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Krzysztof Mudryk
Sebastian Werle *Editors*

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Spread Mustard and Prospects for Biofuels

Tetyana Kozina, Olena Ovcharuk, Ivan Trach, Viktoriya Levytska, Oleg Ovcharuk, Taras Hutsol, Krzysztof Mudryk, Marcin Jewiarz, Marek Wrobel and Krzysztof Dziedzic

Abstract The paper presents research aimed to determine the potential of waste biomass from the processing of mustard. Raw material for research came from the central part of Ukraine. Studies have shown that mustard residues are a valuable raw material for the production of solid biofuels in the form of briquettes or pellets. Values of quality parameters (such as calorific value, durability, density) are comparable to those found in commercial solid biofuels. Analysis of ash content showed an increased content of mineral fractions, which were the source of plant surface impurities applied by atmospheric agents (rain, wind).

Keywords Mustard · Solid biofuels · Pellet durability · Waste biomass

1 Introduction

In the modern developed world, a lot of energy is used: for domestic needs, transport, industry Combustion of fossil fuels is the most common way of producing energy. However, each stage of it negatively affects to the environment: CO_2, SO_2, NO, particulate matter and dust are released. In addition, oxides of heavy

T. Kozina · O. Ovcharuk · I. Trach · V. Levytska · O. Ovcharuk (✉) · T. Hutsol
State Agrarian and Engineering University in Podillia, Khmelnytskyi, Ukraine
e-mail: ovcharuk.oleh@gmail.com

T. Hutsol
e-mail: pro-gp@pdatu.edu.ua

K. Mudryk · M. Jewiarz · M. Wrobel · K. Dziedzic
Faculty of Production and Power Engineering, University of Agriculture in Krakow, ul. Balicka 116 B, 30-149 Krakow, Poland
e-mail: Krzyszto.Mudryk@ur.krakow.pl

M. Jewiarz
e-mail: marcin.jewiarz@urk.edu.pl

M. Wrobel
e-mail: marek.wrobel@urk.edu.pl

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metals are emitted into the atmosphere. CO_2 is the main component of greenhouse gases, contributes to global warming, while other SO_2 and NO acid gases form acid precipitates, impair the air quality. The combustion of fossil fuels, including motor fuels, is the source of approximately 80% of the emissions.

Therefore, the actual task is to find fuel that can replace the practical properties of oil, but won't pollute the environment. At least in part this can only be provided by biofuels.

For Ukraine, which, on the one hand, is 55% dependents on imported fuel, and on the other—not fully utilizes the potential of agriculture, biomass-based energy production would overcome dependence on imported energy, to approach Europe and to contribute to climate change prevention This requires the biofuel market creation as an alternative energy source. Thanks to this, it is possible to receive about 15 million tons of equivalent fuel, if 5 million ha of land is considered as a potential for growing energy plants and mastering the processing of crop residues. Having such a potential, it is possible to maintain wasteless agriculture and ecological state improvement of the environment [1].

The biomass usage for energy production already now accounts for about half of all renewable energy sources in the world, in Europe it reaches 70%, Sweden—64%, Denmark and Austria—33%. After 20 years, biomass prices will be as good calculated as to coal, oil or gas. Experts expect, that investments in the market of growing energy plants will increase until 2020 up to 25 billion dollars [1].

For Ukraine, bioenergy is one of the strategic directions for the renewable energy sector development. Sufficient energy potential of straw and plant wastes was noted. A significant part of the straw after harvesting is pressed into bales, briquettes and pellets and is used for heating. At 14 enterprises of oil industry, more than 500 thousand tons of sunflower husk is burnt and 120 thousand tons of it is granuled.

