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ANALYSIS OF SELECTED PHYSICAL AND CHEMICAL PROPERTIES OF PLANT BIOMASS OF AGRICULTURAL ORIGIN IN TERMS OF ITS ENERGY USE

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Abstract

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The paper presents an analysis made for water content, ash and organic matter - combustible, including its elemental composition, the part carbon, hydrogen, oxygen, nitrogen, sulfur and chlorine in plant biomass of agricultural origin. It was also considered to be determined correlations between the physical and chemical parameters in relation to the amount contained in the test material expressed heat combustion in the air-dry state. For the following types of straw with winter wheat, winter triticale varieties Grenado and Fredro, rye, mix cereal and buckwheat were selected. Determination was made in accordance with generally accepted and applied method. The statistical analysis of test results acquired to determine average values, standard deviations, and Pearson correlation coefficients. Also was carried out ANOVA. The significance of differences between means determined using Tukey's test. The level of significance $\alpha = 0.05$. The study showed that the selected physical and chemical characteristics of winter triticale straw Grenado two varieties of winter wheat and Fredro, mix cereal, buckwheat and rye in terms of their energy use was beneficial and desirable. This was confirmed also made comparison of results with those presented by other researchers. Nevertheless, for each parameter, there were significant differences between the means of the raw material concerned. Solid biomass of rye straw and cereal mix, due to the high content of combustible ingredients is the raw material for the most favorable parameters for energy use. The wide variation in the elemental composition of organic matter, as well as their impact on the combustion process and exhaust emissions of individual fuels of agricultural origin indicates a need for further research in this area and make them public.

Key words: plant biomass, physical and chemical properties

Introduction

Of all renewable, environmentally-friendly energy sources, it is biomass that has enjoyed continued interest. The basis for this group of solid bio-fuels is primarily field crops. As a result of the agricultural competition for the farming space between the production for food, industry and fodder purposes, and energy crops, it is recommended that residual biomass and the surplus of conventional crops, such as cereal or other straw and grass from permanent grasslands (hay) be used (Świętochowski et al., 2006).

It is noteworthy however, that plant-based biomass in its raw, unprocessed state is a highly heterogeneous material that is diverse in terms of its physical characteristics (Denisiuk, 2009; Rybak, 2009; Wandrasz and Wandrasz, 2006).

As a fuel, biomass is made up of three basic substances (Rybak, 2009) – organic matter (flammable), mineral matter and moisture. The proportion of these determines the bio-

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mass energy content, expressed as the heat of combustion. In the case of organic matter, the proportion of elements, such as carbon, hydrogen, oxygen, nitrogen, sulphur and chlorine, is also important. The content of individual elements in solid fuels, such as biomass, varies between different types of fuel and is dependent on their carbonification level. Moreover, the proportion of carbon, hydrogen, and oxygen is conditional on the metamorphic grade. In this respect, the higher the grade, the more substantial the increase in the content of carbon is. Also, as the metamorphic grade increases, the proportion of oxygen drops, with a slight decrease in hydrogen content. The proportion of nitrogen and sulphur are, however, in practice, independent of a fuel's metamorphic grade and produce harmful oxides during combustion. When biomass is burned, other elements present within it in small quantities create a mineral substance, i.e. ash (Kowalczyk-Juśko, 2009; Moroń et al., 2013; Rybak, 2009; Wandrasz and Wandrasz, 2006).

Quantitative differences in chemical composition are found not only between different types of biomass, but also within the same species. It is contingent on the habitat quality and on the agricultural practices used (Świętochowski et al., 2006).

Relevant literature provides information on the chemical composition of biomass — mainly on energy crops and their energy levels (Denisiuk, 2009; Rybak, 2009; Wandrasz and Wandrasz, 2006). However, there are no studies that would investigate the relationship between the physical and chemical properties of vegetable biomass produced in agriculture in the context of its use in energy (heat) generation.

The objective of this study is to analyze the determined content of water, ash and flammable organic matter, taking into account its elemental composition, i.e. the proportions of carbon, hydrogen, oxygen, nitrogen, sulphur and chlorine in vegetable biomass produced in agriculture. The study also examines the correlations between certain physical and chemical parameters considered in relation to the energy content of the sample material, expressed as the heat of combustion.

Materials and Methods

The straw selected for testing includes crops of winter wheat, Grenado and Fredro winter triticale, rye, as well as a mix of cereal and buckwheat. These materials were supplied by two sources. Wheat, rye, cereal-mix and buckwheat straw were provided by an agricultural farm located in Snopków. Triticale straw, in turn, was delivered by the Małopolska Plant Farm in Kraków, Palikije branch.

