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Impact of physical properties of selected plant raw materials on the quality and energy intensity of briquettes produced

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Abstract: *Impact of physical properties of selected plant raw materials on the quality and energy intensity of briquettes produced.* The article presents an analysis of impact of physical properties of selected plant raw materials on the quality and energy intensity of briquettes produced in a hydraulic piston briquette press. The following materials were used for research: triticale straw, meadow hay and giant miscanthus stalks. During the briquette production process, the moisture content in ground raw materials ranged between 11.9 and 13.5%. During research, the calorific value was determined, as well as particle size and bulk density and tapped density of briquetting raw materials. Measurements of physical properties of briquettes, including length, diameter and mass, were taken to calculate volumetric density. Energy density of briquettes was also determined, as well as bulk density and mechanical durability and capacity of the briquetting machine and electricity consumption. Depending on the type of briquetted raw materials and their physical properties, a statistically significant impact on the quality and energy intensity of the briquettes produced was found.

Key words: plant biomass, briquettes, physical and quality properties, energy intensity

INTRODUCTION

The diminishing resources of conventional fuels and the necessity to protect the natural environment have led to dynamic development of modern technologies of use of renewable energy sources, including biomass obtained from agricultural and forest production. Biomass is now one of the most significant sources of renewable energy in the world and the third most significant source of energy after coal and crude oil. However, in comparison with conventional raw materials and some renewable energy sources, it has many advantages, as well as disadvantages. The main advantages include: lower emission of harmful combustion products, possibility of using local resources and production surplus, relatively lower financial expenditures for acquisition of this type of energy, decentralization of production of energy and increased energy security of the country. The disadvantages include: low bulk density in unprocessed form, wide range of moisture content (15–60%), seasonal availability of some types of biomass, potential biological and fire threats, lower calorific value in comparison with fossil fuels and high content of volatile compounds, chlorine and sulfur compounds [McKendry 2002, Skonecki et al. 2011, Kołodziej and Matyka (Ed.) 2012, Niedziółka (Ed.) 2014].

Biomass of plant origin is the basic source of renewable energy also in Poland and has a substantial energy potential. It includes by-products of farming, forestry and agricultural and food industry [Janowicz 2006]. Use of biomass in unprocessed form is very problematic due to high moisture content, low bulk and energy density. Its calorific value depends on such factors, as: the type, moisture content and mode of storage. In order to improve usability of biomass for energy purposes, it is subjected to agglomeration in such forms as briquettes and pellets [Panwar et al. 2011, Hejft and Obidziński 2015, Sharma et al. 2015, Niedziółka et al. 2015].

The process of agglomeration of ground plant raw materials results from application of external forces, coming from compacting pressure, and internal forces, associated with intermolecular interactions. The briquettes produced may vary in terms of dimensions and shape, depending on the type of compacting device used. On the other hand, density and mechanical durability of briquettes depend both on the working parameters of the device and the physical properties of the raw materials used. These include: working pressure of the compacting unit, raw material moisture content, grinding level and particle size, as well as the internal friction coefficient [Skonecki and Potręć 2010, Hebda and Złobecki 2011, Kachel-Jakubowska et al. 2013].

The proper course of the process of compacting of ground plant material influences greatly the quality of biofuel obtained. Optimization of this process should take into account the designation of the biofuels produced. It is also important to select the proper grinding and compacting equipment and their working parameters. Therefore, proper preparation of biomass, in particular, by grinding prior to briquetting, is one of the significant stages of production of solid biofuels [Frączek (Ed.), 2010, Sypuła et al. 2010, Hejft 2011, Lisowski and Świętochowski 2011].

The objective of research was an analysis of impact of physical properties of selected plant raw materials on the quality and energy intensity of briquettes produced in a hydraulic piston briquette press.

MATERIAL AND METHODS

The following materials were used for research: triticale straw, meadow hay and giant miscanthus stalks. Before briquetting, they were ground using a hammer mill type H 111/1, equipped with two sieves of mesh diameter of 20 mm. A hydraulic piston briquetting press type JUNIOR was used, made by Deta Polska, at the working pressure of 10 MPa.

During analysis, relative moisture content of the raw materials was determined using a laboratory analytical scale MAX 50/1/WH, their calorific value was verified using the calorimetric method with an isoperibolic calorimeter Parr 6400, the particle size was determined using a laboratory shaker type LPzE-4e, and bulk density was determined according to standard PN-EN 15103:2010, while tapped density was checked using a container of capacity of 50 dm^3.

