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Heavy metals concentration in conventionally and organically grown vegetables

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SHORT COMMUNICATION

Abstract

Consumers' awareness and concerns regarding health and environmental issues associated with intensive and highly industrialised agriculture is the main cause of the constantly growing interest in organic farming. Most consumers believe that organically grown vegetables are healthier, more nutritious and of better quality. In the current study, samples of commonly used vegetable and soil were collected from organic and conventional farms. Using Atomic absorption spectroscopy, the plant samples were analysed and tested for concentration of heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn). A chemical analysis of collected samples showed that there are significant differences between vegetables cultivated in the two growing systems. Generally, conventionally grown vegetables tend to contain higher concentrations of some elements; however the results are not conclusive. It was also found that celery and parsley leaves have a tendency to assimilate more heavy metals compared to other vegetables.

Keywords: heavy metals, vegetables, organic farming, conventional farming

1. Introduction

Modern agriculture, particularly in the developed countries has reached a tremendous productivity level. It became possible due to an increased use of mineral fertilisers, pesticides and the general industrialisation of agriculture, but also because of new plant varieties that are better adapted and produce higher yields. Although the food production became easier and more efficient, serious environmental and health issues appeared as a consequence of intensive growing systems. The results of unsustainable food production lead to water-, soil- as well as food products contamination with nitrates, heavy metals, pesticides residues, eutrophication of fresh waters and cause changes in the lower layer of the atmosphere. Furthermore, there is a growing number of evidence showing that intensive agriculture significantly affects soil microbial communities which are crucial for many ecosystem services (Hafez and Theimann, 2003). Therefore, during the last decades, the consumer trust toward food products drastically decreased, also due to numerous scandals associated with food contamination with BSE, avian influenza, dioxin, pesticides and antibiotics residues, as well as heavy metals (D'Mello, 2003).

Agricultural soils can contain a number of heavy metals which concentration depends mainly on the geological parent material composition. The variation in heavy metals composition is usually associated with biological and geochemical cycles occurring in the soil. Certain of them are essential or beneficial to the plant because of their importance in growth and development; however, when the concentration reaches a specific threshold, they can become toxic. Anthropogenic activities such as agricultural practices, transport, industrial activities and waste disposal (Lund, 1990) can contribute to the total amount of these elements and significantly increase its content in the soils. Agricultural activities such as inorganic fertilisers, pesticides and manure application as well as sewage irrigation (Nan *et al.*, 2002) are known to be the sources of contaminants, therefore it is no surprise that agricultural soils are often characterised by higher level of these elements compare to untreated soils. It was confirmed that some fertilisers and pesticides contain various levels of heavy metals such as Cd and Cu (Kabata-Pendias and Pendias, 1992). Many of these substances are very persistent and do not undergo biodegradation processes (Adriano, 2001). Therefore, a continuous and heavy application of some agrochemicals and soil amendments can increase the accumulation of heavy metals in agricultural soils over time (Siamwalla, 1996). Moreover, heavy metals can be transformed, depending on the soil physicochemical properties and environmental conditions. They become readily available for the plants, get into the food chain and eventually accumulate in human bodies (Wei and Yang, 2010). Although some heavy metals are known for their bio-importance as trace elements, it is also known that they can be biotoxic and cause many undesired effects of great concern to human health (Duruibe *et al.,* 2007). It is particularly dangerous when a continuous exposure occur, even at very low doses.

The fear of food contaminants and general low quality and safety of conventional products are the most common reasons why people reach more frequently for organic foods. Subsequently, this has resulted in an increasing demand for this kind of products. Generally, organic farming is defined as growing systems which exclude the use of soluble minerals as fertilisers and synthetic pesticides (Trewavas, 2004). It is an agricultural system that assures higher quality food production but also positively affects environment and natural resources such as water, soil and biodiversity.

The goal of the current study was to investigate if there is any significant difference in the concentration of heavy metals such as Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn between some vegetables. In order to provide a comparison, plant and soil samples were collected from organically and conventionally managed farms. The crops selected for this study are commonly used in Eastern-European diet root vegetables.

