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THE CONTENT OF HEAVY METALS IN THE WOOD OF HEALTHY AND DYING BEECH TREES (*FAGUS SYLVATICA* L.)*

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Abstract. The total content of mineral substances (ash) and heavy metals (Al, Cd, Cr, Cu, Fe, Mn, Pb) in the wood of healthy and dying beech trees from different regions of Poland was subject to analysis. The material for the analysis came from the nine Forest Districts in which Poland's main sources of beech wood are located. Two healthy and dying sample trees of the same age were collected from each stand bearing symptoms of weakened vitality and decline of trees. Wood samples cut out of the central zone between cambium and pith, of the cross section of the trunk at the butt-end of beech trees aged 80-145 were used for analysis. The content of mineral substances in the wood of healthy and dying trees was within a similar value range. No statistically significant difference in the content of each of the analysed elements was found in healthy and dying trees. A relationship was found between the content of heavy metals in wood and geographic origin of trees.

Key words: heavy metals, European beech, beech wood, Poland, health condition, tree vitality, forest decline

INTRODUCTION

The European beech (*Fagus sylvatica* L.) is one of the main broadleaved tree species in our country. In recent years, the problem of the mass decline of broadleaved trees has also affected beech. The phenomenon of large-scale decline of beech forests has been known in Europe since the end of the 19th century, however, it intensified in the middle of 1980s. The causes of beech decline are sought in intensive, concurrent impact of environmental (droughts, low temperatures), biotic (insects, fungi and other pathogenic organisms) and anthropogenic (incorrect silvicultural management, environment contamination) factors [Lonsdale 1986, Pitelka and Raynal 1989, Roloff 1989, Innes 1992,

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Kandler and Innes 1995, Oszako 1997, Szczepkowski 2000, 2001, Sierota 2001, Szczepkowski and Schollenberger 2001, Szczepkowski and Szyndel 2001, Szczepkowski and Tarasiuk 2005].

The concentration level of elements in plants depends on a variety of factors [Kabata-Pendias and Pendias 1999, Kozłowska 2008]. The quantity of mineral compounds in wood depends on the species, age, tree section, growth condition (soil, climate, environment), or felling time [Baule and Fricker 1973, Prosiński 1984, Fengel and Wegener 1989, Hagemeyer and Schäfer 1995].

The current studies are aimed at defining the content of heavy metals in beech (*Fagus sylvatica* L.) wood in relation to the health condition of trees.

Beech wood samples for the research came from stands in those Forest Districts in which beech trees showed visible signs of decline and excessive self-thinning over the past two decades. A pair of trees ("healthy" – "dying") of the same age was selected from the same stand to reduce the impact of the environment on the examined parameter. When such a tree pair could not be found within one stand it was selected from different stands of comparable natural/forest characteristics. The material for analysis was collected from stands located in different regions of Poland, which may be indicative of the possibility of spatial (geographic) variability of a given parameter of beech wood. The obtained data enabled comparison with the results of studies on oak trees.

MATERIALS AND METHODS

The material for the studies was collected from 11 stands located within nine Forest Districts (Fig. 1) representing the main source of beech wood. The stands from which wood samples were taken for analysis are situated in five Natural-Forest Regions: the Baltic Region I represented by three Forest Districts (Wejherowo, Czaplinek, Świerczyna), Wielkopolsko-Pomorska Region III – by one Forest District (Milicz), Małopolska Region VI – by two Forest Districts (Rogów, Tomaszów), Sudeten Region VII – by one Forest District (Lądek Zdrój), Carpathian Region VIII – by two Forest Districts (Wetlina, Kańczuga). Two trees with average diameter belonging to the 1st and 2nd Kraft biosocial class were selected. They featured a straight stem, without visible signs of diseases and injuries (cankers, cracks, fruiting bodies of fungi, signs of insect occurrence). The trees represented two vitality categories according to the classification by Roloff [1989] and Dmyterko [1999]: vital trees (0 or 0/1 degree) and damaged trees (3 or 2/3 degree). Beech wood samples were cut out of the stem butt-end of trees aged 80-145 (Table 1). The trees were felled in the second half of the growing season. Beech wood samples cut out of the central zone between the cambium and the pith of the stem cross section were used for testing. Wood samples contained ca 10 annual rings. The wood with an 8.5 per cent moisture content was broken up in the Retsch grinder Ultra Centrifugal Mill ZM 1 to obtain the form of sawdust. After sorting, the fraction which went through a 1 mm mash sieve and stopped on a 0.5 mm sieve was used for testing. The wood was burnt at a temperature of 480°C and mineralized with concentrated hydrochloric acid diluted with redistilled water at a ratio 1:1.