Determining relative moisture content of raw materials, samples of ground biomass were collected (approximately 5 g each) and placed in the drying chamber of the analytical scales, and then dried in the temperature of 120°C until reaching constant mass. Moisture content measurements were repeated three times. To conduct the sieve analysis of raw materials, samples of mass of 100 g (±1 g) were prepared and a laboratory shaker was used with the set of sieves of the following mesh dimensions: 3.15, 2.8, 2.0, 1.4, 1.0, 0.5, 0.25 mm, and particle size was determined in accordance with the standard PN-EN 15149-2:2011.

Measurements of physical properties of briquettes produced using the hydraulic piston press included the length, diameter and mass. Briquette samples of mass of 1,000 g (±10 g) were collected, and measurements were repeated five times. Geometrical dimensions of briquettes were determined using a caliper at the accuracy of ±0.1 mm, and mass was determined using laboratory scales at the accuracy of ±0.1 g.

Bulk density of the briquettes produced was calculated on the basis of measurements of physical properties, repeated five times. Mechanical durability of briquettes were performed at a test bench according to standard PN-EN 15210-2:2011. The drum rotational speed was 21 rpm (±0.1 rpm), the trial time was 5 min, and the sample mass was 2,000 g (±100 g). After the durability test, the briquettes were screened using sieves of mesh diameter of 31.5 mm.

Energy intensity of the briquetting process for the plant raw materials used was measured using a special unit. It consisted of a meter for parameters of the power supply network type Lumel N14 with current transformers to measure the energy consumption, relating it to the mass of briquettes produced.

The obtained results of physical properties of the raw materials, as well as briquette density and durability, were subjected to statistical analysis, using variance analysis and Tukey's test. For this purpose, SAS Enterprise Guide 5.1 statistical software was used. For all analyses, the significance level applied was $\alpha = 0.05$.

RESULTS AND DISCUSSION

The relative moisture content for briquetted raw materials ranged from 11.9% for giant miscanthus stalks to 13.5% for meadow hay, while the calorific value ranged from 16.5 $MJ \cdot kg^{-3}$ for meadow hay to 17.2 $MJ \cdot kg^{-3}$ for giant miscanthus stalks (Table 1).

On the basis of the screening analysis conducted, it was found that the highest mass share of fraction of particle length above 3.15 mm was present in triticale straw (74.6%), while the lowest value was recorded for giant miscanthus (55.5%). On the other hand, the mass share of dust fraction of particles blow 0.5 mm ranged from 4.1% for giant miscanthus stalks to 6.7% for meadow hay and 8.9% for triticale straw (Table 2).

TABLE 1. Relative moisture content and calorific value of briquetted plant raw materials

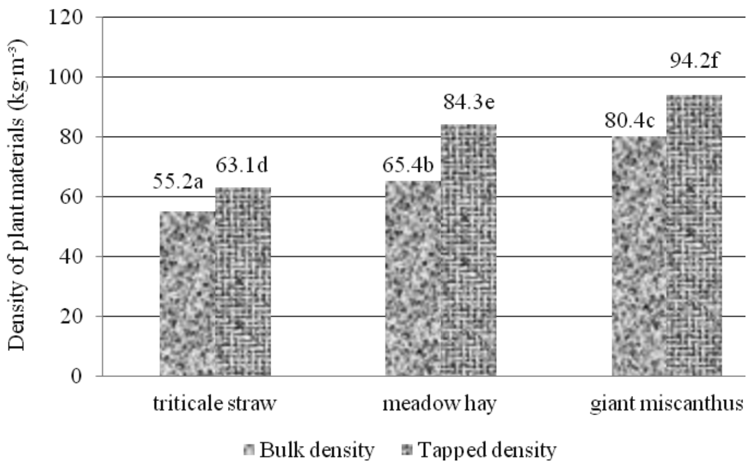
Material type	Relative moisture content [%]		Calorific value [$MJ \cdot kg^{-1}$]	
	from–to	average	from–to	average
Triticale straw	12.3–12.8	12.6	16.3–16.9	16.7
Meadow hay	13.1–13.8	13.5	16.1–16.8	16.5
Giant miscanthus	11.7–12.3	11.9	16.9–17.4	17.2

TABLE 2. Particle size of the briquetted plant raw materials [%]

Material type	Sieve mesh [mm]							
	3.15	2.8	2.0	1.4	1.0	0.5	0.25	0.0
Triticale straw	74.6	0.1	0.4	2.5	4.4	9.1	6.4	2.5
Meadow hay	61.8	1.1	1.7	6.9	10.6	11.2	3.9	2.8
Giant miscanthus	55.5	1.3	8.7	15.6	7.9	6.9	2.6	1.5

The research conducted indicates that the briquette densities obtained were influenced greatly by the level of grinding and particle size of the raw materials. The lowest bulk density was recorded for triticale straw (55.2 kg·m^{-3}), somewhat higher (by 18.5%) – for meadow hay, and the highest – for giant miscanthus (by 45.7%). On the other hand, tapped density amounted to 63.1 kg·m^{-3} for triticale straw, and it was higher by 1/3 for meadow high and almost 1.5 times for giant miscanthus. On the basis of the results obtained, statistically significant differences were found, both in terms of bulk and tapped density, between all of the raw materials examined (Fig. 1).