2. Materials and methods

The following root vegetables were selected for the study: beet (*Beta vulgaris* L.), onion (*Allium cepa* L.), carrot (*Daucus carota* L.), parsley (*Petroselinum crispum*), leek (*Allium porrum* L.), celery (*Apium graveolens* L.) and potato (*Solanum tuberosum* L). The vegetables were collected in 2010 mid-autumn from two private farms; conventional (51°10’57”N 15°32’18”E) and organic (51°51’59”N 14°50’25”E) located in the western part of Poland. In the conventional farm, compound fertilisers (NPK) were frequently applied during the growing season, as well as nitrogenous, phosphorus and some organic fertilisers. On the other hand, in the organic production only compost and green manure were applied together with lime to increase the pH. Soils samples from both farms were collected at 15 cm depth. The collected plants and soil samples were transported to the laboratory in paper bags. Fresh soil samples were used for the determination of pH. The plants were rinsed with distilled water, cut into smaller pieces and dried at 80 °C for 24 h. When the plants were completely dry they were grinded in the laboratory grinder (M20, IKA® Works Inc., Wilmington, NC, USA). Soils samples were air-dried in the room temperature (21 °C), organic matter was removed and samples were homogenised using a mortar and pestle. Afterwards, soil samples were passed through a 2 mm sieve. Homogenised plant material and soil samples (500 mg of dry weight) were subsequently digested with 3 ml of concentrated nitric acid (68%, ultra-pure) and 2 ml of hydrogen peroxide (35%, pro analysis) until the evolution of nitrous oxide gas stopped and the digest became clear. After dilution to 50 ml, the plant and soil digests were analysed for Fe, Mn, Cu, Mg and Zn using Flame Atomic Absorption Spectroscopy, whereas, Cd, Pb, Ni, Co and Cr using Electrothermal Atomic Absorption Spectrometry with Graphite Furnace GF3000 (GBC Scientific Equipment, Hampshire, IL, USA), both with an AVANTA PM Atomic Absorption Spectrophotometer from GBC Scientific Equipment (GBC Scientific Equipment). All analyses were carried out in triplicate and the elements were measured against standards (Atomic Absorption Standard Solution, Sigma-Aldrich St. Louis, MO, USA). The results were calculated on a dry weight basis.

The obtained results were analysed using statistical methods. Student’s t-test was applied to evaluate the significance of the differences in the concentration of chemical elements between the vegetables of two growing systems. All statistical analysis were performed using the STATISTICA 9.1 software (TIBCO Software Inc., Palo Alto, CA, USA).

3. Results

The content of heavy metals detected in the plant tissues of organically and conventionally grown vegetables is presented in Table 1. The statistical analysis demonstrated significant differences in concentration of heavy metals (Cd, Co, Cr, Cu, Fe Ma, Ni and Zn) in some vegetables. However, no clear pattern in the elements’ content between the two systems was observed.

A significantly higher concentration of Cd was detected in leek, celery, carrot, potato and onion grown in the conventional farm compared to organic one. The highest concentration of this metal was found in celery compare to others vegetables, which was 0.528 and 1.08 mg/kg in the organic and conventional respectively. The content of this element in the remaining vegetables was between 0.049 and 0.170 mg/kg in the organically grown plant and from 0.049 to 0.243 mg/kg in conventionally. The concentration of Co in organic crops was between 0.020 and 0.130 mg/kg, while in conventional it was generally higher, from 0.016 mg/kg in the carrot to 0.218 mg/kg in the parsley

Table 1. Mean and standard deviation (SD) of heavy metals concentration (mg/kg) in the organically and conventionally grown vegetable.[1]

