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FRACTIONAL COMPOSITION OF HUMIC COMPOUNDS AND THE CAPACITY TO BIND CADMIUM IONS FROM THE SOLUTION BY BIOLOGICALLY AND THERMALLY PROCESSED *MISCANTHUS GIGANTEUS* BIOMASS*

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A b s t r a c t. The capacity of functional groups of soil organic matter to form organometallic complexes may efficiently reduce the risk of migration of toxic ions of heavy metals in the environment. Therefore, a research was conducted to determine the effect of composting and pyrolysis of *Miscanthus giganteus* biomass on the quality of humic compounds and on the ability of these materials to bind cadmium ions from the solution. Both processes did not cause any significantly favorable changes in fractional composition of the humic compounds of the transformed *Miscanthus giganteus* biomass. In the case of the unprocessed and composted biomass, changes in cadmium sorption by the materials used in the research, depending on Cd dose and how long the sample was in contact with the solution, had a similar course, which indicates that the responses taking place directly after the application of the solution that contained Cd ions were stable. In the case of thermal processing of *Miscanthus giganteus* biomass, it was found that Cd content in the solution decreased with time. Lower cadmium concentrations in the extracts after separation of the biomass were determined in the series with biologically transformed *Miscanthus giganteus*.

K e y w o r d s : compost, biochar, humic compounds, cadmium sorption, *Miscanthus giganteus*

INTRODUCTION

Among pollutants that enter the environment, heavy metals are a hazardous group (Fu and Wang 2011, Monachese *et al*. 2012). It is a heterogeneous group of elements that has different chemical properties and have different impact on the biosphere. Due to their high toxicity and bioaccumulation capacity, these elements constitute a serious threat to living organisms, including human health and life (Järup 2003, Singh *et al.* 2011, Monachese *et al*. 2012).

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The toxicity of heavy metals is associated not only with their content, but also with their affinity to form complexes with different compounds, including organic matter (Weng *et al*. 2002, Gondek 2006). The research results published hitherto published research results prove that sorption of ions of heavy metals takes place thanks to the presence of functional groups such as carboxylic, phenolic or hydroxylic groups on the surface of a sorbing substance (Pino *et al*. 2006, Meena *et al*. 2008). Binding of heavy metals with functional groups may occur, among other things, as a result of ionic exchange or the reaction of complexing. The efficiency of the process of binding of heavy metals by organic matter is influenced by many factors, including the type of organic matter, degree of processing and size reduction of organic matter, pH of the solution, temperature, ionic strength, concentration of an element or the ratio of its dose and the amount of organic matter (Fu and Wang 2011). The natural capacity of organic materials for binding heavy metals can be increased by transforming the organic materials, e.g. in biological or thermal processes, which significantly contributes to modification of their properties (Gondek *et al*. 2014a, Gondek *et al*. 2014b).

Composting is one of biological methods of biomass transformation. This process is based on biochemical reactions taking place with the use of microorganisms (Tuomela *et al.* 2000, Gondek *et al.* 2014b). In general, the composting process has several stages, as a result of which compost is obtained. The duration of the composting process varies and can be appropriately modified depending on the applied composting technology applied and on the qualitative requirements for the solid product of the process (compost) in terms of its further intended use (Tuomela *et al.* 2000, Gondek *et al.* 2014b, Kopeć *et al.* 2015, Czekała *et al.* 2016).

Thermal transformation under limited air access, i.e. pyrolysis, is an alternative for biological processes of converting plant biomass (IBI 2012). Carbonization product, which is also called biochar, is one of the products created in consequence of this process. The amount and quality of biochar obtained in the pyrolysis process depend on several factors, including moisture and size reduction of raw materials used in its production, as well as on parameters of the process (Hossain *et al.* 2011, Gondek *et al.* 2014a, Enders *et al.* 2012, Jindo *et al.* 2014).