The content of heavy metals (Al, Cd, Cr, Cu, Fe, Mn, Pb) was marked using the ICP-AES method in the Analytical Centre of the Warsaw University of Life Sciences – SGGW.

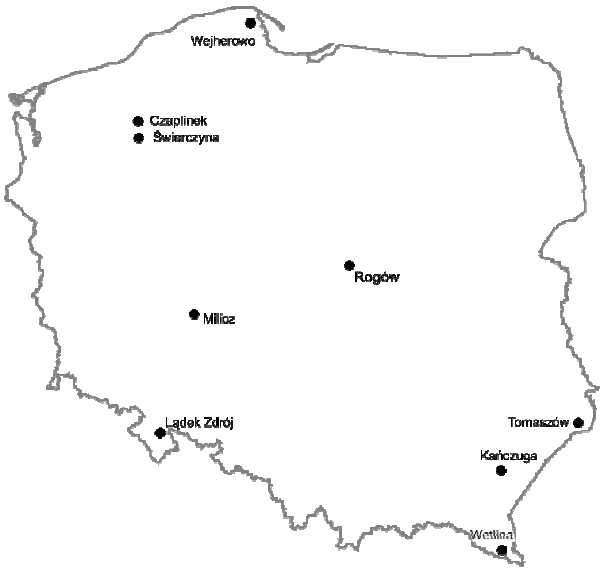

Fig. 1. Location of Forest Districts from where wood used for measuring the content of heavy metals in the stems of healthy and dying beech trees was collected
Rys. 1. Lokalizacja nadleśnictw, w których pozyskano drewno do badania zawartości metali ciężkich w pniach buków zdrowych i zamierających

Table 1. Characterisation of beech stands used for examining the relationship between healthiness of beech trees and heavy metal content in their wood
Tabela 1. Charakterystyka drzewostanów bukowych, w których pozyskano drewno do badań zależności między stanem zdrowotnym buków a zawartością metali ciężkich w ich drewnie

Forest District Nadleśnictwo	Compartment or subcompartment Oddział, pododdział	Forest habitat type Siedliskowy typ lasu	Mean DBH $D_{śr}$ cm	Age, years Wiek, lata
Czaplinek	37c	Lśw	30.5	122
Kańczuga	89a[a], 70a[b]	LWyż	44.2[a], 47.5[b]	107[a], 92[b]
Lądek Zdrój	314f	LMG	45.4	140
Milicz	207a	Lśw	58.7	132
Rogów	161a, d, 160g	LMśw	38.4	88
Świerczyna	83c[a], 42c[b]	Lśw	46.7[a], 65.2[b]	110[a], 145[b]
Tomaszów	79f	LWyż	52.0	131
Wejherowo	176b	LMśw	29.0	110
Wetlina	123a	LG	38.8	80

[a]Healthy tree. [b]Damaged tree. LMśw – fresh mixed broadleaved forest, LWyż – upland broadleaved forest, LMG – mountain mixed broadleaved forest, Lśw – fresh broadleaved forest, LG – mountain broadleaved forest.
[a]Drzewo zdrowe. [b]Drzewo zamierające.

A statistical analysis of the obtained results was carried out using STATISTICA 7.1. The Mann-Whitney test was used to verify zero hypotheses.

RESULTS AND DISCUSSION

Mineral substances (ash)

The tests showed that the content of mineral substances (ash) in the wood of healthy beeches (0.1-0.8%) and dying beeches (0.1-0.7%) was within similar value ranges (Table 2). The mean ash content in the wood of healthy and dying trees was at the same level equalling 0.5%. The obtained results are close to literature data which demonstrate that the ash content in beech wood is between 0.3 and 1.0% [Prosiński 1984, Fengel and Wegener 1989].

