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Agricultural and forest biomass as feedstock in the manufacture of solid biofuels

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Abstract. The study involved 15 types of pellets produced from biomass from agricultural, forestry and production residues. The aim of this study was to determine moisture, ash content, calorific value and net calorific value of biofuels. Pellet made from pure wood sawdust was characterized by the best quality in terms of value of energy (the highest calorific value and the lowest ash content) and met the requirements of DIN 51731. The calorific value of pellets from agricultural residues was lower by about 10% and its ash content almost 900% higher than that of post-production sawdust. Pellets from biomass of perennial crops and production residues, despite their flaws, are likely to be future-attractive, renewable biofuels, in particular for applications in power industry and municipal heating.

key words: biomass, energy crops, post-production residues, pellets, ash content, calorific value

INTRODUCTION

Nowadays, the main source of biomass for energy purposes are forests and timber industry. However, in the light of the law regulation, the structure of the biomass source must be changed to the increase of the share of biomass from agricultural production residues and agro-food industry (Dz.U. nr 156, poz. 969), which is a big challenge for agriculture (Budzyński et al., 2009; Grzybek, 2008; Kuś, Faber, 2009).

One of the major sources of biomass is to be long-term energy crops grown on agricultural land: native species of willow (*Salix* L.), Poland-acclimatized Sida (*Sida hermaphrodita* R.), giant perennial grass – Miscanthus (*Miscanthus x giganteus* J.M.Greef & M.Deuter) and other (Grzybek, 2006; Kuś, 2008; Podlaski et al., 2009; Stolarski, 2004, 2009; Stolarski et al., 2006, 2008, 2009; Szczukowski et al., 2000, 2004).

Solid, fresh biomass as a fuel compared to mineral resources such as coal in terms of physicochemical properties of fuel is less attractive. This is due to (among other reasons) too low density of biomass, making it difficult to transport, storage and dosing for the boilers. In addition, a wide range of moisture from a few percentage points to as much as 50–60% and low volumetric energy content hinder the distribution of biomass in the basal form. Therefore, electric utilities are interested in processed biomass, refined to the form of pellets. Pellets compared to the original form of biomass have lower moisture, higher density which increases their concentration of energy (Grzybek, 2004; Kowalik, 2002; Stolarski et al., 2005; Szczukowski et al., 2004). However, the calorific value of pellets, and the ash content varies largely depending on the origin of the material used for pelletizing.

The paper posed the hypothesis that the biomass from agricultural and agro-food industry can be the raw material for pellet production, and the quality of produced biofuel will probably be standing close to the one obtained from forest biomass residue. The aim of this study was to determine moisture, ash content and heating net calorific value of pellets produced from agricultural and forestry biomass.

MATERIAL AND METHODS

The study was carried out on 15 types of pellets produced from biomass: perennial energy crops (willow, Sida, giant Miscanthus), agricultural residues (straw of cereals – triticale, straw of hemp (for oil), cereal bran, residues of cleaning grass seeds, sunflower marc), forest residues (wood shavings, the bark of coniferous trees), wood (pine and oak sawdust), food industry (apple pomace, coffee marc) and mixed (75% pine sawdust + 25% cereal bran by weight).

The representative samples of pellets of each type of biomass were collected. The assays for each trait were per-

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formed in the laboratory of Department of Plant Breeding and Seed Production (University in Olsztyn) in three replications. Pellet moisture was determined by dryer-weight method (by PN-80/G-04511 standard). Then, individual samples of biofuels were crushed in the analytical mill "IKA FMC 10 basic", using sieves with mesh diameter of 0.25 mm. The ash content was determined in so prepared analytic samples (by PN-80/G-0512 standard). In addition, the heat of combustion of the biofuels was determined in the calorimeter IKA C 2000, based on the dynamic method (by PN-81/G-04513 standard) and the calorific value was calculated accounting for their moisture in the working state.

