.org/10.1016/j.ccst.2021.100005
6. Jasinskas, A.; Streikus, D.; Vonzodas, T. 2020. Fibrous hemp (Felina 32, USO 31, Finola) and fibrous nettle processing and usage of pressed biofuel for energy purposes. *Renewable Energy*, 149, 11–21. https://doi.org/10.1016/j.renene.2019.12.007
7. Clifton-Brown, J.; Lewandowski, I.; Andersson, B. 2001. Performance of 15 Miscanthus Genotypes at Five in Europe. *Agronomy Journal*, 93, 1014–1019. https://doi.org/10.2134/agronj2001.9351013x
8. Lewandowski, I.; Jonathan, M.O.; Scurlock, J.M.O.; Lindvall, E.; Christoud, M. 2003. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. *Biomass Bioenergy*, 25, 335. https://doi.org/10.1016/S0961-9534(03)00030-8
9. Iglinski, B.; Iglin, A.; Kujawski, W.; Buczkowski, M.; Cichosz, R. 2011.Bioenergy in Poland. Renew. *Sustain. energy reviews* 2011, 15, 2999. https://doi.org/10.1016/j.rser.2011.02.037
10. Lessa, M.O.; Calixto, G.Q.; Chagas, B.M.E; Aguiar, E.M.; Melo, M.A.F.; Braga, R.M. 2021. Energetic characterization and flash pyrolysis of different elephant grass cultivars (*Pennisetum purpureum Schum*.). *The Canadian Journal of Chemical Engineering*, 24309. https://doi.org/10.1002/cjce.24309
11. 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* 2018, 11, 3398, 1–13. https://doi.org/10.3390/en11123398
12. Sumalan, R.L.; Muntean, C.; Kostov, A.; Krzanovic, D. 2020. The cup plant (*Silphium perfoliatum* L.) – a viable solution for bioremediating soils polluted with heavy metals. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 2020, 48(4), 2095-2113. https://doi.org/10.15835/nbha48412160
13. Šiaudinis, G.; Jasinskas, A.; Karčauskienė, D.; Skuodienė, R.; Repšienė, R. 2023. The impact of nitrogen on the yield formation of *Artemisia dubia* Wall.: efficiency and assessment of energy parameters. *Plants*, 12(13), 1–12. https://doi.org/10.3390/plants12132441
14. Minajeva, A.; Jasinskas, A.; Domeika, R.; Vaiciukevičius, E.; Lemanas, E.; Bielski, S. 2021. The Study of the Faba Bean Waste and Potato Peels Recycling for Pellet Production and Usage for Energy Conversion. *Energies*, 14, 2954. https://doi.org/10.3390/en14102954
15. LAND 43-2013. Emission rates for combustion plants. 2013. (In Lithuanian).
16. Raudonius, S.; Jodaugienė, D.; Pupalienė, R.; Trečiokas, K. 2009. Research methodology. Academy, Kaunas District, 34p. (In Lithuanian).
17. Jasinskas, A: Zvicevičius, E. 2008. Biomass production engineering: a textbook for high schools. Lithuanian University of Agriculture. Academy, Kaunas distr.: IDP Solutions, 98 p. (In Lithuanian).
18. Ungureanu, N.; Vladut, V.; Voicu, G.; Dinca, M.N.; Zabava, B.S.2018. Influence of biomass moisture content on pellet properties–Review. *Engineering for Rural Development*, 17, 1876–1883. https://doi.org/10.22616/ERDev2018.17.N449
19. Greinert, A.; Mrówczyńska, M.; Grech, R.; Szefner, W. 2020. The Use of Plant Biomass Pellets for Energy Production by Combustion in Dedicated Furnaces. *Energies*, 13, 463. https://doi.org/10.3390/en13020463
20. Maj, G.; Krzaczek, P.; Gołębiowski, W.; Słowik, T.;Szyszlak-Bargłowicz, J.; Zając, G. 2022. Energy Consumption and Quality of Pellets Made of Waste from Corn Grain Drying Process. *Sustainability*, 14, 8129. https://doi.org/10.3390/su14138129

21. Tumuluru, J.S. 2018. Effect of pellet die diameter on density and durability of pellets made from high moisture woody and herbaceous biomass. *Carbon Resources Conversion*, 1, 44–54. https://doi.org/10.1016/j.crcon.2018.06.002
22. Ozturk, H.H.; Ayhan, B.; Turgut, K. 2019. An assessment of the energetic properties of fuel pellets made by agricultural wastes. *Land Reclamation, Earth Observation & Surveying, Environmental Engineering*, 8, 9–16.