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Original Research

Influence of Row Covers on Heavy Metal Accumulation in Chinese Cabbage (*Brassica pekinensis* Rupr.)

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Abstract

The aim of our research was to show the impact of covering Chinese cabbage (*Brassica pekinensis* Rupr.), cultivated in Southern Poland in field conditions, with non-woven fleece, on the accumulation of chosen heavy metals in plants. The heavy metals (Cd, Pb, Cu, Mn, Zn) were analyzed in young plants immediately after removing the covers, and in the mature cabbages during harvest. The levels of trace elements in the external and the internal leaves of the cabbage head were also compared. After removing the covers, the lower levels of heavy metals were observed in covered Chinese cabbages in comparison to the control plants grown in an open field. In turn, during harvesting, much higher levels of heavy metals were found in plants covered with fleece, except Mn and Zn, where accumulation did not depend on the method of cultivation. The content of Cd, Pb, and Mn turned out to be much higher in the external leaves in comparison to the internal leaves. However, the internal leaves accumulated statistically much more copper and zinc in comparison to the external leaves of the plants.

Keywords: Chinese cabbage, covering, non-woven fleece, heavy metals

Introduction

In Poland, the typical method of spring cultivation of Chinese cabbage grown in a field is to use plastic covers, mainly non-woven fleece (PP). The main aim of covering is to improve the microclimate conditions in the immediate surroundings of the plants, especially air temperature and humidity [1-3]. The permeability of light or PAR radiation through non-woven fleece is defined at the level of 60-80% of what is registered outside [4], but its lower intensity under the covers is compensated by the more advanced development of the assimilation surface of the plants [5]. A more comfortable microclimate under the covers in comparison to an open field leads to acceleration of growing and harvesting of plants [6, 7], and to diversification in the content of nutritional or ballast elements [2, 8-11]. A valuation of these changes may be conducted based on comparison of chemical parameters of plants cultivated under the non-woven covers and those cultivated in the open field, immediately after the period of covering or during the following stages of production and harvesting. Undoubtedly, the differences in chemical compositions may occur after removal of the covers. The interesting issue is the influence of flat covers on further accumulation of trace elements and whether this influence may be permanent and observable also after further weeks of cultivation without covers, i.e. during harvest. Some of the reports show that plastic covers have no great influence on the later content of chosen chemical components within the edible parts of vegetable crops [5, 12].

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The economic activities of people influence a lot of nature conditions. Pollution of air, water, and soil is not neutral for horticultural production and results in crops of poorer quality. Abundant accumulation of harmful trace elements by cultivated plants creates a potential threat to consumer health. The main source of chemical elements for plants is the soil [13-16], but significant amounts of some of them, especially anthropogenic ones, may be accumulated from atmospheric dust and from rain passing through leaves [17-20]. This fact basically concerns vegetable crops that have a large surface area of leaves [21]. The level of accumulation of heavy metals also depends on the type of plant organ, whereas the distribution of metals also varies between particular parts of a specific organ [22-24]. In the production of vegetable crops, the use of plastic covers, which are a mechanical barrier for falling dust consisting of heavy metals, may lead to a lower accumulation of these trace elements in plants [25]. On the other hand, the higher intensity growth of covered plants implies a more intense absorption of nutrients, and there is the possibility that ballast trace elements are accumulated with nutrients in a non selective way [3, 26, 27]. The increased accumulation of heavy metals by covered plants may be observed, especially during cultivation on contaminated soils [8].

This research was conducted in a region that is intensively used by horticulture. The aim was to evaluate how the covering of Chinese cabbage with non-woven fleece (PP), and hence creating a better microclimate surrounding the plants, will influence changes in the chemical composition of this vegetable species, including heavy metals accumulation.

Experimental Procedures

In 2003-05 the experiment was placed on an experimental field in Kraków-Mydlniki (southern Poland), and the analytical part was completed in a laboratory of the Department of Vegetable and Medicinal Plants at the University of Agriculture in Kraków. The seedlings of Chinese cabbage (*Brassica pekinensis* Rupr.) were prepared in 96-cell trays of a VEFI A/S system in a greenhouse. Optiko F_1 (Bejo Zaden) cultivar was used in the experiment. The chemical composition of plants was evaluated, especially the level of accumulation of the chosen heavy metals according to the method of covering. Single-factor objects of the experiment were plants cultivated under the 17 g/m^2 non-woven fleece covers and in an open field (control). The experiment started in the third decade of April and was repeated four times. There were 60 plants on the single plot. The covering period lasted for between 15 to 26 days after planting the seedlings, depending on the year of the experiment and weather conditions. The harvests took place in the 1st half of June.