Among the biofuel recovery biofuels, a significant proportion is occupied by solid biofuels. The oldest fuel used by mankind is wood. At present, energy forests consisting of fast-growing breeds (poplar, eucalyptus, etc.) are growing in the world for the production of firewood or biomass. Modern biofuels are fuel pellets and briquettes. These are pressed products from wood waste (sawdust, chips, bark, thin and substandard wood, residues from logging operations), straw, agricultural waste (husk of sunflower, nutshell, manure, chicken manure) and biomass. Wood pellets are called pellets, they have the shape of cylindrical or spherical granules with a diameter of 8–23 mm and a length of 10–30 mm [2–5].

Energy carriers of biological origin (mainly manure, etc.) are also known. They are briquetted, dried and burned in fireplaces of apartment houses and furnaces of thermal power stations, producing cheap electric power.

Potential is the crop waste usage, namely untreated or with a minimum degree of preparation for incineration: sawdust, chips, bark, husk, straw, etc.

The solid biofuel industry in Ukraine is fully oriented for export, as more than 90% of fuel pellets and briquettes are exported from the country. The main importers of solid biofuels are Poland, Germany, Italy. The solid biofuel industry in Ukraine continues to grow at a rapid pace, as evidenced by the following data: in 2008. In Ukraine, pellets and briquettes were produced together with

77 thousand tons; In 2009—350 thousand tons (pellets—260 thousand tons, briquettes—90 thousand tons) [6].

Research work is part of the research conducted by the Department of Ecology and Balanced Nature Management, the Faculty of Agrotechnology and Balanced Nature Management of the Podilskyi State Agrarian and Engineering University in cooperation with the Renewable Energy Laboratory of the Engineering Institute of Krakow Agricultural University.

The work aim is the effective solve of the biofuel production problem due to a comprehensive assessment of residues of crops' various types and their wastes during post-harvest processing.

The target of research is the process of determining effective sources of raw materials and establishing the productive, energy potential of mustard plants.

The experimental unit is the vegetational remains of mustard.

As a work result, important scientific and practical results have been obtained, which consist in identifying promising sources of biofuel on the basis of an integrated assessment of the potential of mustard plants stubble remains, developing biofuel production technologies and introducing them into Ukraine's energy sector, which is of immediate interest today.

The economic importance of research results lies in: increasing the diversity of raw materials at the expense of agricultural plants; Identification of effective non-traditional and alternative sources of biofuel feedstocks; technology creation for fuel production based on the energy efficiency of mustard plants [7–9].

According to the State Statistics Service of Ukraine, according to the results of 2016 the area of mustard sown area was 44.5 thousand ha. The main areas are located in the regions, thousand hectares of Khersonska—11.1, Zaporizhka—4.9, Khmelnytska—1.5, Cherkaska—1.0, Vinnytska—1.1, Kyivska—1.7, Poltavska—1.4, Luganska—3.1, Donetska—5.7, Chernihivska—2.6, Kharkivska—1.2 and others (see Fig. 1).

It was analyzed the data of sown areas, we found that mustard crops are located on 75% of the territory of Ukraine.

Agroecological advantages of growing mustard in Ukraine, its medicobiological properties, high profitability of production contribute to the further development of the sales market, its processing and increasing the culture profitability.

Taking into account the multifaceted national economic importance of mustard (oil, technical, fodder, sideral, nectareous) and unpretentious it has recently attracted attention as a raw material base for the replenishment of plant resources in agriculture.

In the western regions of Ukraine, the mustard stems reach height from the main and post harvest spurting 120–130 sm. The mustard sticks and stubble residues are not widely used, in most cases remain on the field. Therefore, there is a need to conduct research on mustard raw materials for suitability for biofuel production in the form of pellets and briquettes.

The effectiveness of the bioenergy development in Ukraine depends on the work coordination in this sector and the proper choice of priorities. First of all, at the governmental level, there should be defined a single state body that would deal with

Fig. 1 The region of mustard cultivation in Ukraine (year 2016)

all issues in the bioenergy sector and coordinate the work of other involved organizations and institutions. Priority areas of development should be defined in the state program for the development of bioenergy in Ukraine, while ensuring its financing and improving the legislative sphere.