It is a fact that thermal processing of organic materials is definitely faster than the biological one. Nevertheless, thermal processing is less efficient, and product standardization and manufacture technology require maximum unification of the processed material. Additionally, too high temperature of the process leads to losses of some elements from the organic material, including carbon and nitrogen. Carbon and nitrogen losses can lower the utility value of the product, and they undoubtedly affect the number and type of functional groups. Changes in physical and chemical structures of organic materials that occur in biological and thermal processing can significantly affect the sorption capacity of the materials in relation to heavy metals. The use of such materials for binding heavy metal ions found in sewage, waters draining off from landfill sites and in a soil solution may affect not only the detoxification of the environment these materials have been introduced for, but it also may contribute to, e.g., the sequestration of carbon compounds in soil.

Organic matter is important in terms of limiting the migration of heavy metal ions in the environment. The capacity of functional groups of organic matter to form organometallic complexes may efficiently reduce the risk of migration of toxic ions of heavy metals in the environment (Krishnani *et al.* 2008, Boguta and Sokołowska 2013, Zeng *et al.* 2014). Indicating products which have the mentioned properties gains practical importance. Therefore, a research was conducted to determine the effect of biological or thermal processing of *Miscanthus giganteus* biomass on the quality of humic compounds and the possibility of these materials to bind cadmium ions from the solution.

MATERIAL AND METHODS

Characteristics of plant material used in the research

Biomass of the above-ground parts of *Miscanthus giganteus* used in the research came from arable farming located within the Malopolska region (southern Poland), on a soil classified as type and subtype of typical brown soils with particle size composition of loamy sand. The collected above-ground parts of the plants, after prior size reduction (1-2 cm), were subjected to biological processing. In the case of the material intended for thermal processing, the biomass was dried at a temperature of 65°C and then broken up and sifted through a sieve with a 4 mm mesh.

Biological transformation (composting) of *Miscanthus giganteus*

Biological processing was conducted for 91 days (13 weeks) in PVC reactors (34 x 26 x 32.5 cm) capable of holding approximately 25 liters of biomass. The research was conducted in two replications. The reactors had perforated bottoms, which enabled aeration of the biomass and drainage of leachates. During the experiment, temperature of the biomass was monitored using automatic recorders placed in the biological material. The moisture was also monitored and kept at 45%. The biomass in the reactors was aerated in cycles, entering 0.1 m^3 air min^{-1}, 4 times a day. To maintain optimal conditions of the process (better aeration and homogenization of the material), once a week the biomass was taken out of the reactors and mixed manually. Due to low volumetric heat capacity, temperature of the biologically processed material was not significantly varied, but is indicative of regularity of the process.

Thermal transformation of *Miscanthus giganteus* to biochar

Thermal processing of *Miscanthus giganteus* biomass was conducted at a station designed for gasification of biomass, at reduced air access (1-2% O_2) (IBI 2012). The rate of heating the combustion chamber was 10°C min^{-1}. Temperature inside the combustion chamber was 300°C, and exposure time was 15 minutes. The selection of time and temperature of pyrolysis was set according to preliminary own research and results of other authors' research (Lu *et al.* 2013, A. Mendez *et al.* 2013, Gondek *et al.* 2014a).

Analysis of sorption capacity of compost and biochar relative to cadmium

The biological and thermal processing of the above-ground parts of *Miscanthus giganteus* produced the material for the next research stage in which the Cd sorption capacity of the unprocessed and processed biomass was evaluated in relation to cadmium. The experimental design consisted of 3 materials: unprocessed above-ground parts of the plants (UB), biologically processed above-ground parts of the plants (BPB), and thermally processed above-ground parts of the plants (TPB).

Analytical samples (1.00 g) of biomass of the unprocessed *Miscanthus giganteus* biomass (UB), after biological processing (BPB), and after thermal processing (TPB) were placed in PP vessels and treated with solutions (prepared redestilled water) that contained the following doses (d) of cadmium: 0, 25, 50 and 100 mg Cd dm^{-3}. The solutions were prepared using redistilled water and hydrated cadmium sulfate ($3CdSO_4 \cdot 8H_2O$). Suspensions of the organic materials and solutions were shaken on a laboratory shaker for (t): 1, 24, 48, 96, 192, 384 and 768 h. After each extraction time, the suspension was filtered, separating the solution from the solid parts. The experiment was conducted at room temperature (25.0±1.9°C). In the obtained filtrates, cadmium content was determined using the ICP-OES technique on a Perkin Elmer Optima 7300 DV instrument.