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Parsley (root)									
Organic	**0.123**	0.065	1.38	**3.85**	29.8	18.1	4.02	2.26	42.3
SD	**0.016**	0.039	0.842	**0.350**	14.9	0.577	0.414	1.51	19.0
Conventional	**0.049**	0.094	1.71	**7.18**	33.5	18.1	4.17	1.44	16.6
SD	**0.004**	0.032	0.455	**0.342**	4.95	0.577	2.02	0.725	1.51
t	**7.97**	-0.996	-0.601	**-11.7**	-0.399	0.000	-0.128	0.852	2.33
P	**0.001**	0.376	0.580	**0.000**	0.710	1.000	0.905	0.442	0.080
Beet									
Organic	0.049	**0.020**	1.28	**3.34**	**22.7**	25.1	4.35	1.12	**23.0**
SD	0.004	**0.014**	0.680	**0.254**	**4.27**	1.15	0.322	0.229	**1.56**
Conventional	0.099	**0.092**	2.17	**4.15**	**34.3**	24.8	4.25	1.70	**15.5**
SD	0.069	**0.002**	0.167	**0.084**	**4.10**	14.4	0.245	0.635	**1.15**
t	-1.23	**-7.86**	-2.20	**-5.26**	**-3.38**	0.040	0.41	-1.50	**6.66**
P	0.283	**0.001**	0.092	**0.006**	**0.028**	0.970	0.700	0.206	**0.003**
Parsley (leaves)									
Organic	0.125	0.107	1.96	7.43	**26.8**	45.1	4.60	2.14	**72.1**
SD	0.071	0.056	0.596	0.712	**15.2**	3.05	0.321	0.765	**3.57**
Conventional	0.091	0.218	5.54	11.9	**106**	56.8	6.41	2.20	**46.1**
SD	0.023	0.124	3.64	3.83	**33.6**	12.6	1.55	0.106	**13.5**
t	0.777	-1.41	-1.67	-1.99	**-3.74**	-1.55	-1.98	-0.156	**3.21**
P	0.480	0.231	0.168	0.116	**0.020**	0.196	0.119	0.884	**0.033**
Leek									
Organic	**0.096**	0.130	1.40	3.59	31.6	**17.1**	4.17	1.51	30.1
SD	**0.001**	0.042	0.685	0.329	5.65	**0.577**	0.550	0.732	1.41
Conventional	**0.169**	0.143	1.93	4.50	33.5	**21.8**	4.29	2.051	27.4
SD	**0.006**	0.047	0.051	0.467	21.2	**1.52**	0.263	0.373	1.02
t	**-20.2**	-0.357	-1.33	-2.74	-0.147	**-4.95**	-0.353	-1.13	2.67
P	**0.000**	0.739	0.252	0.052	0.890	**0.008**	0.742	0.319	0.055
Celery									
Organic	**0.528**	0.094	1.50	12.4	**41.2**	**29.5**	4.72	2.07	41.1
SD	**0.075**	0.067	0.302	0.548	**18.2**	**1.00**	0.130	0.969	2.28
Conventional	**1.08**	0.106	2.02	11.9	**72.4**	**62.8**	5.01	2.43	37.5
SD	**0.018**	0.017	0.170	0.154	**2.45**	**1.15**	0.374	0.249	5.88
t	**-12.4**	-0.285	-2.61	1.73	**-2.94**	**-37.7**	-1.29	-0.612	0.979
P	**0.000**	0.790	0.059	0.157	**0.042**	**0.000**	0.265	0.574	0.383
Carrot									
Organic	**0.170**	**0.089**	1.97	3.74	11.2	13.1	5.89	0.935	**24.9**
SD	**0.004**	**0.033**	0.803	0.400	4.32	4.61	3.04	0.143	**2.80**
Conventional	**0.243**	**0.016**	1.23	4.46	6.86	14.8	4.17	2.35	**13.8**
SD	**0.012**	**0.010**	0.795	0.221	0.503	0.577	0.512	0.988	**2.55**
t	**-9.77**	**3.66**	1.13	-2.73	1.72	-0.620	0.962	-2.46	**5.05**
P	**0.001**	**0.021**	0.320	0.052	0.160	0.569	0.390	0.069	**0.007**
Potato									
Organic	**0.056**	0.080	0.880	**5.39**	17.9	12.1	**3.87**	2.99	18.3
SD	**0.007**	0.011	0.237	**0.047**	3.00	1.52	**0.093**	0.374	1.99
Conventional	**0.073**	0.071	0.721	**2.46**	23.8	11.1	**4.14**	2.30	12.7
SD	**0.007**	0.052	0.253	**0.106**	9.80	0.577	**0.085**	1.25	3.84
t	**-3.06**	0.306	0.790	**43.7**	-0.997	1.06	**-3.79**	0.916	2.25
P	**0.037**	0.775	0.474	**0.000**	0.375	1.00	**0.019**	0.411	0.087

Table 1. Continued.