The obtained material was crushed using H 111 hammer mill with 8 mm sieves. The resultant material was subsequently sampled for further lab tests to determine the content of:

- water – using the weighing method in line with the PN-EN 14774-2:2010 standard;
- ash – using the weighing method in line with the PN-EN 14775:2010 standard;
- carbon and hydrogen – using IR absorption in line with the CEN 15104:2006 standard;
- nitrogen – using an automatic Katharometer in line with the CEN 15104:2006 standard;
- sulphur – using an automatic IR analyser in line with the PN-G-04584:2001 standard;
- chlorine – using the Eschka method in line with the PN-ISO 587:2000 standard, Section 7.2.1;
- oxygen – as the combined percentage of ash, carbon, hydrogen, nitrogen, sulphur and chlorine, in dry basis,
- organic (flammable) matter – as the combined percentage of moisture and ash;
- heat of combustion in the air-dry state – using calorimetry in line with the PN-EN 14918:2010 standard.

Statistical analysis of test results involved the determination of mean values, standard deviations and Pearson product-moment correlation coefficient. This was followed by the analysis of variance (ANOVA) for a single factor. The significance of differences between the means was determined using the Tukey's test. The adopted significance level was $\alpha = 0.05$.

Results and Discussion

The mean content chemical and physical properties for the examined research material please see Table 1.

The mean content of flammable substances in the analyzed vegetable material was between 79.23% (buckwheat straw) to 84.27% (rye straw) (Table 1). Water content ranged from 13.11% for the Grenado triticale, to 15.35% for the Fredro triticale (Table 1). Rye straw demonstrated the lowest ash content (1.89%), while the highest mineral (ash) content was recorded for buckwheat straw - 6.28% (Table 1).

Depending on the type of material, standard deviations for these parameters were respectively 0.000-0.106%, 0.012-0.073% and 0.016-0.65%. ANOVA established significant differences between the means in the individual material groups ($p = 0.00000$), and the Tukey's test identified only a single homogenous group for both flammable substance and water (Table 1). The benchmarking of water and ash contents against reference data led to a conclusion that, under the experimental conditions, the proportion of these parameters for cereal straw was comparable (Demirbas, 2004; Denisiuk, 2009; Kowalczyk-Juśko, 2009; Rybak, 2009; Wandrasz and Wandrasz, 2006).

The mean carbon content in the analyzed vegetable samples ranged from slightly above 44% (buckwheat straw) to nearly 48% (rye straw). Hydrogen content was between 5.56% for buckwheat straw, and 5.92% for rye straw. The lowest oxygen content was found in Grenado triticale straw (42.06%) and the highest in Cereal mix straw – 43.39% (Table 1).

Depending on the type of material, standard deviations for these parameters were respectively 0.016-0.041%, 0.008-0.024% and 0.033-0.123%. ANOVA again established significant differences between the means in the individual material groups (p = 0.00000), and the Tukey's test identified only a single homogenous group for carbon, three for hydrogen and two for oxygen (Table 1).

The mean nitrogen content in the analyzed vegetable samples ranged from slightly below 0.6% (cereal-mix straw) to ca. 1.2% (winter wheat straw) (Table 1). Cereal-mix straw also showed the lowest sulphur content (0.06%), with the highest content being found in buckwheat straw (0.13%) (Table 1). The lowest chlorine content was found in rye straw (0.018%) and the highest in Fredro triticale straw 0.123% (Table1).

Depending on the type of material, standard deviations for these parameters were respectively 0.008-0.033%, 0.008-0.016% and 0.001-0.002%. ANOVA established significant differences between the means in the individual material groups (p = 0.00000), and the Tukey's test identified only a single homogenous group for nitrogen, four for sulphur and one for chlorine (Table 1).

The benchmarking of the results against reference data again led to a conclusion that, under the experimental conditions, the proportion of these parameters for cereal straw was comparable (Demirbas, 2004; Denisiuk, 2009; Rybak, 2009; Wandrasz and Wandrasz, 2006).

The amount of these elements nitrogen, sulphur and chlorine in the selected biomass is minute, yet still relevant, as they influence combustion products (combustion gasses) and the operation of energy-generation systems (boiler corrosion) (Sztyma-Horwat and Styszko, 2011).

The assessment of the selected materials for their applicability in energy generation allowed the determination of their heat of combustion, as presented in Table 1.