Research of Lisowski and Świętochowski [2011] indicates that bulk density of ground material from energy crops dependent on the plant species, the mode of grounding of material and the dimension and shape of particles, and for the cut giant miscanthus straws it was 68 kg·m^{-3}. Sypuła et al. [2010] provide that the highest bulk density for giant miscanthus was obtained for particles cut to the length of 7.1 mm (about 95 kg·m^{-3}), while average bulk density of ground giant miscanthus amounted to 61.2 kg·m^{-3}. Research conducted by Skonecki et al. [2011] also suggests that bulk density depends on the raw material type and its grounding level, and for gi-



Average values marked with the same letter do not show a statistically significant difference at the level α = 0.05.

FIGURE 1. Average bulk and tapped density of briquetted plant materials

ant miscanthus in bulk and tapped state, it amounted to 71.5 and 92.9 kg·m^{-3} respectively.

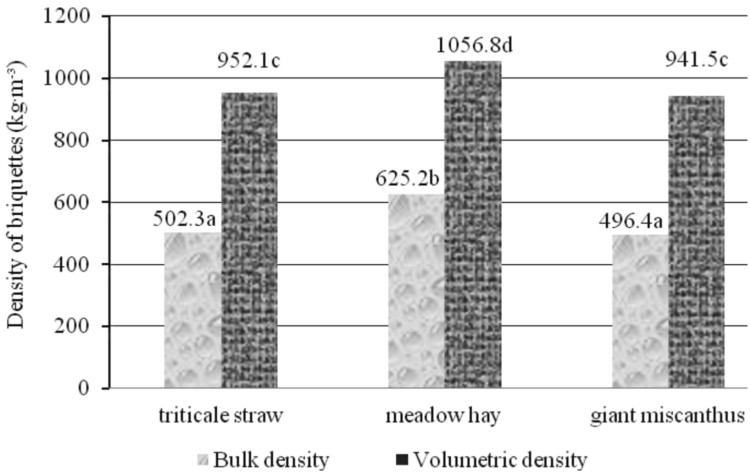
The average length of briquettes produced was from 23.2 mm for meadow hay to 33.4 mm for giant miscanthus, and their average mass was 48.1 and 61.6 g, respectively. The length and mass of the briquettes produced was influenced by the type of raw material, as well as its grinding and the level in the fill chamber. In the case of briquette length, statistically significant differences were found between all of the raw materials examined, and for briquette mass – between triticale straw and meadow hay and giant miscanthus (Table 3). The diameter of the briquettes produced was constant, amounting to 50 mm.

The average bulk density of briquettes was within the range of 496.4 kg·m^{-3} for giant miscanthus to 625.2 kg·m^{-3} for meadow hay. On the other hand, average volumetric density of briquettes was 941.5 and 1,056.8 kg·m^{-3}, respectively. Statistically significant differences were found between bulk density of briquettes made of triticale straw and giant miscanthus and bulk density of briquettes made of meadow hay. Similar correlations were found for volumetric density of the briquettes produced (Fig. 2).

TABLE 3. Length and mass of briquettes made of plant raw materials examined

Material type	Briquette length [mm]		Briquette mass [mm]	
	from–to	average	from–to	average
Triticale straw	25.8–27.1	26.5 a	48.6–50.3	49.5 a
Meadow hay	22.6–24.1	23.2 b	45.2–50.2	48.1 a
Giant miscanthus	31.6–35.8	33.4 c	58.4–64.1	61.6 b

Average values marked with the same letter do not show a statistically significant difference at the level α = 0.05.



Average values marked with the same letter do not show a statistically significant difference at the level α = 0.05.

FIGURE 2. Average bulk density and volumetric density of briquettes made of plant raw materials examined

TABLE 4. Volumetric calorific density and mechanical durability of briquettes made of plant raw materials examined

Material type	Volumetric calorific value [GJ·m^{-3}]		Mechanical durability [%]	
	from–to	average	from–to	average
Triticale straw	15.5–16.1	15.9	92.6–94.2	93.7 a
Meadow hay	17.0–17.7	17.4	95.3–97.2	96.6 b
Giant miscanthus	15.9–16.4	16.2	70.6–73.8	72.4 c

Average values marked with the same letter do not show a statistically significant difference at the level $\alpha = 0.05$.