2 Materials and Methods

The study material was mustard residue containing both damaged seed as well as seed coat and stem fragments. The research material was obtained after processing the 2016 crops in Ukraine. On Fig. 2 is presented sample of research material that has been subjected to a detailed analysis of physicochemical properties in terms of energy potential.

The test material was sampled and prepared according to the PN-EN 14778_2011e and PN-EN 14780_2011e standards. Based on prepared samples complex analysis of physicochemical parameters was performer. The estimated quantities were:

– Moisture content,
– Bulk density,
– Volatile matter content,
– Ash content,
– Higher and lower heating value,

Fig. 2 Sample of raw material

– Mechanical durability of formed granulates,
– Specific density.

Moisture content M_{ar} [%] assigned according to the PN-EN ISO 18134-1:2015-11 standard. Material sample of weight aprox. 300 g placed in the dry container was dried in convective drier in 105 °C ± 2 for 4 h, or when mass will remain constant.

Bulk density BD [kg m^{-3}] of the raw material and produced pellets was measured according to the PN-EN ISO 17828:2016-02 standard based on measurement of sample mass, placed in the vessel with known volume.

Volatile matter V_d [%] determined according to the procedure proposed in PN-EN 15148_2010e standard. The dry crucible with lid filled with the test material (1 ± 0.1 g), is weight (accuracy 0.0001 g) and treated in furnace for 7 min in 910 ± 10 °C.

Ash content [%] was determined according to the guides in PN-EN ISO 18122:2016-01 standard. The test sample was placed in the annealing dish, weighed (accuracy 0.0001 g) treated in furnace for 3 h in 550 ± 10 °C.

Gross calorific value $qV_{gr,ar}$ [J g^{-1}] **and net calorific value $qp_{net,ar}$** [J g^{-1}] were estimated on high class automatic, isoperibolic calorimeter C6000 produced by IKA. The measurement is made according to the PN-EN-14918:2010 standard, based on sample mass (accuracy 0.0001 g) and temperature difference.

Mechanical durability of briquettes DU [%] measurement was based on guidelines presented in PN-EN ISO 17831-2: 2016-02 standard and consisted of weighing the briquettes on the RadWag laboratory weight to the nearest 0.1 g and placing them in tester drum. The mechanical durability test at a rotational speed of 21 rpm takes about 5 min (one test). After that briquettes were sieved through an orifice hole with a diameter of 32 mm to remove fractions created during crashing of the briquette. The prepared pellets were weighed using a laboratory scale to the nearest 0.1 g.

Mechanical durability of pellets DU [%] the test goes according to similar procedures as for briquettes in chamber appropriate shape and dimensions of the chamber in accordance with PN-EN ISO 17831-1:2016-02. The test chamber is smaller and rotates at a speed of 50 rpm. The duration of one test is 10 min. At the end of the test, the pellets are screened through an orifice hole with a hole diameter of 3.15 mm. Screening of the sample is made to remove fine fractions that have detached from the granulate during the test. The material remaining on the sieve is weighed on a laboratory scale to the nearest 0.1 g.

Specific density of the briquettes and pellets SD [kg/m^3] was assigned based on geometry measurements (height and diameter), made with use of calliper, and weight of the individual granules. The measurement was made on 10 randomly chosen granules.

Granulation of the samples to the briquettes was done using a POR ECOMEC Junior briquetting machine. It produces a briquette with a diameter of about 50 mm and a length dependent on the bulk density of the raw material (smaller density of raw material results in shorter length of briquettes and vice versa). This machine has possibility of regulation of the working pressure in the compaction chamber. When the pressure in the hydraulic system changes, the force that affects the piston changes as the pressure in the compaction chamber changes. The hydraulic pressure of the press is controlled by a sensor and could be also read on the pressure gauge. The agglomeration pressure was set at 47 MPa (the highest working pressure of Junior briquettes allowed for continuous work).