The heat of combustion for the sampled materials usually was ca. 15-16 MJ·kg^{-1}, with only rye wheat and cereal-mix wheat having higher values (nearly 17 MJ·kg^{-1}) (Table 1). Depending on the type of material, standard deviations for this parameter ranged 0.024-0.057 MJ·kg^{-1}. ANOVA again established significant differences between the means in the individual material groups (p = 0.00000), and the Tukey's test identified three homogenous groups (Table 1). The results obtained under the experimental conditions proved comparable with reference data (Demirbas, 2004; Denisiuk, 2009; Kowalczyk-Juśko, 2004; Rybak, 2009; Wandrasz and Wandrasz, 2006; Wilk, 2006).

For the materials in question showed negative linear trends between the heat of combustion and the content of water, ash, nitrogen, sulphur and chlorine (Figure 1a,e,f g); and positive between the heat of combustion and the content of carbon, hydrogen and oxygen (Fig 1b,c,d).

Table 1
The mean content chemical and physical properties for the examined research material, values, a-d − homogeneous groups (α = 0.05)

Parameter	Denomination	Species of straw					
		Triticale Grenado	Triticale Fredro	Cereal mix	Winter wheat	Buckwheat	Rye
Water content	%	15.35	13.11 a	14.09 a	14.03	14.49	13.85
Organic matter content		80.46	83.11 a	82.81 a	82.59	79.23	84.26
Ash content		4.19	3.78	3.1	3.38	6.28	1.89
Carbon	%, d.b.	46.64	46.50 a	46.98 a	47	44.4	47.94
Hydrogen		5.83 a	5.74 b	5.85 a. c	5.79 a. b. c	5.56	5.92
Oxygen		26.7	29.98	29.30 a	28.40 b	28.13 b	29.46 a
Nitrogen		1.07	0.7	0.59	1.19	0.88 a	0.85 a
Sulphur		0.12 a	0.09 a. b	0.06 b. c	0.12 a. b. d	0.13 a. d	0.07 b. c
Chlorine		0.09 a	0.09 a	0.03	0.08	0.12	0.02
Heat of combustion	MJ·kg^{-1}	15.62 a	15.40 b	16.67 c	15.36 b	15.72 a	16.79 c

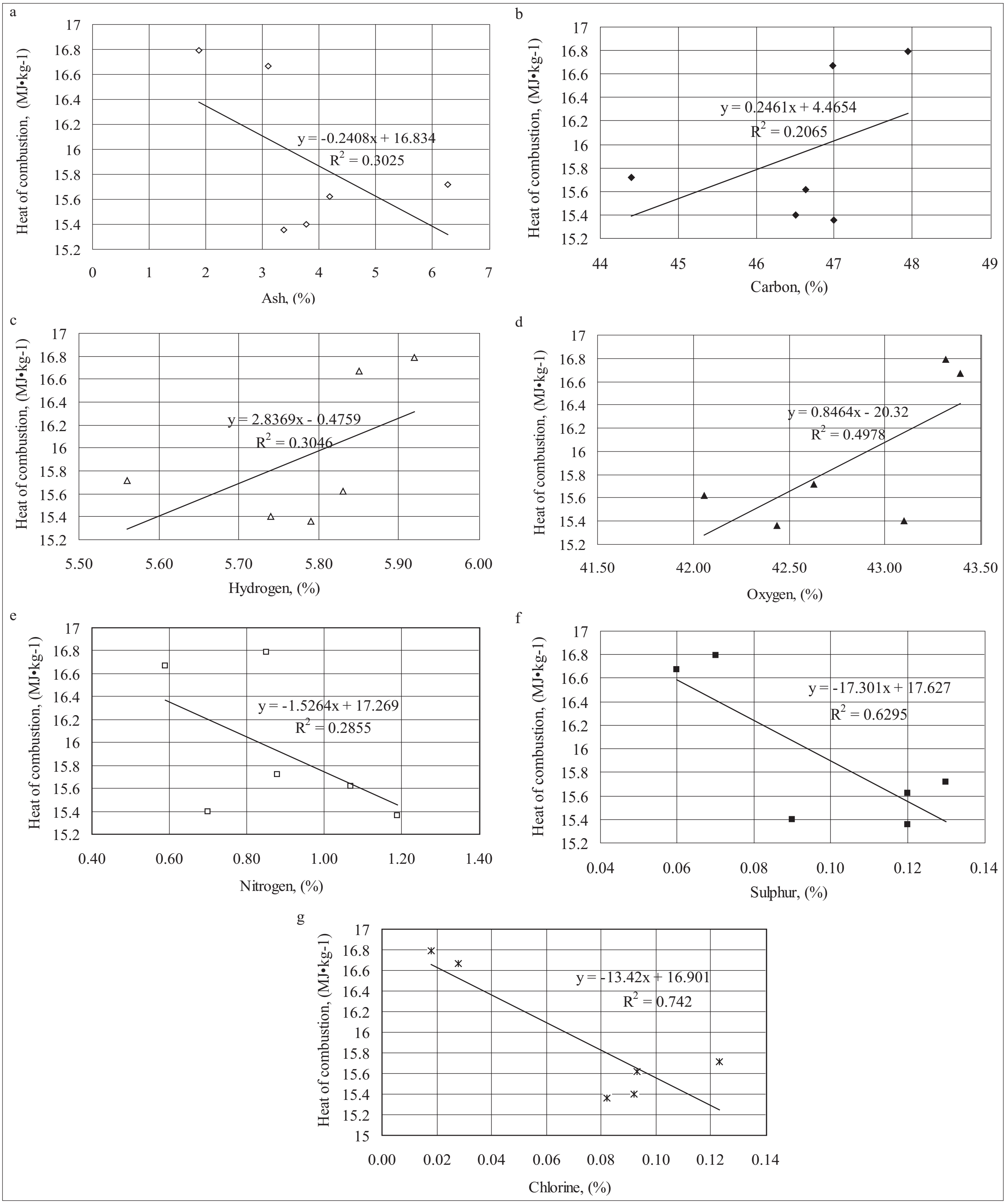
a
Heat of combustion, (MJ•kg-1)
Ash, (%)
y = -0.2408x + 16.834
R2 = 0.3025
b
Heat of combustion, (MJ•kg-1)
Carbon, (%)
y = 0.2461x + 4.4654
R2 = 0.2065
c
Heat of combustion, (MJ•kg-1)
Hydrogen, (%)
y = 2.8369x - 0.4759
R2 = 0.3046
d
Heat of combustion, (MJ•kg-1)
Oxygen, (%)
y = 0.8464x - 20.32
R2 = 0.4978
e
Heat of combustion, (MJ•kg-1)
Nitrogen, (%)
y = -1.5264x + 17.269
R2 = 0.2855
f
Heat of combustion, (MJ•kg-1)
Sulphur, (%)
y = -17.301x + 17.627
R2 = 0.6295
g
Heat of combustion, (MJ•kg-1)
Chlorine, (%)
y = -13.42x + 16.901
R2 = 0.742