The volumetric calorific density of briquettes was influenced by their volumetric density and calorific value of the raw materials. The highest density was recorded for briquettes made of meadow hay (17.4 GJ·m^{-3}), it was slightly lower for giant miscanthus (by 7%) and triticale straw (by 9%). Also the highest was mechanical durability of briquettes made of meadow hay (96.6%), and the lowest – of giant miscanthus (72.4%). Statistically significant differences were found between mechanical durability of briquettes made of all raw materials examined (Table 4). Lower mechanical durability was influenced by structure of raw materials briquetted and their moisture content. This has been confirmed in research conducted by Hebda and Złobecki [2011], who found that the best moisture content of straw for briquetting was between 10 and 15%, for which the durability achieved ranged from 93 to 97%.

Efficiency of the briquetting press depended on the particle size of the raw materials and their bulk density. In the case of compacting of triticale straw, it amounted to 22.1 kg·h^{-1}, which was higher by 21% in comparison with giant miscanthus and 24% in comparison with meadow hay. Statistically significant differences were recorded between the efficiency of briquetting of triticale straw and the same efficiency for meadow hay and giant miscanthus. On the other hand, power consumption was greatly determined by raw material type and briquetting machine capacity. Energy consumption by the briquetting process ranged between 0.125 kWh·kg^{-1} for meadow high and 0.132 kWh·kg^{-1} for triticale straw. Statistically significant differences were found between energy consumption of production of briquettes made of triticale straw and meadow hay (Table 5).

TABLE 5. Capacity and power consumption of briquetting of the raw materials examined

Material type	Efficiency [kg·h^{-1}]		Energy demand [kWh·kg^{-1}]	
	from–to	average	from–to	average
Triticale straw	20.8–23.3	22.1 a	0.127–0.138	0.132 a
Meadow hay	26.6–28.3	27.4 b	0.121–0128	0.125 b
Giant miscanthus	25.5–28.1	26.8 b	0.125–0.133	–

Average values marked with the same letter do not show a statistically significant difference at the level $\alpha = 0.05$.

Efficiency and energy consumption in production of briquettes of plant biomass are influenced by many factors, including: type of raw material, moisture content and level of grinding, as well as bulk density. The work edited by Frączek [2010] indicates that unit energy consumption by briquette production depended on the type of agglomerated plant materials, the level of their grinding and the pressure of compacting, and for grass and perennials it ranged between 18 Wh·kg^{-1} (at the pressure of 17 MPa) and 58 Wh·kg^{-1} (47 MPa). Also the author's research [Niedziółka et al. 2015] showed that energy consumption by briquetting depended on the type of raw material compacted, as well as efficiency and working pressure of the briquetting press (6–10 MPa), and it ranged from 0.108–0.134 kWh·kg^{-1} for wheat straw to 0.089–0.115 kWh·kg^{-1} for rape straw.

CONCLUSIONS

On the basis of analysis of the research results obtained, the following conclusions can be drawn:

1. A statistically significant impact on the quality features, efficiency and energy consumption by briquette production was exerted by such factors, as: type of raw material, the level of its grinding and particle size, as well as bulk and tapped density.
2. The physical properties of briquettes produced, with regard to their length and mass, were influenced by the type of raw material agglomerated, as well as its grinding, and thus better filling of the fill chamber of the briquetting press.
3. Depending on physical properties of the raw materials examined, statistically significant differences were found between bulk density of briquettes made of triticale straw and giant miscanthus and bulk density of briquettes made of meadow hay. Similar correlations were found for volumetric density of the briquettes produced.
4. Mechanical durability of the briquettes obtained depended largely on the type of raw material compacted, as well as its physical properties. The highest mechanical durability was recorded for briquettes made of shadow hay (96.6%), somewhat lower – for triticale straw briquettes (93.7%), and the lowest – for giant miscanthus briquettes (72.4%).
5. More advantageous physical properties, influencing both the quality and efficiency and power consumption of the briquette production process, were found in the case of agglomeration of meadow high, and much less advantageous – for triticale straw and giant miscanthus.

REFERENCES

FRĄCZEK J. (Ed.). 2010: Optymalizacja procesu produkcji paliw kompaktowanych wytwarzanych z roślin energetycznych. Wyd. PTIR, Kraków.

HEBDA T., ZŁOBECKI A. 2011: Wpływ wilgotności słomy na trwałość kinetyczną brykietów. Inżynieria Rolnicza 6 (131): 45–52.