Samples of pellets were made on Kovo Novak MGL 200 which is semi-industrial line for pelleting organic fractions with capacity up to 100 kg/h. According to the discernment of the market, the diameter of the designed pellet was set at 8 mm and the length of about 10–15 mm.

3 Result and Discussion

The conducted research allowed to collect important data allowing to assess the energy potential of the mustard residues and susceptibility to agglomeration processes.

Table 1 shows the results of the basic material characteristics in terms of energy use. It need to be noticed that the value of the ash content over 12% suggests that there could considerable contamination of the raw material with mineral fractions (mainly soil). The analysis of harvesting and post-processing technology of mustard plants showed that the source of pollution was the mineral fractions deposited on the plant during the vegetation season by atmospheric agents (rain and wind). The remaining tested parameters are satisfactory and similar to those of other recognized energy commodities such as cereal straw or miscanthus from energy crops [6, 10].

Table 1 Results of qualitative assessment of raw material

	Moisture content M_{ar} [%]	Ash content A_{ar} [%]	Net calorific vaule $qp_{net,ar}$ [MJ kg^{-1}]	Volotile matter V_{ar} [%]	Bulk density BD_{ar} [kg m^{-3}]
1	11.2 ± 0.08	12.75 ± 0.4	16.48 ± 0.12	68.2 ± 0.56	195 ± 4.6

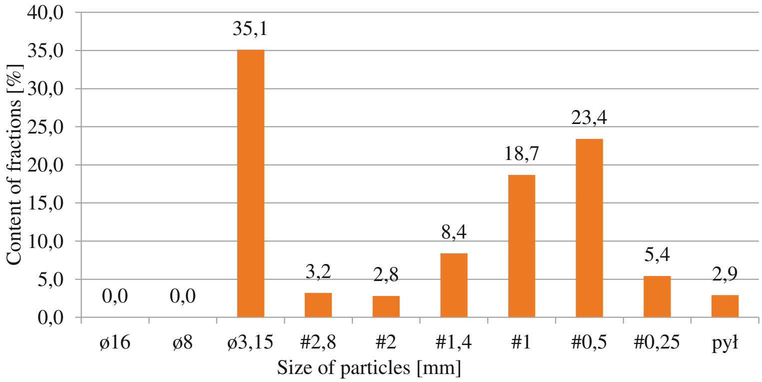

Fig. 3 Granulometric composition of raw material

Raw material was then subjected to agglomerated to two forms briquettes (aprox. 50 mm diameter) and pellets (diameter 8 mm). One of the most important parameters determining the course of the process is the grain size distribution of the raw material. The results of the sieve analysis are shown in Fig. 3. By analysis of the obtained data, it can be seen that the main fraction (35.1%) were particles that have been sieved through a screen with 8 mm holes and retained on a 3.15 mm hole sieve. The second main fraction can be distinguished by a geometry of 1.4–0.5 mm (sieved through a 1.4 mm sieve and sequentially stopped on a # 1 mm perforated sieve and # 0.5 mm) which together sum up to 42.1%. Such grain size distribution is proper for agglomeration processes. The contribution of both larger particles and smaller ones is essential for the proper formation of internal forces between particles, which determines agglomerates' durability [11].

Conducted agglomeration tests both to form of briquettes and pellets results in good quality agglomerates. The detailed results are presented in Table 2. In both cases, high value of specific density, for pellets even above 1 g/cm^3.

Table 2 Results of qualitative assessment of granulates

Type	Mechanical durability DU [%]	Specific density SD [kg m^{-3}]	Bulk density BD [kg m^{-3}]
Brykiet	94.3 ± 0.2	936.5 ± 15.8	479 ± 19.5
Pelet	95.6 ± 0.4	1146 ± 25.1	683 ± 14.4

The obtained results clearly indicate that using the classic methods of agglomeration it is possible to obtain from the tested raw material granulates with satisfactory quality parameters. The density of granules as well as their durability clearly indicate that it is possible to produce high quality granules in the form of briquettes or pellets on industrial scale, even for demanding purposes like heating plants or households usage.