Chemical analyses

In order to characterize the chemical composition of the obtained materials in the *Miscanthus giganteus* biomass before and after processing, dry matter content was determined after drying the materials at the temperature of 105°C for 12 hours (Jindo *et al.* 2012). Next the materials were crushed in a laboratory mill and subjected to chemical analyses. The organic matter content was determined after incinerating the sample in a chamber furnace at 550°C for 12 h (Kopeć *et al.* 2013). The total cadmium content was determined after incinerating the sample in a chamber furnace at 450°C for 12 hours and mineralization of the residue in a mixture of concentrated nitric and perchloric acid (3:2) (v/v). The pH of the materials (material : water = 1:5) was electrochemically determined using a pH meter (pH – meter CP-505) (Meier *et al.* 2015), the content of total nitrogen was determined using a CNS analyser (Vario MAX Cube manufactured by Elementar). Cd concentration was determined in the obtained solutions by inductively coupled plasma optical emission spectrometry (ICP-OES), using a Perkin Elmer Optima 7300 DV instrument (Oleszczuk *et al.* 2007).

Fractional composition of humic compounds

Extraction of humic acids was conducted by the Schnitzer method (Griffith and Schnitzer 1975), using a 0.5 mol dm^{-3} NaOH solution (Cex) (extraction for 24 hours). Carbon of humic acids (Cha) was separated from the extract after acidification with sulfuric acid to pH ~ 2. Carbon content in both fractions was determined by the oxidation-titration method. Content of carbon of fulvic acids (Cfa) and non-hydrolyzing carbon (Cnh) was calculated from the difference of, respectively:

$$\mathrm{Cfa} = \mathrm{Cex} - \mathrm{Cha} \tag{1}$$

$$\mathrm{Cnh} = \mathrm{Ct} - \mathrm{Cex} \tag{2}$$

Optical properties of humic acids

Optical properties within UV-VIS range for 0.02% humic acid solutions in 0.1 mol dm^{-3} NaOH were determined using a Beckman DU 640 spectrophotometer after dilution of the initial samples in 0.1 mol dm^{-3} NaOH in 1:5 ratio. Based on the obtained results, values of the A4/6 index were calculated as a ratio of absorbance values at wavelengths of 465 and 665 nm.

Statistical computations

A three-factor analysis of variance in a completely random design was conducted for the results obtained (using F-Fisher test). The significance of differences between arithmetic means was verified based on homogenous groups determined by Tukey's t-test at the significance level $\alpha < 0.05$. Backward stepwise multiple regression was used in order to eliminate factors that did not affect the model which allowed to estimate the conditional expected value of random variable.

RESULTS AND DISCUSSION

Chemical composition of materials

Due to the way it was processed, *Miscanthus giganteus* biomass used in the research varied in terms of dry matter content, organic matter and content of total forms of cadmium (Tab. 1). The highest content of dry matter and organic matter was determined in the unprocessed *Miscanthus giganteus* biomass (UB). Both composting and pyrolysis caused a reduction of organic matter content. Moreover, both of the processes of biological and thermal transformation of *Miscanthus giganteus* resulted in an increase in the pH value of the products. The highest content of total nitrogen was determined in the biomass after thermal processing. Comparing the materials used in the research, it was found that the highest cadmium content was determined in the biomass of *Miscanthus giganteus* after thermal processing. The increase in the content of trace elements in the materials subjected to thermal and biological processing is confirmed by results obtained by these and other authors (Gondek *et al.* 2014a, Liu *et al.* 2014). Both in the case of biological as well as thermal processing, the increase in heavy metals content, including cadmium, results from the reduction of organic matter content of the processed biomass, which leads to an increase in their content (Gondek *et al.* 2014a, Gondek *et al.* 2014b).