Table 2. Ash content in the wood of healthy and dying beech trees from different regions of Poland, %

Tabela 2. Zawartość popiołu w drewnie buków zdrowych i zamierających pochodzących z różnych regionów Polski, %

Forest District Nadleśnictwo	Healthy tree Drzewo zdrowe	Damaged tree Drzewo zamierające
Czaplinek	0.3	0.5
Kańczuga	0.7	0.6
Lądek Zdrój	0.7	0.5
Milicz	0.5	0.4
Rogów	0.8	0.7
Świerczyna	0.6	0.6
Tomaszów	0.5	0.4
Wejherowo	0.7	0.5
Wetlina	0.1	0.1
Mean – Średnia	0.5	0.5

At the majority of sites, the ash content in the wood of healthy trees was higher than in the wood of dying trees. At two sites (Świerczyna, Wetlina), these values were at the same level. The exception was the Czaplinek site where the ash content in the wood of a dying tree was higher than in the case of a healthy tree. The authors found a similar tendency in the case of oak wood, noting a higher (or the same) ash content in healthy than in dying trees for the majority of cases [Szczepkowski and Nicewicz 2008].

The lowest ash content in wood in both, healthy (0.1%) and dying (0.1%) beech trees was detected at the Wetlina site (the Carpathians). The highest ash content in both groups of healthy trees (0.8%) and dying trees (0.7%) was found at the Rogów sites (Central Poland; Table 2). Among the stands under analysis, the two aforementioned

Wetlina and Rogów stands were youngest: 80 and 88 years, respectively (Table 1). The Carpathian beech forests (Wetlina) represented the mountain broadleaved forest, while the Central Poland beech forest (Rogów) – the fresh mixed broadleaved forest habitat type. The examined wood samples came from stands representing five forest habitat types (fresh broadleaved forest – Lśw, upland broadleaved forest – LWyż, fresh mixed broadleaved forest LMśw, montane mixed broadleaved forest – LMG, and mountain broadleaved – LG). A relatively high ash content (0.7%) in a group of healthy trees was detected also in beech wood from LWyż (Kańczuga), LMG (Lądek Zdrój) and LMśw (Wejherowo). In the group of dying trees, only the wood sample from LMśw in Rogów had such a high ash content (0.7%).

The pH value of the tested wood of both, healthy and dying beeches was slightly acid and ranged from 5.07 to 5.70 [Piętka et al. 2005]. There were no significant differences in wood between healthy and dying trees, however, in six cases out of nine, the pH of the wood of dying trees was slightly lower than the pH of the wood of healthy trees. In five out of six sites where the wood pH was lower in dying trees, also the ash content was lower in the wood of dying trees than in the wood of healthy trees. Such a tendency was also observed in similar studies on oak wood [Szczepkowski and Nicewicz 2008].

Heavy metals

The heavy metal content data show that the wood of healthy beeches contained 34 to 301 mg/kg of dry mass of examined elements (Table 3). The lowest content of heavy metals was detected in beech wood from Wejherowo (Pomorze Gdańskie) – 34 mg/kg of dry mass, while the highest (nearly 9-fold higher) – in the beech wood from Kańczuga – 301 mg/kg of dry mass (Table 3).

Table 3. Total content of heavy metals in the wood of healthy and dying beech trees from different regions of Poland, mg/kg of dry mass

Tabela 3. Sumaryczna zawartość badanych metali ciężkich w drewnie buków zdrowych i zamierających pochodzących z różnych regionów Polski, mg/kg suchej masy

Forest District Nadleśnictwo	Healthy tree Drzewo zdrowe	Damaged tree Drzewo zamierające
Czaplinek	152.88	410.14
Kańczuga	300.64	194.08
Lądek Zdrój	44.46	82.78
Milicz	186.06	159.81
Rogów	227.49	187.56
Świerczyna	209.89	336.05
Tomaszów	97.33	112.73
Wejherowo	33.63	29.49
Wetlina	89.44	95.80

The wood of dying beeches contained similar concentrations of heavy metals compared to healthy trees. The total content of examined heavy metals ranged from 29 mg/kg of dry mass (Wejherowo) to 411 mg/kg of dry mass (Czaplinek; Table 3).

In the case of beech, a correlation was found between the concentrations of heavy metals in wood and the geographic origin of the trees. As mentioned before, the lowest concentrations of heavy metals were detected in the beech wood from the Baltic Region – Wejherowo (healthy trees – 34 mg/kg of dry mass, dying trees – 29 mg/kg of dry mass) and from the mountain locations: Lądek Zdrój (44 and 83 mg/kg of dry mass) and Wetlina (89 and 96 mg/kg of dry mass), as well as from the remaining Forest Districts (from the north-western, Central Poland to the south-eastern Forest Districts) – from ca 100 to 300 mg/kg of dry mass (Table 3).