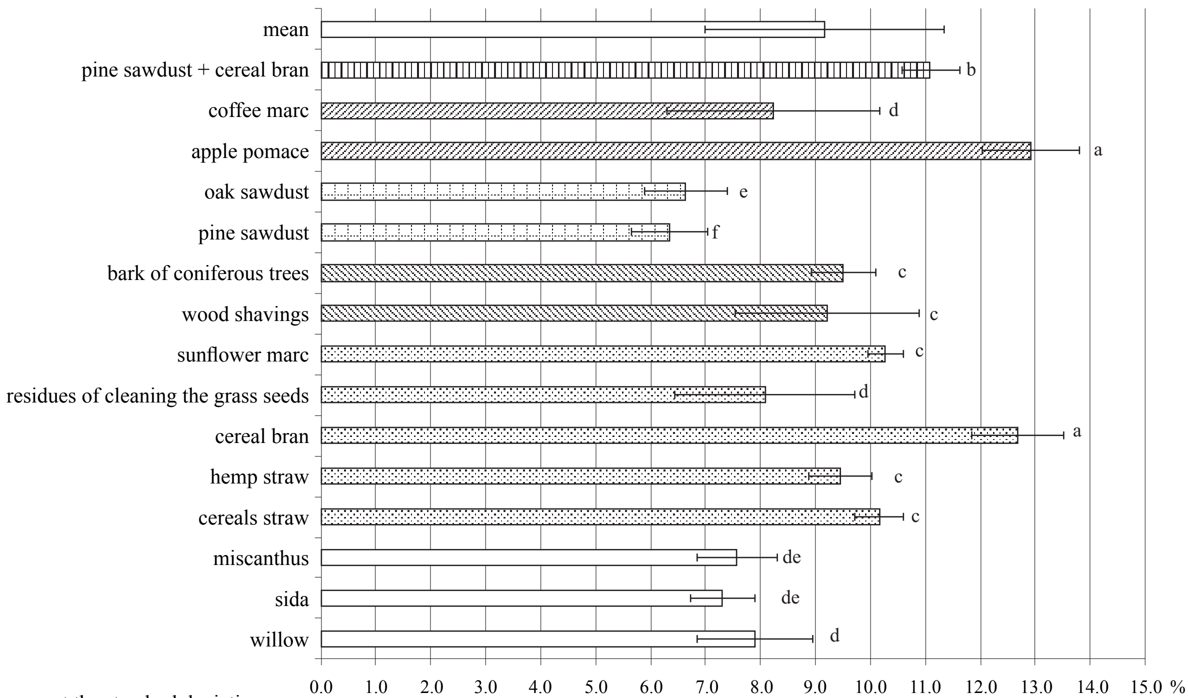
The results were analyzed using computer package STATISTICA 9.0 PL. Arithmetic means and standard deviation were calculated for the studied traits. The multiple-comparison SNK test which groups together means of similar values was applied to identify statistically homogeneous groups at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The moisture of pellets was low, averaging 9.2% (Fig. 1). Pellets produced from pine sawdust had the lowest moisture content (6.3%). Slightly, but significantly higher humidity was found in pellets from oak sawdust. In the remaining fuels the value of this trait ranged from 7.3% for Sida to 12.9% in the pellets from apple pomace. The requirements of DIN 51731 standard allow the pellets with a moisture content of 12% to be put on the market. Pellets derived from apple pomace and cereal bran did not meet that standard. In other studies, moisture of pellets also varied in a narrow range from 7.04% in the pellets from beech sawdust to 12.04% for pellets made from sunflower marc (Stolarski et al., 2007).

The ash content of pellets produced from different types of biomass averaged 3.5% (Fig. 2). The pellets produced from oak sawdust was characterized by the lowest, positive value of that trait (0.5% DM). Statistically, they were in the same homogeneous group with pine sawdust pellets (0.9% DM). The ash content in the pellets from willow biomass was 1.8% DM. The apple pomace pellets were in the third group of fuels in terms of ash content. Whereas, in the fourth group of fuels in terms of this value were fuel from sunflower marc, bark of conifers, wood shavings, mixture of sawdust and bran, and the biomass from Sida, Miscanthus and hemp (2.3–3.2% DM). The highest ash content (11.1% DM) of the examined biofuels was found in pellets made from the residue from cleaning of grass seeds. In the pellets from straw the ash content was 7% DM, while in bran it was by 0.7 percentage points lower.