Immediately after the period of using the covers, the plant material was collected (from both experimental objects, in total – 32 samples) for laboratory analysis in order to evaluate the fresh and dry matter of Chinese cabbage and the level of the chosen heavy metals. The fresh matter was estimated by weighing the whole above-ground part of the plants. The dry matter was estimated using the drier method at 92-95ºC. In order to evaluate the level of heavy metals the following procedure was used. Samples of plants were washed in demineralized water, dried at 105ºC and fragmented by a colloidal mill (Retsch). The material (5 g) was burnt wet at 500ºC, and the ash gained in this way was dissolved in 20% solution HNO_3 [28]. The mineral elements, such as cadmium, lead, copper, manganese and zinc, were marked using the spectroscopy method of absorption ASA on a Spectr 20 AA produced by Varian.

After harvesting, the fresh and the dry matter and the level of heavy metals were also marked according to the methods quoted above. However, in the case of heavy metals the evaluations were made for whole Chinese cabbage heads and for leaves, depending on their position in a plant. In comparing the accumulation of trace elements in leaves, the leaves that were inside the cabbage head as well as those that were external were considered. In the statistical analysis the type of covers and the type of leaf position were considered in this case to be experimental factors.

A detailed evaluation of the soil in the experimental field was made. The soil was classified as a typical brown soil type, grey brown soil subtype of stabilized fluvial alluvium, and silt loam laying on medium-heavy soil underlain by very fine sandy soil. Based on samples of soil taken before and after the experiment, the content of heavy metals in the topsoil was evaluated. Moreover, soluble fractions were also marked [28].

The results are presented as a three-year-average of research. The data obtained in this way were evaluated based on an analysis of variance, using the STATISTICA (StatSoft Inc., USA) software package. The mean differences were estimated at a significance level $p < 0.05$ using Tukey's HSD test.

Results

Table 1 presents data concerning the fresh and dry matter of the above-ground part of Chinese cabbage just after the end of covering and during harvesting. The significant influence of covering on the fresh matter of plants was observed. The fresh matter of plants weighs 237.4 g per plant more after the covers have been removed and 332.6 g per plant more during harvests, in comparison to Chinese cabbage cultivated without covers. The total amount of the dry matter in covered Chinese cabbage was higher by 207.0% (after covering) or 16.1% (during harvests) in comparison to plants cultivated in the open field.

Tables 2 and 3 present the results of laboratory analysis concerning the level of chosen heavy metals in Chinese cabbage, at this point the covers were removed (rosette phase) and during harvesting (mature plants) for both objects, namely plants cultivated under the fleece and in the open field.

Table 1. Fresh and dry matter of Chinese cabbage directly after covering and during harvests.

Treatments	Fresh matter (g/plant)	Dry matter	
		% f.m.	g/plant
After covering			
Row cover	316.4±24.83 b	5.94±0.04 a	18.79±1.52 b
Open field	79.0±5.80 a	7.74±0.11 b	6.12±0.42 a
ANOVA	p < 0.001	p < 0.001	p < 0.001
During harvests			
Row cover	2047.4±139.39 b	4.19±0.09 a	85.79±5.58 b
Open field	1714.8±97.95 a	4.31±0.03 b	73.91±3.92 a
ANOVA	p < 0.01	p < 0.05	p < 0.05

Mean values within a column, followed by different lowercase-letter, are significantly different at $p < 0.05$ (Tukey's HSD test); ±SD – standard deviation

Immediately after the end of the covering period, significantly higher levels of cadmium and lead were observed in the Chinese cabbage cultivated in the open field (Table 2). The plants from that experimental object consisted of 0.02 mg/kg d.m. cadmium more than the plants covered with non-woven fleece. The difference in absolute values was minor, but it was statistically proven. Also, a higher level of lead accumulation in these plants was observed (on average 0.84 mg/kg d.m. more). An interesting change in the level of those heavy metals during harvesting, compared to the time when covers were removed, was observed. The highest levels of Cd and Pb were observed in cabbages covered earlier with non-woven fleece. Differences in comparison to Chinese cabbage cultivated in the open field were 0.08 and 1.09 mg/kg d.m., respectively.