Table 1. Content of dry weight, organic matter and total cadmium in *Miscanthus giganteus* biomass used in the experiment

Determination	Unprocessed aboveground parts of the plants (UB)	Biologically processed aboveground parts of the plants (BPB)	Thermally processed aboveground parts of the plants (TPB)
Dry weight (g kg^{-1})	784±70	571±51	977±2
pH	6.29±0.60	6.70±0.55	6.94±0.61
Organic matter (g kg^{-1} d.m.)	967±2	955±2	933±3
Total N (g kg^{-1} d.m.)	4.22±0.40	3.92±0.30	4.99±0.14
Cd (mg kg^{-1} d.m.)	0.40±0.04	0.52±0.03	0.58±0.01

± standard deviation, n = 4

Fractional composition of humic compounds

Analysis of fractional composition of the humic compounds showed a significant effect of both types of *Miscanthus giganteus* biomass processing on the content of carbon compounds that undergo extraction (Tab. 2). Both composting and pyrolysis caused an over two-fold increase in the content of extractable carbon compounds, in comparison to the content determined in the unprocessed biomass. Similar relations apply to humic and fulvic acid carbon content. The content of fulvic acid carbon, regardless of the way of processing, was higher than the content of humic acid carbon. Nevertheless, a more favorable effect on the content of the fraction of humic compounds was found in the case of biomass biological processing.

Table 2. Content of carbon of each fraction in *Miscanthus giganteus* biomass used in the experiment

Determination	Unprocessed above-ground parts of the plants (UB)	Biologically processed above-ground parts of the plants (BPB)	Thermally processed above-ground parts of the plants (TPB)
C extracted (g kg^{-1} d.m.)	52.4±0.6	122.1±0.6	112.4±0.3
C humic acids (g kg^{-1} d.m.)	11.5±0.8	32.6±0.6	27.3±0.2
C fulvic acids (g kg^{-1} d.m.)	40.8±0.7	89.4±0.7	85.1±0.2
C non-hydrolyzing (g kg^{-1} d.m.)	381±7	298±13	179±8
A4:A6 ratio[1]	7.19±0.11	5.77±0.36	7.02±0.20

Explanatory notes: ± standard deviation, n = 4; [1]the ratio of absorbance of humic acids in the wave length 465 to 665 nm

The results obtained indicate that in the case of fractional composition of humic compounds, neither biological nor thermal processing of the *Miscanthus giganteus* biomass were favorable in the case of the content of labile fractions, especially of humic acid carbon. According to Sánchez-Monedero *et al.* (2002), humic acids generated during composting are similar, both in molecular composition and in the content of functional groups, to the composition of soil humic acids. The conducted composting of *Miscanthus giganteus* did not lead to obtainment of similar dependencies, which might have been caused by the type of composted biomass and too short duration of the process. As Gondek *et al.* (2014b) showed in their research, proper nitrogen content is important for the composting process to be effective. The authors quoted obtained clearly higher values of the Cha:Cfa ratio in composts with added edible oil and urea. On the other hand, they found much lower values of the mentioned parameter, below one, in the control compost and in the compost with an addition of starch. Research results of Réveillé *et al.* (2003) indicate that maturity has a significant impact on carbon distribution in particular fractions of humic compounds extracted from sewage sludge. Moreover, as the quoted authors observed, substances such as lipids may be, aside from the processing technology, of significant importance in this matter.

The capacity to bind cadmium ions from the solution by biologically and thermally processed *Miscanthus giganteus* biomass

Cadmium content in the extracts is shown on 3D charts for the unprocessed (UB), biologically processed (BPB), and thermally processed (TPB) *Miscanthus giganteus* biomass (Figs 1-3). What is characteristic for all the materials is how cadmium concentration in the filtrate increased along with increasing the cadmium dose. The lowest cadmium concentrations in the filtrate concerned the biomass of biologically processed *Miscanthus giganteus* (BPB). In the case of the unprocessed biomass and biomass after processing, the direction of changes in cadmium concentration, depending on Cd dose and how long the sample was in contact with the solution, had a similar course, which indicates that the responses taking place after the application of the solution that contained Cd ions were stable. In the case of thermally processed biomass (TPB), the amount of cadmium residue in the filtrate was significantly higher, and it decreased with time. This phenomenon indicates that the sorption capacity of this material directly after mixing with the solution containing cadmium ions was lower, and that the efficiency of this process increased with time.