The cited standard DIN 51731 permits on the market pellets with ash content below 1.5%. In this study these criteria were met by pellets made from clean, post-production oak and from pine sawdust without bark. Pellets made from other biomass did not meet the criteria of this standard. However, it could be used primarily as industrial pellets to be applied in the power industry and in municipal heating.



error bars represent the standard deviation
a, b, c – homogeneous group ...

Fig. 1. Pellet humidity from various types of biomass [%] (source: authors' own research)

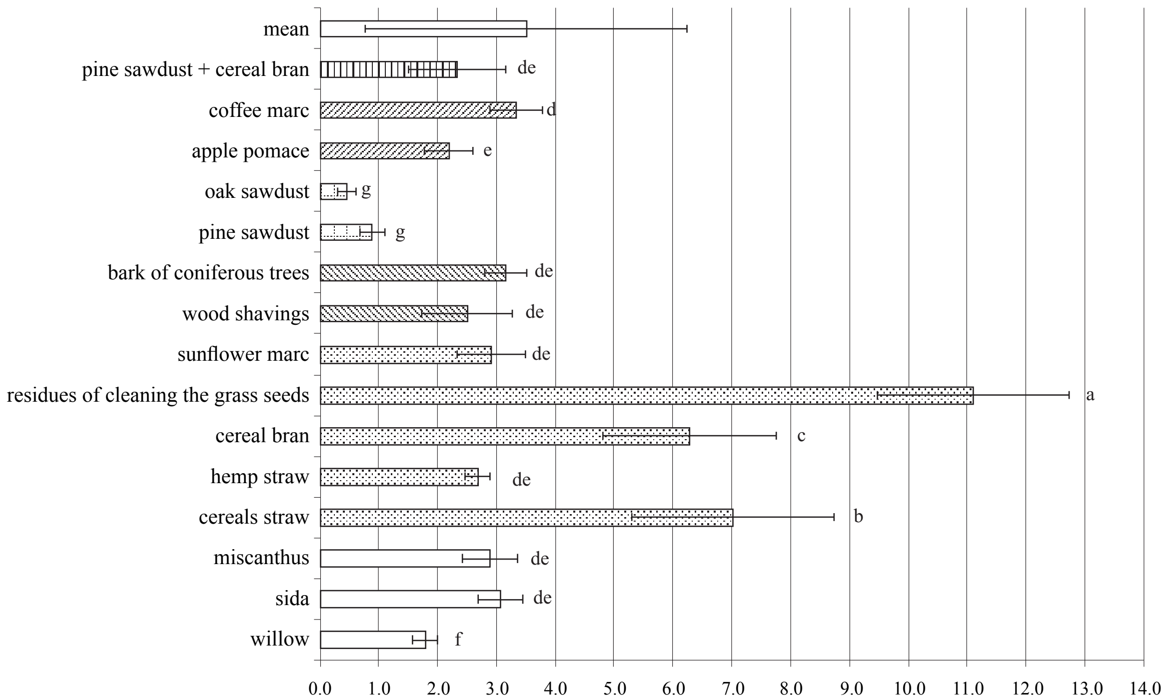


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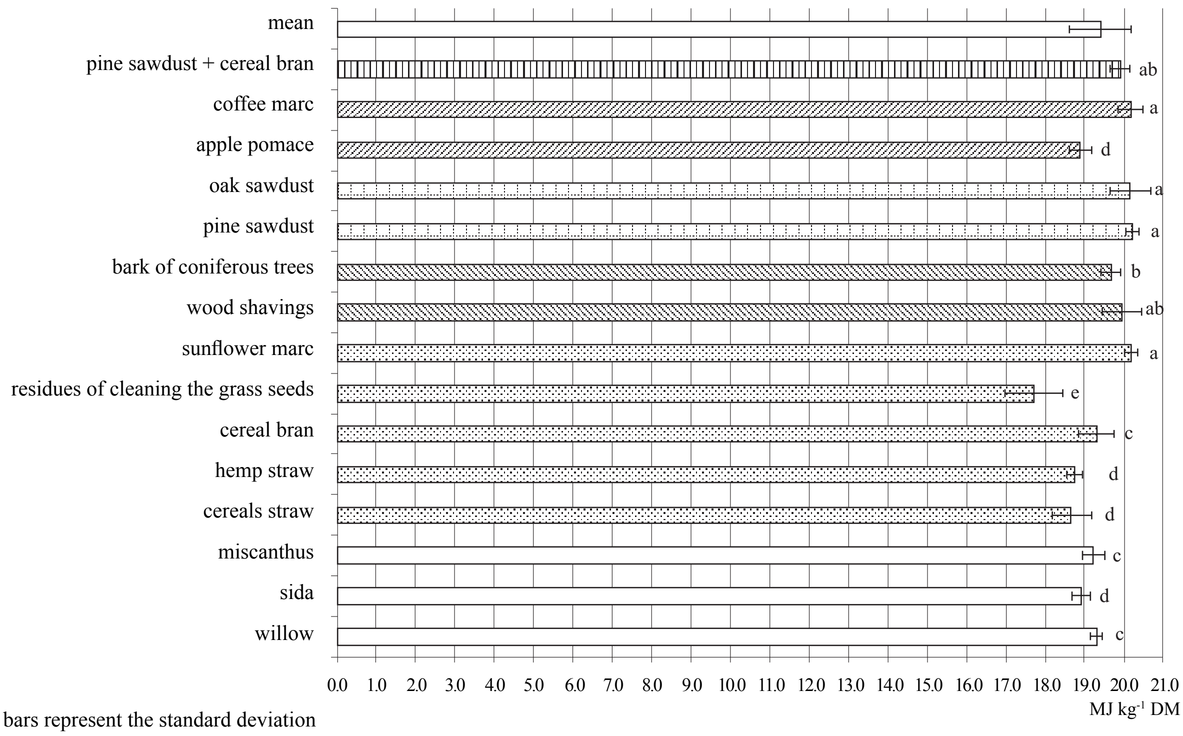
Fig. 2. The ash content of pellets of different types of biomass [% DM].
(source: authors' own research)



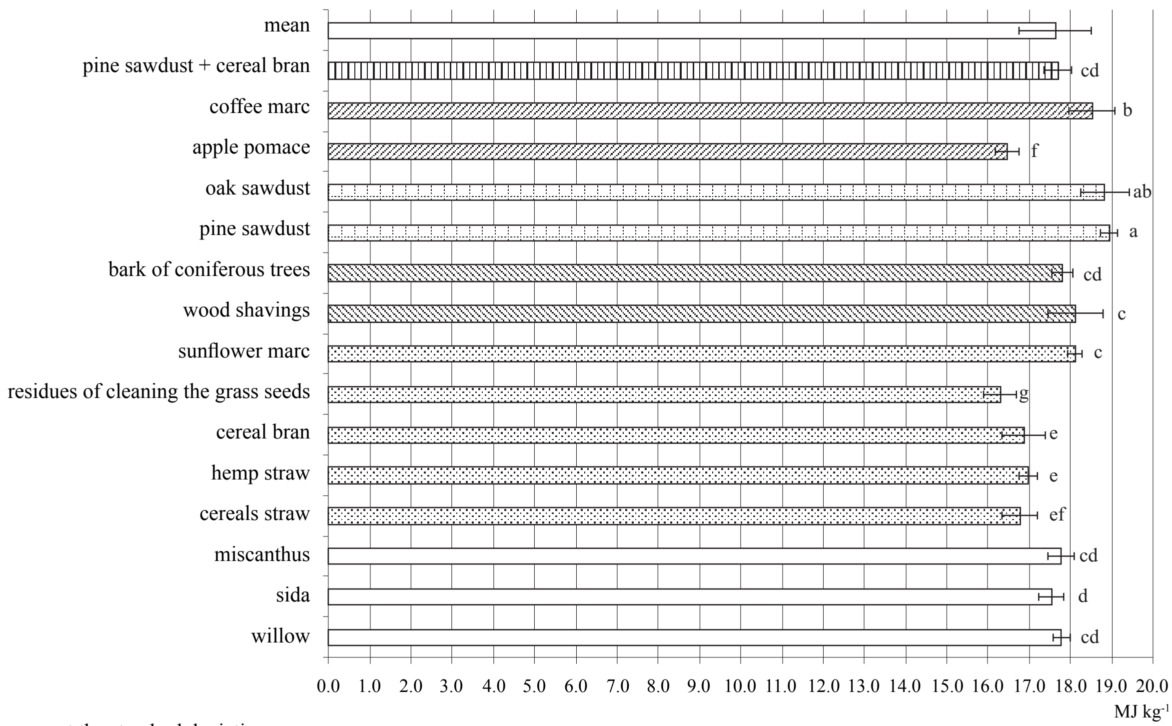
error bars represent the standard deviation
a, b, c ... – homogeneous group