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Onion									
Organic	**0.163**	**0.052**	**1.26**	4.09	13.2	**15.8**	4.91	2.94	**25.1**
SD	**0.015**	**0.006**	**0.260**	0.813	5.31	**1.52**	0.616	1.71	**3.47**
Conventional	**0.216**	**0.087**	**0.392**	2.94	7.80	**18.8**	4.21	0.955	**12.3**
SD	**0.011**	**0.014**	**0.301**	0.300	1.44	**0.577**	0.172	0.754	**0.208**
t	**-5.04**	**-3.94**	**3.80**	2.28	1.69	**-3.18**	1.89	1.83	**6.39**
P	**0.007**	**0.017**	**0.019**	0.084	0.164	**0.033**	0.132	0.140	**0.003**

[1] Bold = significant different at $P<0.05$.

leaves. Significant differences were found only in the case of the conventional beet and onion which contained a higher level of this element than organically grown beet and onion, while opposite was true for carrot. Five of the tested vegetables contained similar concentration of Co, irrespectively of the cultivation system. There is not much differences in the concentration of Cr between the two systems. However, organic onion showed a significantly higher concentration of this element (1.26 mg/kg) compared to the one grown conventionally. The highest amount of Cu, which was 12.4 mg/kg for organic and 11.9 mg/kg for conventional, was reported in celery. The root of parsley and beet showed a statistically higher content of this element compared to organic ones. On the other hand, the Cu level was significantly lower in conventional potato than in the organic one. Generally, conventionally grown vegetables tended to have a higher concentration of Fe compared to organic ones; however, significantly higher values were recorded in the case of beet, parsley leaves and celery. The highest content of this metal was found in the celery which was 72.4 mg/kg. Similarly, as in the case of other elements, the highest content of Mn was recorded in celery and parsley leaves, which were 56.8 and 62.8 mg/kg in the conventional system. The differences were significant only in the case of leek, celery and onion, where conventionally grown vegetable showed a higher level of this element than the one cultivated in an organic way. There was not much variation in the amount of Ni between the vegetables from the two growing systems. Only in the organic potato, the amount of Ni, which was 3.87 mg/kg, was significantly lower than in conventional one. Although, the concentration of Pb tended to be higher in conventionally grown vegetables, no significant differences were found. Zn was the only element which showed generally higher concentration in organic crops. Significant differences were found in beet, parsley leaves, carrot and onion. Again, it was found that parsley leaves and celery accumulated the most of this element, which were 72.1 and 41.1 mg/kg in the case of organic crops.

Results of heavy metals concentration in organically and conventionally cultivated soils and pH are presented in Table 2. Higher concentrations of Co, Cr, Cu, Fe, Mn and Ni were reported in conventionally treated soil. Similar level between two systems was recorded in the case of Cd and Pb, while Zn concentration (65.5 mg/kg) was much higher in organic soil compare to conventional one (23.3 mg/kg). The pH of both soils were neutral, however pH of conventional soil was 0.3 lower than the organic one.

4. Discussion

Comparisons of heavy metals concentration in the organic and conventional crops are often complicated due to the interactive effects of farming practices, climatic conditions, soil quality, time of harvest, as well as proximity to the potential source of contamination.

Table 2. Average concentration of heavy metals (mg/kg) and pH in the organically and conventionally cultivated soils.

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	pH
Organic	0.39	0.58	2.93	10.75	3,060	314	0.97	20.7	65.5	7.05
Conventional	0.23	4.41	10.60	12.54	7,225	452	5.22	20.5	23.3	6.75
Allowed level*	4.00	–	150	–	–	–	100	100	–	–

* Following the Decree of the Minister for the Environment of 9 September 2002 (Ministry of environment, 2002).