The concentrations of cations in the beech wood samples were not equal. The content of Cr, Pb and Cd in the examined material was in general at the lowest level – 1 mg/kg of dry mass. The Cd content in all wood samples oscillated between 0.02 and 0.15 mg/kg, except for the wood of the healthy tree from the Kańczuga site, where the content of this element was at the level of 1.04 mg/kg. The content of Pb ranged from 0.11 to 0.48 mg/kg, except for the wood of the healthy tree from the Kańczuga site where, like in the case of Cd, it was highest – 2.01 mg/kg. The content of chromium (Cr) ranged from 0.15 to 0.49 mg/kg of dry mass (Table 4), while the level of 0.25 mg/kg of dry mass was exceeded only at one site (Wejherowo). Kaźmierczakowa et al. [1984] and Braniewski [1993] in their studies showed a similar content of cadmium in the stem wood of 100-year-old beeches from the southern regions of Poland which confirmed the results of our studies. However, the concentration of chromium in the studies by Kaźmierczakowa et al. [1984] was found to be markedly lower (trace quantities up to 0.05 ppm) compared to our results. On the other hand, Fober [1990] quotes foreign studies' findings in which the concentration of chromium in the wood of beech stems was significantly higher – 11 ppm.

The content of copper, iron and aluminium ranged from several to a dozen or so mg/kg of dry mass (Table 4). In this group of elements, the greatest differences between their concentrations in wood and tree healthiness were noted for aluminium at the Kańczuga site where Al content was four times higher in the wood of the dying tree; iron at the Tomaszów site where Fe concentrations were 3-fold higher in the wood of the dying tree and for copper at the Tomaszów site where Cu content was 6-fold higher in the wood of the healthy tree. The Cu content at nine sites under study was higher in the wood of healthy trees. Like in the studies of oak wood [Szczepkowski and Nicewicz 2008], a higher content of aluminium was detected in the wood of dying trees than of healthy ones at the majority of beech sites. It is interesting to note that lower concentrations of aluminium were found in beech wood (5.03-18.92 mg/kg) than in oak wood (6.56-127.23 mg/kg). Taking into consideration the fact that part of beech and oak wood samples were taken from stands located in the same Forest Districts (Kańczuga, Milicz, Świerczyna, Wejherowo) and from stands representing the same forest habitat type, it was the wood pH that might have had an impact on the content of this element. Oak wood had lower pH (3.40-4.26) and accumulated more aluminium than beech wood (pH 5.07-5.70). It is generally known that the acid pH value causes an increase in the activity of this element. In earlier studies quoted by Fober [1990], the Al concentrations in the wood of stems of mature beeches were determined at a level of ca 3 ppm which may be linked to a lower contamination of the environment in the past.

Table 4. Content of heavy metals in the wood of healthy and dying beech trees, mg/kg of dry mass
Tabela 4. Zawartość metali ciężkich w drewnie buków zdrowych i zamierających, mg/kg suchej masy

Tree health grade Stopień zdrowotności drzewa	Heavy metals – Metale ciężkie mg/kg				
	minimum minimum	maximum maksimum	mean średnia	SD	Vx
			Al		
Healthy – Zdrowe	5.03	16.55	9.44	3.90	41.30
Damaged – Zamierające	9.16	18.92	4.69	3.63	39.68
			Cr		
Healthy – Zdrowe	0.19	0.49	0.26	0.08	32.37
Damaged – Zamierające	0.15	0.27	0.22	0.03	11.31
			Cu		
Healthy – Zdrowe	1.46	16.76	2.84	3.51	123.69
Damaged – Zamierające	1.07	3.51	2.06	0.65	31.74
			Fe		
Healthy – Zdrowe	6.39	13.44	8.45	1.92	22.74
Damaged – Zamierające	5.00	42.69	13.14	10.25	78.04
			Mn		
Healthy – Zdrowe	8.24	325.49	127.78	90.35	70.71
Damaged – Zamierające	9.72	392.65	152.87	120.48	78.81
			Pb		
Healthy – Zdrowe	0.11	2.01	0.44	0.42	94.75
Damaged – Zamierające	0.21	0.49	0.36	0.11	30.75
			Cd		
Healthy – Zdrowe	0.02	1.04	0.15	0.24	154.65
Damaged – Zamierające	0.02	0.19	0.10	0.05	50.23

SD – standard deviation, Vx – variability coefficient.
SD – odchylenie standardowe, Vx – współczynnik zmienności.