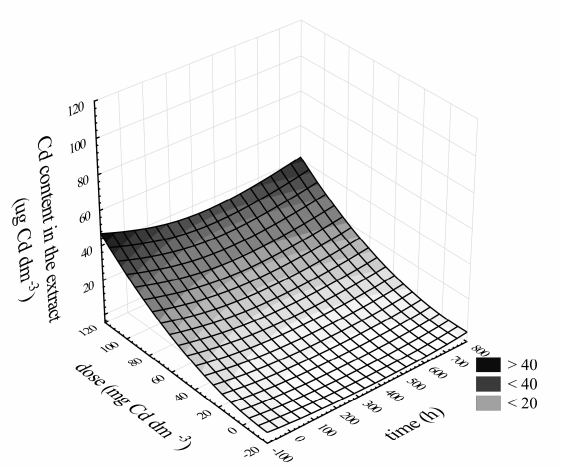

Fig. 1. Dependence of cadmium content in the extract on the concentration (dose) and extraction time for unprocessed biomass of *Miscanthus giganteus* (UB)

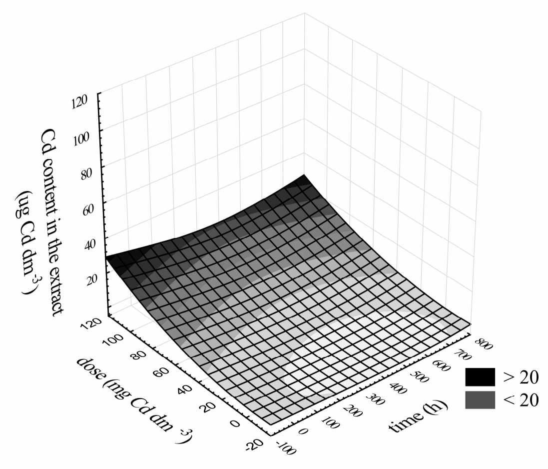

Fig. 2. Dependence of cadmium content in the extract on the concentration (dose) and extraction time for biologically processed biomass of *Miscanthus giganteus* (BPB)

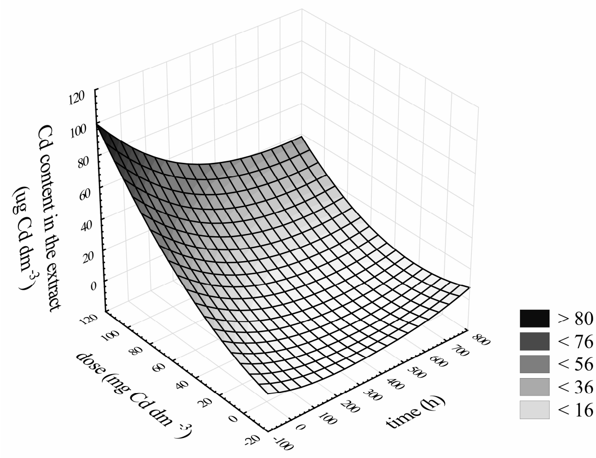

Fig. 3. Dependence of cadmium content in the extract on the concentration (dose) and extraction time for thermally processed biomass of *Miscanthus giganteus* (TPB)

The backward stepwise multiple regression confirms the graphically illustrated course of dependencies of cadmium concentration in the filtrate on the Cd dose and on the time of biomass contact with the solution (Tab. 3). In the case of the unprocessed (UB) and biologically processed (BPB) material, values of the determination coefficient are, respectively, 0.848 and 0.797, which is indicative of a high share of cases in explanation of the proposed model. Significance of the parameters suggests a relation between the share of the applied cadmium dose and the concentration of this element in the filtrate. The regression confirmed, also at a great value of the determination coefficient, that in the case of the material after thermal processing not only the level of applied cadmium is important, but also the fact that the force of binding of this element at the beginning of the studied period was weaker. Negative value (–0.023) of the b coefficient b for the time variable proves that.