4 Conclusions

The use of waste materials from various industries is a very important element in the energy sector economy. Raw materials often have properties imparted in processing processes that are beneficial from the point of view of their energy use (humidity, grain size, etc.). Therefore, the production of biofuels, including solid fuels, is often relatively inexpensive compared to the biomass obtained from targeted plantations. This is the case such types of raw material were examined. Characteristics of the material predispose it to the conversion to solid fuels. Both briquetting and pelleting methods have shown great agglomeration potential. Depending on market demand (pellets, briquettes), the use of this raw material in production processes can be easily controlled. The results of our research have confirmed that in the agricultural residue sector have a high potential for fuels that can be quickly applied.

References

1. Kaletnik, H.M.: Development of the Biofuel Market in Ukraine: Monograph, 464 p. Ahrarna nauka, Kiev (2008)
2. Zhuchenko, A.A.: Adaptation Potential of Cultivated Plants (Ecological and Genetic Basis), 768 p. Kishenev: Shtinitsa (1999)
3. Zanuda, A.: Biofuel is another chance for Ukraine. Electronic resource: http://www.bbc.co.uk/ukrainian/business/2011/04/110405_bioenergy_az_ob.shtml (access mode)
4. Scientists have created an almost perfect biofuel. Club "The Financier". http://news.finance.ua/ua/~/1/0/all/2013/03/01/297700. Access mode
5. Dubinevych, Yu.: Economic feasibility of production of biofuel from rape in Ukraine. Electronic resource: http://archive.nbuv.gov.ua/portal/chem_biol/vldau/APK/2012_19_1/files/12dujriu.pdf. Access mode
6. Mudryk, K., Fraczek, J., Slipek, Z., Francik, S., Wrobel, M.: Chosen physico-mechanical properties of cutleaf coneflower (*Rudbeckia laciniata* L.) shoots. Eng. Rural Dev. Jelgava (2013). Available at: http://tf.llu.lv/conference/proceedings2013/Papers/122_Mudryk_K.pdf
7. Levytska, V., Mushynskyi, A., Hutsol, T.: Histological Changes in Kidneys of Rabbits Affected by Spontaneous Encephalitozoonosis Scientific Achievements in Agricultural Engineering, Agronomy and Veterinary Medicine. Monograph, Vol. 1, pp 77–93. Traikon, Krakov (2017). http://188.190.33.56:7980/jspui/handle/123456789/15

8. Kravchuk, A.: The formation of the raw materials market for the bio-fuel production. Electronic resource: http://archive.nbuv.gov.ua/Portal/soc_gum/znptdau/2012_4/20–25.pdf. Access mode
9. Bulgakov, V., Adamchuk, V., Gutcol, T.: Theory of the ploughing mechanism of the sugar beet combine harvester (Theorie der rodewerkzeuge der zuckerrübenerntemaschinen). Agric. Eng. (Inżynieria Rolnicza) (2014) http://ir.ptir.org/artykuly/en/152/IR(152)_3606_en.pdf
10. Wrobel, M., Frączek, J., Francik, S., Slipek, Z., Mudryk, K.: Influence of degree of fragmentation on chosen quality parameters of briquette made from biomass of cup plant *Silphium perfoliatum* L. Eng. Rural Dev. Jelgava (2013). Available at: http://tf.llu.lv/conference/proceedings2013/Papers/121_Wrobel_M.pdf
11. Fraczek, J., Cieślikowski, B., Kuboń, M., Mudryk, K., Sikora, J., Szeląg-Sikora, A., Wcisło, G. Wróbel, M.: Produkcja biopaliw—problemy wybrane,. PTIR, Kraków (2014). ISBN 978-83-64-64377-04-4