Fig. 3. Combustion heat of pellet of different types of biomass [MJ kg^{-1} DM].
(source: authors' own research)

In other studies, the ash content of willow pellets was lower (1.4% DM), and for Sida pellets was higher (3.4% DM) than limit value (Stolarski et al., 2005). In subsequent studies, though, the ash content in these species was respectively 2.2% and 2.7% DM (Stolarski et al., 2007). Król et al. (2010) indicate that the ash content of willow biomass was 2.6% DM and this feature for Sida and Miscanthus biomass was substantially higher, respectively 4.2% and 4.4% DM. The authors cited determined ash in sunflower straw at 5.5% DM and at half that amount (2.65% DM) in sunflower husk. Stolarski et al. (2007) indicate that the ash content in the pellets from the remains of sunflower was 3.5% DM. Varied content of ash in the biomass from the agro-food industry was determined by Borycka (2009). The value of this trait ranged from 1.24% to 3.40% for apple and carrots, respectively.

The combustion heat of tested biofuels was high and averaged 19.4 MJ kg^{-1} DM (Fig. 3). To the homogeneous group of pellets with the highest calorific value were classified: coffee and sunflower marc, oak and pine sawdust. In the second homogeneous group were biofuels derived from the mixture of branches of forest trees and bran with sawdust. The third group included pellets from the bark of conifers. In the fourth group were placed pellets from willow, Miscanthus and cereal bran. In the fifth homogeneous group were biofuels from apple pomace, wheat straw, hemp straw, and Sida. The last homogeneous group with the lowest combustion heat was composed of the pelleted residue from cleaning of grass seeds, a product that contained large quantities of mineral impurities.

The calorific value of individual biofuels taking into account their humidity is shown in Figure 4. In the case of this trait variation in the number of homogeneous groups was greater than that for combustion heat, since as many as ten groups were identified. The highest calorific value was shown by pine sawdust pellets 18.9 MJ kg^{-1}, slightly lower by oak sawdust pellets. High calorific value (18,1–18,5 MJ kg^{-1}) was characteristic of pellets from the coffee marc, those from sunflower marc and from the mixture of branches of forest trees. Pellets from willow, Miscanthus, conifer bark as well as from the mixture of sawdust and bran were characterized by a calorific value of 17.7–17.8 MJ kg^{-1}. However, by far the lowest average calorific value of pellets was found in those made from the residue left in the cleaning process of grass seeds 16.3 MJ kg^{-1}. In other studies, the calorific value of pellets from the sawdust of forest trees ranged from 17.7 to 18.0 MJ kg^{-1} (Stolarski et al., 2007). The pellets made from the biomass of energy crops had a calorific value of about 17 MJ kg^{-1}. In the biofuel made from post-processing residues the calorific value was lower by about 0.6 MJ kg^{-1}. Król et al. (2010) indicate that willow biomass was characterized by a higher calorific value (17.2 MJ kg^{-1}) than the biomass of Miscanthus and Sida (about 16.5 MJ kg^{-1}). In the above-cited studies high



error bars represent the standard deviation
a, b, c ... – homogeneous group

Fig. 4. The calorific value of pellets of different types of biomass [MJ kg^{-1}].
(source: authors' own research)

Table 1. Characteristics of pellets made from different origins of biomass.