Table 3. Parameters of backward stepwise multiple regression of the cadmium concentration in the extract on a dose and extraction time for different methods of processing the material

Factors	b^*	St. er. – z b*	b	St. er. – z b*	t(82)	p
Unprocessed above-ground parts of the plants (UB) R = 0.921; R^2 = 0.848; F(1.82) = 458.86 p						
Free term			–2.905	0.762	–3.808	0.000
Concentration (mg Cd dm^{-3})	0.921	0.043	0.285	0.013	21.421	0.000
Biologically processed above-ground parts of the plants (BPB) R = 0.893; R^2 = 0.797; F(1.82) = 321.64 p						
Free term			–1.902	0.555	–3.426	0.001
Concentration (mg Cd dm^{-3})	0.893	0.049	0.173	0.009	17.934	0.000
Thermally processed above-ground parts of the plants (TPB) R = 0.892; R^2 = 0.796; F(2.81) = 157.68 p						
Free term			0.085*	1.830*	0.046*	0.963*
Time (h)	–0.278	0.050	–0.023	0.004	–5.549	0.000
Concentration (mg Cd dm^{-3})	0.847	0.050	0.475	0.028	16.868	0.000

*insignificant

Significant differences between the processing methods were found. The lowest cadmium concentration in the filtrate after separation of the biomass, which indicated strong affinity of this element, was determined in the series with biologically processed *Miscanthus giganteus* (BPB). While in the case of cadmium doses up to 25 mg Cd dm^{-3} the sorption capacity of this material was not different than the sorption capacity of the unprocessed material (UB), considerable differences appeared in the case of higher cadmium doses, indicating that the material applied as a sorbent affected Cd binding (Tab. 4). The biologically processed biomass (BPB) affected cadmium binding to a higher degree in the case of higher concentrations of the applied Cd than the unprocessed material (UB). Mean cadmium concentration in the filtrate after separation of the *Miscanthus giganteus* biomass from biologically processed biomass (BPB) for doses and time extraction was almost three times lower (5.701 mg Cd dm^{-3}) than values calculated for thermally processed biomass (TPB) (16.039 mg Cd dm^{-3}).

Mean values for Cd dose in the solution indicate that each following dose significantly modified concentration of cadmium in the solution; in the case of dose 25 mg Cd dm^{-3}, 9.51 times less Cd remained in the extract, and in the case of concentrations 50 mg and 100 mg Cd dm^{-3} – 5.59 and 3.31 times less, respectively (Tab. 4). It correspond to the diminishing sorption strength along with the increase in pressure on the materials. With an assumption of a four-fold increase in Cd concentration in the solution (25 to 100 mg Cd dm^{-3}), after completion of the experiment for extraction time and materials, the mean content of this element in the filtrate increased over eleven-fold.

Analysis of variance allows to determine that after 8 days (192 h) no significant differences in cadmium content in the solution between mean values were detected for the processing method and metal dose (Tab. 4). Of course, earlier analysis suggested that the thermally processed material (TPB) influenced this dependence most. One can, however, think that the sorption strength of the system stabilizes in this period, regardless of the type of biomass processing and level of metal pressure.

Table 4. Analysis of variance of factors (t-time, d-dose, m-method; t×d, d×m, m×t) taken into consideration in the experiment

Factors		Dose – d (mg Cd dm^{-3})				Mean t
		0	25	50	100	(d×m)
Time of extraction – t (h)	1	0.002a*	5.349def	18.977i	37.587l	15.479e
	24	0.060a	3.359bcd	12.276h	38.751l	13.612d
	48	0.006a	2.986bc	8.763g	34.202k	11.489c
	96	0.043a	1.782ab	7.063fg	34.321k	10.802b
	192	0.022a	1.547ab	5.819ef	19.837i	6.806a
	348	0.009a	1.684ab	4.808cde	21.0229i	6.881a
	768	0.004a	1.684ab	4.916cdef	20.407i	6.753a
Mean d (m×t)		0.021a	2.628b	8.946c	30.161d	
						Mean m (t×d)
Method - m	UB	0.037a	2.456b	8.130d	27.680g	9.575b
	BPB	0.013a	1.668b	4.118c	17.007f	5.701a
	TPB	0.012a	3.758c	14.590e	45.796h	16.039c

* mean values marked with the same letters do not differ significantly according to the Tukey's t-test at $\alpha \leq 0.05$; factors: the method of transformation × Cd dose x extraction time; biomass unprocessed (UB); biomass biologically processed (BPB); biomass thermally processed (TPB)