Fig. 1.

Analyzing the dealt plant materials, been established their picture in the scheme Van Krevelen (1950), which allows to make a conclusion about the properties of energy in relation to their heat of combustion (Figure 2). When comparing the published literature (Van Krevelen, 1950; Rybak, 2006) from the test results, it was observed that among the materials tested there were beneficial rye straw energy properties which are close to the area characteristic of the timber. Buckwheat straw was the most deviating material from the research group (Figure 2).

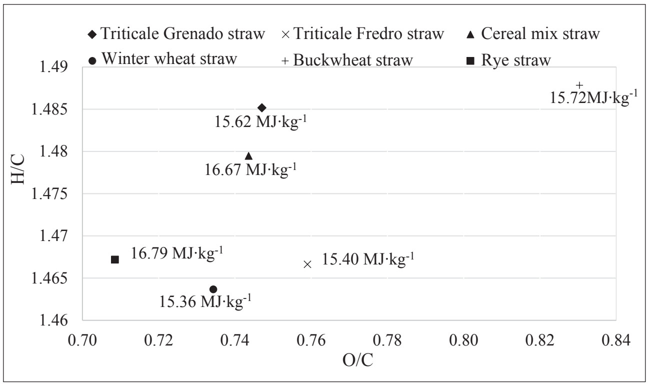

Fig. 2.

Conclusions

The study points to the following conclusions:

- The physical and chemical characteristics of the two species of winter triticale (Grenado and Fredro), winter wheat, cereal-mix, buckwheat and rye straws, assessed against their applicability in energy generation, proved favourable and desirable. This was further confirmed by the benchmarking of the results against reference data presented by other research, also referring to the scheme of Van Krevelen.
- Under the experimental conditions, the highest content of flammable substances, or, more specifically, the highest content of carbon and a considerable amount of hydrogen and oxygen, and, at the same time, the lowest proportion of water and ash, was found in rye straw. Due to the distribution of these parameters, rye-straw biomass was found to have the most favourable properties for application in energy generation, as compared to other examined materials. Similar properties were also found in cereal-mix straw.
- The content of water, carbon, hydrogen and oxygen in the examined test samples was a factor that determined the materials' usability in energy generation. Nevertheless, the considerable elemental variation in the content of organic matter, and its impact on the combustion process, as well as the emission of exhaust gasses of the individual energy sources produced in agriculture demonstrated the need for further research in this area and for the dissemination of the results.

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