In the young plants grown without covers the levels of manganese and zinc were also higher (Table 3). The level of accumulation of these trace elements was higher by 26.41 and 6.15 mg/kg d.m., respectively, compared to the

Table 2. Content of cadmium and lead in Chinese cabbage rosettes directly after covering and in the heads during harvests.

Treatments	Cd		Pb	
	mg/kg d.m.	mg/kg f.m.	mg/kg d.m.	mg/kg f.m.
After covering				
Row cover	1.13±0.01 a	0.076±0.003 a	8.05±0.09 a	0.556±0.002 a
Open field	1.15±0.01 b	0.100±0.001 b	8.89±0.31 b	0.790±0.018 b
ANOVA	p < 0.01	p < 0.001	p < 0.01	p < 0.001
During harvests				
Row cover	0.63±0.01 b	0.032±0.001 b	4.07±0.18 b	0.225±0.013 b
Open field	0.55±0.01 a	0.029±0.000 a	2.98±0.18 a	0.185±0.008 a
ANOVA	p < 0.001	p < 0.001	p < 0.001	p < 0.01

Mean values within a column followed by a different lowercase-letter are significantly different at $p < 0.05$ (Tukey's HSD test); ±SD – standard deviation

Table 3. Content of copper, manganese and zinc in Chinese cabbage rosettes directly after covering and in the heads during harvests.

Treatments	Cu		Mn		Zn	
	mg/kg d.m.	mg/kg f.m.	mg/kg d.m.	mg/kg f.m.	mg/kg d.m.	mg/kg f.m.
After covering						
Row cover	9.40±0.30 a	0.578±0.018 a	30.88±0.39 a	1.832±0.027 a	58.93±1.29 a	3.578±0.085 a
Open field	9.24±0.17 a	0.741±0.010 b	57.29±0.37 b	4.435±0.058 b	65.08±0.92 b	5.144±0.123 b
ANOVA	n.s.	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001
During harvests						
Row cover	11.84±0.10 b	0.508±0.011 b	16.50±0.54 a	0.691±0.038 a	67.17±0.50 a	2.882±0.066 a
Open field	11.08±0.05 a	0.488±0.004 a	16.63±0.25 a	0.716±0.012 a	67.27±1.54 a	2.956±0.077 a
ANOVA	p < 0.001	p < 0.05	n.s.	n.s.	n.s.	n.s.

Mean values within a column followed by different lowercase-letter are significantly different at $p < 0.05$ (Tukey's HSD test); ±SD – standard deviation

Table 4. Total content of heavy metals and their soluble fraction in the soil before and after experiment (mg/kg d.m.).

Concentrations	Cd	Pb	Cu	Mn	Zn
Total content					
Before experiment	1.02±0.00 a	43.69±0.05 b	13.08±0.06 b	528.75±0.42 b	145.70±0.15 b
After experiment	1.00±0.01 a	41.58±0.52 a	12.32±0.13 a	522.75±1.97 a	143.44±0.06 a
ANOVA	n.s.	p < 0.01	p < 0.001	p < 0.01	p < 0.001
Soluble fraction					
Before experiment	0.96±0.01 b	37.37±0.09 b	5.88±0.07 a	253.30±1.93 b	56.67±0.62 b
After experiment	0.88±0.02 a	35.78±0.28 a	5.74±0.03 a	238.78±2.08 a	54.74±0.46 a
ANOVA	p < 0.01	p < 0.001	p < 0.05	p < 0.01	p < 0.05

Mean values within a column followed by different lowercase-letter are significantly different at $p < 0.05$ (Tukey's HSD test); ±SD – standard deviation

plants covered with non-woven fleece. The content of copper, estimated with mg/kg d.m., was an exception. It was statistically similar in both experimental objects. However, the amount of that trace element, considered per fresh matter, was also higher for the non-covered plants. During harvesting the increase in the level of copper was observed in Chinese cabbage covered with non-woven fleece (on average by 0.76 mg/kg d.m.). The accumulation of manganese and zinc in mature Chinese cabbage did not depend on the method of cultivation.

The data connected to accumulation of heavy metals in the external and internal leaves of Chinese cabbage are presented in Fig. 1. The level of cadmium, lead, and manganese turned out to be far less in the internal leaves in comparison to the external ones. It was the other way around when considering copper and zinc.