As it can be concluded from literature, the process of biosorption of heavy metal ions from solutions, especially using organic by-materials, may find many applications owing to lower costs and high efficiency (Shin and Rowell 2005, Zhao *et al.* 2011). The main role in this process will be played by organic materials which have hemicellulose, cellulose and lignin in their structure, whereas an important role is attributed to modification of properties of such materials (Guo *et al.* 2008, Jindo *et al.* 2014, Martinho *et al.* 2015). As shown by Kumar and Bandyopadhyay (2006), chemical modification of rice husks caused an increase in the sorption capacity of this material in relation to cadmium ions. Based on numerous research studies it has been established that the surface of complexing and of ionic exchange are one of main factors that influence the process of sorption of heavy metal ions (Serrano *et al.* 2009, Pehlivan *et al.* 2009). Taking this statement into account, thermal processing should cause much better results in comparison to biologically processed biomass. When analyzing the obtained results of the authors' own research, this diversity applied only to the initial stages of the experiment, but not in favor of the thermally processed biomass. With time, differences in the sorption capacity of individual materials were becoming more and more blurred. Despite various factors (activity of microorganisms in the case of composting; temperature in the case of pyrolysis) used in processing of the *Miscanthus giganteus* biomass, comparable contents of extracted carbon and of C content in humic acids were obtained, which may explain the relatively small differences in sorption capacities of the used materials. As Kim *et al.* (2013) showed in their research, temperature was an important factor influencing the sorption of cadmium ions from the solution by biochar produced from *Miscanthus giganteus*. Higher temperature of biomass processing resulted in biochar with a higher aromatic structure and fewer polar functional groups. The quoted authors showed that at the temperature of $\geq 500°C$, pH values and sorption surface of the obtained biochar increase significantly. On the other hand, Seelsaen *et al.* (2006) showed that vegetable waste compost is characterized by high sorption capacity in relation to heavy metal ions, and can be used for their absorption from solutions. It should be emphasized, however, that the degree of size reduction of organic material was an important factor in this case, which in consequence influenced the sorption surface of sorbent.

CONCLUSIONS

In the case of fractional composition of humic compounds, neither biological nor thermal processing of the *Miscanthus giganteus* biomass was favorable in the case of the content of labile fractions, especially of humic acid carbon. In the case of the unprocessed and composted biomass, changes in Cd sorption by the materials used, depending on Cd concentration and how long the sample was in contact with the solution, had a similar course, which indicates that the responses taking place directly after the application of the solution that contained Cd ions were stable.

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SKŁAD FRAKCYJNY ZWIĄZKÓW HUMUSOWYCH ORAZ ZDOLNOŚCI WIĄZANIA JONÓW KADMU Z ROZTWORU PRZEZ BIOMASĘ *MISCANTHUS GIGANTEUS* PRZEKSZTAŁCONĄ BIOLOGICZNIE I TERMICZNIE

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S t r e s z c z e n i e . Zdolność grup funkcyjnych materii organicznej do tworzenia kompleksów metaloorganicznych może wydajnie zmniejszyć ryzyko migracji jonów toksycznych metali ciężkich w środowisku. W związku z tym przeprowadzono badania, których celem było określenie wpływu kompostowania i pirolizy biomasy *Miscanthus giganteus* na jakość związków humusowych oraz możliwości wiązania jonów kadmu z roztworu przez te materiały. Oba procesy nie spowodowały znacząco korzystnych zmian w składzie frakcyjnym związków humusowych przekształconej biomasy *Miscanthus giganteus*. Przebieg zmian sorpcji kadmu przez materiały wykorzystane w badaniach, w zależności od dawki Cd i czasu kontaktu próbki z roztworem w przypadku biomasy nieprzetworzonej i przekompostowanej zachodził podobnie świadcząc o stabilnych reakcjach mających miejsce bezpośrednio po aplikacji roztworu zawierającego jony Cd. W przypadku termicznego przekształcenia biomasy *Miscanthus giganteus* stwierdzono zmniejszanie się zawartości Cd w roztworze wraz z upływem czasu. Mniejsze stężenia kadmu w ekstraktach po oddzieleniu biomasy oznaczono w serii z *Miscanthus giganteus* przekształconym biologicznie.

S ł o w a k l u c z o w e : kompost, biowęgiel, związki humusowe, sorpcja kadmu, *Miscanthus giganteus*