The content of manganese in the wood of healthy beeches was 8.24-325.49 mg/kg of dry mass, while in the wood of dying beeches it was 9.72-392.65 mg/kg of dry mass. The detected mean content of this element in beech wood (healthy trees – 128 mg/kg of dry mass; dying trees – 153 mg/kg of dry mass) was ca 4-fold higher than in the oak wood [Szczepkowski and Nicewicz 2008] of both the healthy and dying trees. Out of five sites at which concentrations of this element in the wood of dying trees were higher compared to healthy ones, the greatest, almost 3-fold difference in Mn concentrations between the examined trees occurred in the Czaplinek and Lądek Zdrój Forest Districts.

In the group of sites where Mn concentrations in the wood of healthy trees were higher than in the wood of dying ones, the greatest difference (1.5-fold) was noted at the Kańczuga site. The German studies also confirmed higher concentrations of manganese in the wood of stems of dying beeches (50-80-year-old) than of healthy beeches [Willems and Meisch 1991].

A comparison of the significance of differences in the concentrations of heavy metals in the wood of healthy and dying trees was performed. The values of this parameter for the majority of examined elements had no normal distribution (Shapiro-Wilk test). Therefore, a decision was taken to use the Mann-Whitney non-parametric test ($\alpha = 0.05$). For each of the examined elements no ground was found to reject a zero hypothesis of the lack of differences in element concentrations in the groups of healthy and dying beech trees.

CONCLUSIONS

The obtained results allow the conclusion that no significant differences were found in heavy metal concentrations in the wood of the beeches growing in the same environmental conditions i.e. in the same stands, but varying in healthiness level. A rising tendency was observed for some heavy metals, pointing to their higher concentrations in the wood of dying trees compared to healthy ones. Out of the nine examined sites, the content of Fe and Cd at six sites and of Al, Cu, Mn and Pb at five sites was found higher in the wood of dying trees than of healthy ones. The content of Cr at the majority of sites was slightly higher in the wood of healthy beeches compared to dying ones, which was in contrast to the results of the studies on oak wood [Szczepkowski and Nicewicz 2008]. On the basis of the obtained results, it can be suggested that the natural concentration level of chromium in beech wood does not exceed 0.3 mg/kg of dry mass. A relationship was found between the content of heavy metals in wood and the geographic origin of trees. Among the examined sites, the lowest total content of analysed elements was detected at the sites located in the northern (Wejherowo) and southern (Wetlina, Lądek Zdrój) regions of Poland. The content of aluminium was lower in beech wood compared to oak wood.

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ZAWARTOŚĆ METALI CIĘŻKICH W DREWNIE BUKÓW (*FAGUS SYLVATICA* L.) ZDROWYCH I ZAMIERAJĄCYCH

Streszczenie. Przeprowadzono badania ogólnej zawartości substancji mineralnych (popiołu) i metali ciężkich (Al, Cd, Cr, Cu, Fe, Mn, Pb) w drewnie buków zdrowych i zamierających z różnych rejonów Polski. Materiał do badań pochodził z dziewięciu nadleśnictw reprezentujących główne bazy surowca tego gatunku w Polsce. Z każdego drzewostanu, w którym obserwowano w przeszłości i obecnie objawy silnego osłabienia, zamierania i nadmiernego wydzielania się drzew, wycięto w tym samym wieku dwa drzewa: zdrowe i zamierające. Analizowano materiał pozyskany ze środkowej strefy, położonej między kambium a rdzeniem, przekroju poprzecznego kłody z odziomkowej części pni buków w wieku 80-145 lat. Udział substancji mineralnych w drewnie buków zdrowych i zamierających zawierał się w bardzo podobnych przedziałach wartości. Nie stwierdzono statystycznie istotnej różnicy dla każdego z badanych pierwiastków w ich zawartości w drewnie drzew zdrowych i zamierających. Zaobserwowano pewną zależność pomiędzy ilością metali ciężkich w drewnie a położeniem geograficznym.

Słowa kluczowe: metale ciężkie, popiół, buk zwyczajny, drewno bukowe, Polska, stan zdrowotny, witalność drzew, zamieranie lasu

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