The internal leaves of Chinese cabbage covered and not covered consisted of similar levels of cadmium. In the external leaves the higher level of cadmium was observed in plants cultivated under non-woven fleece than in the open field. As was already mentioned, the level of lead turned out to be much higher in the external leaves of Chinese cabbage in comparison to the internal ones. The influence of covers, in that case, turned out to be statistically insignificant. However, a slight tendency to accumulate a higher level of that trace element was observed, when the plants were cultivated under the non-woven fleece. In the case of copper, manganese, and zinc, all values turned out to be significantly different. The higher contents of Cu and Zn were observed in the internal leaves, especially in the case of the uncovered Chinese cabbages, in comparison to plants covered with the non-woven fleece. A similar set of differences between experimental objects occurred in the case of the external leaves. The level of Mn depended on both, namely the position of the leaves and used covers. The lowest level of manganese was observed in the internal leaves, especially in plants covered with non-woven fleece. In the case of the external leaves, the covering resulted in a lower accumulation of Mn in comparison to leaves of the control plants.

The total content of heavy metals in the soil before and after the field experiment, are presented in Table 4. The level of cadmium was statistically similar during the whole vegetation period. In the case of other trace elements, a significantly lower level was observed in the soil after the experiment. The changes in comparison to the time before planting the Chinese cabbages were as follows, and respectively for lead, copper, manganese, and zinc: 2.11, 0.76, 6.00, and 2.26 mg/kg d.m.

The soluble fraction of Cd and Cu indicated a different dependency on the time the soil samples were collected (Table 4). The amount of cadmium was significantly lower (on average by 0.08 mg/kg d.m.) after finishing the production cycle of Chinese cabbage, while copper remained at the same level. In turn, similarly to the total level, significantly lower levels of soluble Pb, Mn, and Zn were observed after the vegetation period, and the differences between these values and those observed before planting were: 1.59, 14.52, and 1.93 mg/kg d.m., respectively.

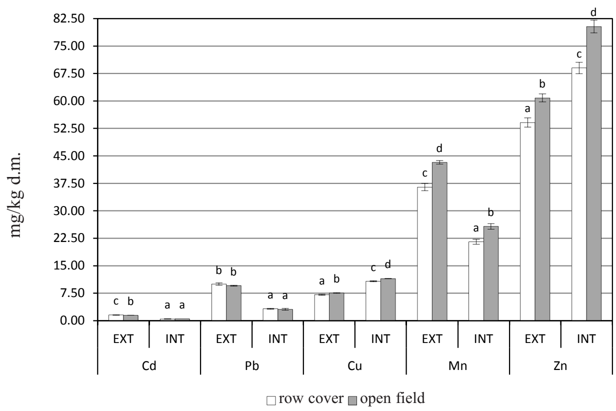

Fig. 1. Content of selected heavy metals in external (EXT) and internal (INT) leaves of Chinese cabbage during harvest.
Mean values of particular heavy metals followed by a different lowercase-letter are significantly different at $p < 0.05$ (Tukey's HSD test); error bars represent standard deviations.

Discussion

The improvement of the microclimate in the immediate environs of vegetable plants covered with non-woven fleece in spring is, undoubtedly, a factor that causes faster growing and leads to a greater biomass than in cultivation without covers. This kind of dependence was noted in the present experiment and proved by results gained by Otto et al. [29], who during production of Chinese cabbage with non-woven fleece covers observed a faster increase of fresh matter of the plant in its vegetation period and during harvest than during cultivation without covers. Similarly, Pulgar et al. [30] and Moreno et al. [10, 11] found out that the total fresh matter of the above-ground parts of Chinese cabbage covered with non-woven fleece was higher than of those not covered.

The total dry matter was higher in comparison to the plants without covers, because of the faster growth of covered plants. Pulgar et al. [30] clearly observed that the dry matter in the Chinese cabbage covered with non-woven fleece was higher than the mass gained from plants cultivated in the open field. Similar results also were published by Moreno et al. [10, 11] and Hernández et al. [31]. The effect of the plastic covers on the amount of dry matter does not always indicate the above-described relationships [2, 5]. The authors concluded that before becoming mature, the Chinese cabbage cultivated under the non-woven fleece was characterized by the higher total dry matter rather than the plants produced without covers, although there were no significant differences during harvesting. Felczyński [12] noted that covering Chinese cabbage with non-woven fleece had no significant influence on the content of the dry matter in the mature heads, and the level of the dry matter was statistically similar to that of plants cultivated in an open field.