HEJFT R. 2011: Energochłonność procesu peletowania i brykietowania. Czysta Energia 6: 40–41.

HEJFT R., OBIDZIŃSKI S. 2015: Pressure agglomeration of plant materials – pellet-

ing and briquetting (Part II). Journal of Research and Applications in Agricultural Engineering 60 (1): 19–22.
JANOWICZ L. 2006: Biomasa w Polsce. Energetyka i Ekologia 8: 601–604.
KACHEL-JAKUBOWSKA M., KRASZKIEWICZ A., SZPRYNGIEL M., NIEDZIÓŁKA I. 2013: Analysis of the characteristics of raw materials used in production of solid biofuels. Agriculture Engineering 2 (143): 103–111.
KOŁODZIEJ B., MATYKA M. (Ed.). 2012: Odnawialne źródła energii. Rolnicze surowce energetyczne. PWRiL, Poznań.
LISOWSKI A., ŚWIĘTOCHOWSKI A. 2011: Gęstość i porowatość pociętego i zmielonego materiału z roślin energetycznych. Polska Energetyka Słoneczna 2–4: 43–47.
McKENDRY P. 2002: Energy production from biomass (Part 1): overview of biomass. Bioresource Technology 83: 37–46.
NIEDZIÓŁKA I. (Ed.). 2014: Technika produkcji brykietów z biomasy roślinnej. Libropolis, Lublin.
NIEDZIÓŁKA I., ZAKLIKA B., KACHEL-JAKUBOWSKA M., KRASZKIEWICZ A., KOWALCZUK J., ZARAJCZYK J. 2015: Analysis of yield and energy consumption in the shredding and briquetting process of selected plant materials. Teka Komisji Motoryzacji i Energetyki Rolnictwa 15 (4): 131–134.
PANWAR V., PRASAD B., WASEWAR K. 2011: Biomass residue briquetting and characterization. Journal of Energy Engineering 137/2: 108–114.
PN-EN 15103:2010. Biopaliwa stałe – Oznaczanie gęstości nasypowej.
PN-EN 15149-2:2011. Biopaliwa stałe. Oznaczanie rozkładu wielkości ziaren. Część 2: Metoda przesiewania wibracyjnego.
PN-EN 15210-2:2011. Biopaliwa stałe. Oznaczanie trwałości mechanicznej brykietów i peletów. Część 2: Brykiety.
SHARMA M.K., GOHIL P., SHARMA N. 2015: Biomass briquette production: a propagation of non-convention technology and future of pollution free thermal energy sources. American Journal of Engineering Research 04/02: 44–50.
SKONECKI S., GAWŁOWSKI S., POTRĘĆ M., LASKOWSKI J. 2011: Właściwości fizyczne i chemiczne surowców roślinnych stosowanych do produkcji biopaliw. Inżynieria Rolnicza 8 (133): 253–260.
SKONECKI S., POTRĘĆ M. 2010: Wpływ wilgotności na ciśnieniowe zagęszczanie biomasy roślinnej. Zeszyty Problemów Postępów Nauk Rolniczych 546: 341–346.
SYPUŁA M., LISOWSKI A., CHLEBOWSKI J., NOWAKOWSKI T., STRUŻYK A. 2010: Bulk density of chopped material of energetic plants. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 56: 29–37.

Streszczenie: *Wpływ cech fizycznych wybranych surowców roślinnych na jakość i energochłonność wytworzonych brykietów*. W artykule przedstawiono analizę wpływu cech fizycznych wybranych surowców roślinnych na jakość i energochłonność produkcji brykietów, w hydraulicznej brykieciarce tłokowej. Do badań wykorzystano następujące surowce: słomę pszenżytnią, siano łąkowe i łodygi miskanta olbrzymiego. Podczas procesu brykietowania wilgotność rozdrobnionych surowców wynosiła od 11,9 do 13,5%. W trakcie badań określano wartość opałową, skład granulometryczny oraz gęstość nasypową i utrzęsioną brykietowanych surowców. Wykonywano także pomiary cech fizycznych wytworzonych brykietów, obejmujących długość, średnicę oraz masę i na tej podstawie obliczano ich gęstość objętościową. Określano również objętościową gęstość energetyczną brykietów oraz ich gęstość nasypową i trwałość mechaniczną, a także wydajność brykieciarki i pobór energii elektrycznej. W zależności od rodzaju brykietowanych surowców i badanych cech fizycznych, stwierdzono ich statystycznie istotny wpływ na jakość i energochłonność wytworzonych brykietów.

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