The organic farm from which the plant samples were collected was located on sandy and sandy loam soils. On the other hand, the soil of the conventional farms were represented mainly by podsols made of clay loam. Therefore, the soil physicochemical characteristic might be one of the causes of the variation in heavy metals concentration in soil and vegetables. Kabata-Pendias and Pendias (1993) explain that in most of soils heavy metals are associated with loamy fraction. Lipiński (2000) analysed 60 soil samples and demonstrated that the light sandy soils accumulate less Cd than heavy clay soils which reflect concentration of this element in potatoes cultivated on this soils. Although in the case of Cd it was not confirmed in our results, it can be true for other elements. It can be assumed that the soil from the conventional farm might facilitate the accumulation and mobility of heavy metals in the soil and, in consequence, increase their concentration in the vegetables. The proximity of the farm to the potential sources of heavy metals should be taken under consideration. The organic farm was located far from the cities and public roads. Thus, the occurrence of potential anthropogenic contaminants was minimal. The conventional farm was located near a road and was surrounded by fields cultivated in a similar way, so some contamination could be associated with anthropogenic activities. There are numbers of studies demonstrating that plants in polluted environment can uptake and accumulate more of the occurring pollutants than the ones growing in uncontaminated sites. For example Stević *et al.* (2010) found that *Tanacetum vulgare* can assimilate more of some elements such as Fe, Si, Al and Ca, when grown in a contaminated site, compared to the one grown in an uncontaminated site. Therefore, one of the probable reasons why the conventionally cultivated soil and vegetables tend to have a higher level of some heavy metals is due to the anthropogenic activity. The major pollutants associated with transportation and increased car circulation are Pb, Cu, Zn and Cd. The presence of these elements can be treated as an indicator of transport contamination (Plak *et al.,* 2010).

It is commonly known that fertilisers, whether organic or mineral, importantly affect the chemical composition of the soil and in consequence the content of some elements in plant tissues. Moreover, it was demonstrated (Nowak *et al.,* 1996) that mineral fertilisers can significantly decrease the soil pH, particularly in the topsoil, which leads to the higher bioavailability of some elements (Gębski, 1998; Kabata-Pendias and Pendias, 1993). Some mineral fertilisers as P>Ca>K>N respectively, are known to have higher content of heavy metals (Sady and Smoleń, 2004). A particularly high level of these elements were found in P fertilisers, where they occur in the following order Cd<Cu<Pb<Ni<Zn (Gorlach and Gambuś, 1997). In the conventional farm mineral fertilisers (NPK) were used several times during the growing season. On the other hand, in the organic production only compost and green manure were applied. Therefore, it is believed that the reason of increased concentration of some heavy metals in conventional crops was due to the application of fertilisers.