Literature data concerning accumulation of heavy metals in the plants produced under the covers and in the open field are sometimes different. The increase in the content of heavy metals as a result of cultivating plants under covers was observed by Curzydło [32] for white cabbage and cauliflower, and by Libik and Siwek [25] for lettuce. The levels of cobalt and nickel in the Chinese cabbage were higher in the plants covered with non-woven fleece in comparison to the control plants (not covered) [9]. More cadmium, copper, and zinc in the covered Chinese cabbage in comparison to the open field were also observed by Moreno et al. [10], but the level of lead was lower. In other reports Moreno et al. [3, 8] observed that the contents of lead and chromium in the Chinese cabbage cultivated under the non-woven fleece were lower in comparison to the non-covered control. On the other hand, covered plants accumulated the highest amount of cadmium. In turn Hernández et al. [31] marked higher levels of copper and iron in the control Chinese cabbage (produced without covers), in comparison to those covered with the non-woven fleece. According to them, the influence of the covers on accumulation of zinc and manganese turned out to be irrelevant.

In the present experiment the highest content of heavy metals was observed in mature heads of covered Chinese cabbage. Manganese and zinc turned out to be exceptions, as their levels were similar in both covered and uncovered plants. The data gathered just after removing the covers, which was a few weeks before harvesting, are interesting. There the levels of heavy metals in the plants were higher in the control rosettes of Chinese cabbage cultivated in the open field. Thus, lower contents of the examined trace elements were observed in the covered plants.

The distribution of heavy metals in the organs of the plants is different depending on the mobility of these elements in the plants [13]. The results of that experiment showed that there were significant differences in the mineral composition between the internal and external leaves of Chinese cabbage. According to Zhenxian et al. [22], the highest accumulation of manganese was observed in the external leaves of Chinese cabbage, and the level of Zn in the internal leaves surpassed that in the external leaves. In the case of these trace elements, the analogical tendency of accumulation, depending on the position of leaves in the plant, was observed in the experiment. Also Lee et al. [33] noted the higher content of manganese in the external leaves of this species in comparison to the internal ones. Manganese is an element of important physiological function, mainly in photosynthesis. Deficiency of Mn is observed firstly in younger leaves [13]. In the present experiment photosynthetically active outer leaves of Chinese cabbage contained more of this element because of its accumulation in chloroplasts. Zhenxian et al. [22] described that the accumulation of copper was similar in both types of leaves, pointing to the relatively similar distribution of that trace element in Chinese cabbage. It was not confirmed by the results of the present experiment, where significantly higher levels of Cu were found in the internal leaves of the plants. The reason is high variability of copper content in plants, which is affected by developmental stage, tissues and organs, and even weather conditions [13].

One more interesting result is the fact that higher levels of Cd and Pb were found in the older, external leaves of Chinese cabbage in comparison to the younger leaves inside the head. Das et al. [34] concluded that cadmium concentration was higher in older leaves than in younger leaves of lettuce and spinach, as a result of higher amounts of Cd-binding peptides in older tissues. Also, Sękara et al. [24] found more cadmium and lead in outer leaves of white cabbage as compared to inner leaves of a head. In the case of lead it could be explained by the poor mobility of this element in the plant's organs.

It was noted that the level of cadmium in Chinese cabbage (in rosettes and mature heads) did not exceed the maximum values (0.2 mg/kg fresh matter) permitted by European Commission Regulation (EC) No. 466/2001 [35]. Concentration of lead in harvested Chinese cabbage heads, although relatively high, was also acceptable. However, in immature rosettes, directly after removal of the non-woven fleece, the accumulation of lead in the plants was higher than that provided for by the EC Regulation (0.3 mg/kg fresh matter).

Conclusions

1. Covering Chinese cabbage with non-woven fleece caused an increase of fresh and dry matter content, determined directly after removing covers and in a stage of harvest maturity.
2. Plant covering decreased the cadmium, lead, manganese and zinc content in Chinese cabbage, analyzed just after removing covers, but increased the levels of Cd, Pb, and Cu in heads in the harvest maturity stage.
3. The contents of cadmium, lead, and manganese were significantly higher in the external leaves of Chinese cabbage in comparison to the internal leaves. The levels of copper and zinc turned out to be highest in the younger leaves.

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