Pellets of biomass	Combustion heat [MJ kg^{-1} DM]	Humidity [%]	Ash content [% DM]	Calorific value [MJ kg^{-1}]
Perennial energy crops	19.15 ±0.28	7.59 ±0.83	2.58 ±0.68	17.70 ±0.30
Agricultural residues	18.92 ±0.93	10.14 ±1.74	6.00 ±3.35	17.00 ±0.71
Forest residues	19.81 ±0.42	9.36 ±1.23	2.83 ±0.68	17.95 ±0.52
Timber industry residues	20.19 ±0.37	6.50 ±0.72	0.67 ±0.28	18.88 ±0.43
Food industry	19.54 ±0.72	10.58 ±2.81	2.77 ±0.72	17.49 ±1.14
Mixed	19.90 ±0.25	11.10 ±0.53	2.33 ±0.83	17.69 ±0.33

± standard deviation
Source: authors' own research

calorific value was found in rapeseed cake (19.9 MJ kg^{-1}), whereas in peanut shells the value was 15.7 MJ kg^{-1}. Borycka (2009) showed large variations of the calorific value of biomass residues from fruit and vegetables. The lowest value of that trait was characterized by apple pomace (15.9 MJ kg^{-1}) and the highest by tomato marc (23.3 MJ kg^{-1}).

Based on the results from this study we can confirm that the quality of the pellets as a biofuel can be varied depending on the type of biomass, from which it was produced. When analyzed for quality using the averaged data from this study sawdust from timber industry was found to have the best suitability as a source of energy. It is characterized by highest calorific value and lowest moisture and ash content (Table 1). Pellets from the biomass from perennial energy crops is characterized by a lower calorific value by an average of 1.2 MJ kg^{-1}. However, the calorific value of biomass pellets from agricultural residues was lower by an average of 1.9 MJ kg^{-1} than pellets from timber industry residues. The ash content of pellets from the biomass of perennial crops, forest residues and food industry residues was 4-fold higher than in the pellets from pure sawdust. By contrast, pellets from agricultural residues biomass contain, on average, almost 9 times more ash, which may limit their use in the manufacture of solid fuel – pellets of high quality for individual customers.

Varied ash contents in the tested fuels are not surprising, because the ash content in different types of biomass is affected by: the characteristics of species, the soil on which the plants grow, fertilization rates, the level of contamination by minerals and biomass-acquisition period (Stolarski et al., 2009). The ash content of dendromass is dependent on parts of the plant from which it was acquired and on the fraction of bark and mineral impurities. Therefore, the pellets from sawdust which did not contain bark or impurities was characterized by the lowest value of that trait. Agricultural biomass contained significantly more ash. In order to produce pellets which would meet the requirements of DIN 51731 the products to be created should include, among other things, post-processing residues of timber industry blended with agricultural biomass.

CONCLUSIONS

1. Pellets made from pure wood sawdust was characterized by the best quality in terms of value of energy (the highest calorific value and lowest ash content) and they met the requirements of DIN 51731 standard.
2. Among the solid biofuels produced from treeless biomass a high calorific value and the lowest content of ash was characterized by a pellet from perennial energy crops.
3. Pellets produced from perennial energy crops, agricultural residues, forestry and food industry did not meet the requirements of DIN 51731 standard because of too high content of ash.
4. The calorific value of pellets from agricultural residues was lower by about 10% and the ash content of almost 900% higher than that of sawmill sawdust.
5. Pellets from biomass of perennial crops and production residues, despite their flaws, are likely to be future-attractive renewable biofuels, in particular for applications in power industry and municipal heating.

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