Generally, our results demonstrate that the concentration of heavy metals in the soil corresponds to its level in plant tissues. Following Polish legislation (Decree of the Minister for the Environment of 9 September 2002; Ministry of Environment, 2002), none of the heavy metal exceeded the allowed level in the soil. The concentration of Cd in both conventional and organically cultivated soils was on a similar level, however differences were found in content of this element in the vegetables. Following Commission Regulation 1881/2006 (EC, 2006), the maximum level of Cd in fresh vegetables should not exceed 0.1 mg/kg. Although conventionally grown vegetables tended to have a higher level of this element, only celery exceeded the recommended level. The amount of Co in the conventional soil was more than seven times higher compared to the organic soil. The difference might be related to the physicochemical differences between the soils. It is known that light sandy soils tend to accumulate less of this element compared to heavy loamy soils (Kabata-Pendias and Pendias, 1993). Our results show that the level of this element is slightly higher in conventionally grown vegetables, however the differences are not of environmental or health importance. The concentration of Cr in crops varies between 0.02 to 1 mg/kg, with an increased level in vegetables harvested in urban gardens (Kabata-Pendias and Pendias, 1993). Our results showed an increased level of this element in vegetables. Although in the conventionally cultivated soil the level of this element was 3 times higher than in the organic one, it was far from reaching the allowed level of 150 mg/kg. Soil monitoring for the region where both farms were located showed that the average concentration of Cu in the soil was 13.4 mg/kg, which was above the level recorded in our study, in both organic and conventional system (Michna, 2001). To cover the physiological demand, the plants need little amounts of this element, usually not more than 2 mg/kg (Kabata-Pendias and Pendias, 1993). The previous study has shown that the concentration of Cu in vegetables varies, and the accumulation depends mostly on the type of vegetable rather than the cultivation system (Worthington, 2001). In our results, the highest concentration of Cu was found in organic (12.4 mg/kg) and conventional (11.9 mg/kg) celeries. Fe is one of the most mobile element and its average concentration in agricultural soils was reported to be 5,783 mg/kg (Właśniewski *et al.,* 2009), which is higher compared to our results for the organic soil but lower for the conventional one. In our results, 6 out of 8 analysed vegetables showed a higher concentration of Fe in conventional crops. It is in opposite to other authors (Williams, 2002; Worthington, 2001), who showed that organic crops tended to have a higher level of this element. Therefore, the results are quite ambiguous and it can be expected that the differences in the concentration of Fe depend on the type of farming systems as well as the type of vegetables. Again, the highest concentration of Fe among all vegetables was recorded in celeries. It was found that sandy soils are usually poorer in Mn compared to loams (Kabata-Pendias and Pendias, 1993), which can be confirmed with current studies, where the sandy soil of the organic farm showed lower concentration then the loamy soil of the conventional one. It is also reflected in the elevated level of this element in conventional vegetables, which is consistent with the findings of Warman and Havard (1996). Similarly to other elements, the highest level of Mn was found in celeries. Level of Ni in the conventionally cultivated soil was about five times higher than in the organic one. It was found that light sandy soils usually contain a lower level of this element compared to heavy clay soils (Kabata-Pendias and Pendias, 1993), which is confirmed in our results. Also, an increased level of Ni in the conventional soil might be the effect of the application of phosphate fertilisers which are known to contain trace amounts of this element. The concentration of Ni in the soil however did not reflect its concentration in the plant tissues. No significant differences between organic and conventional crops were found except for conventional potatoes where the concentration of Ni was higher. Pb concentrations in organic and conventional soils were on a similar level and did not exceed the allowed level of 100 mg/kg (Ministry of environment, 2002). In both cases it was also lower than the average for this region which in 2000 was 26.5 mg/kg. The arable crops can tolerate a relatively high concentration of Pb in the environment, however the accumulation of it in the edible part of plants might be a potential threat for human health (Michna, 2001). Following the Commission Regulation 1881/2006 (EC, 2006), the maximum level of this element in fresh vegetables should not exceed 0.1 mg/kg. It was found that in all the studied vegetables, the concentration of this element exceeded the recommended level. Generally, no significant differences between the two growing systems were found. Zn is a very mobile element that easily gets into the food chain. Average concentration of this element in the soils of south-east Poland in 2001 was 59.7 mg/kg, which was higher compared to the rest of the country. In current results, the level of Zn in the organic soil is more than two times higher than in the conventional one and higher than the average for this region. In consequence, an elevated level of this element was also recorded in the organic vegetables. Following the Commission Regulation 1881/2006 (EC, 2006) the concentration of Zn in fresh vegetables should not exceed 10 mg/kg. In both organic and conventional crops this level was exceeded.

5. Conclusions

Statistical analysis revealed significant differences in the concentration of some heavy metals in the studied vegetables grown in a conventional and organic way. Although 64% of conventionally grown vegetables showed a higher level of heavy metals, it is not possible to unambiguously state that organically grown vegetables are safer and contain less heavy metals. It was observed that certain vegetables such as celery and parsley leaves tend to accumulate higher amount of heavy metals. It is believed that the main reason of the variation in the heavy metals concentration between the two growing systems is due to the fertilisers' application, physicochemical differences of the soil, localisation of both farms as well as differences in bio-assimilation of some elements by the plants.

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