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Selenium compounds in selenium-enriched cabbage*

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Abstract: For the study, cabbage (*Brassica oleracea* var. *capitata* L.) and red cabbage (*Brassica oleracea* var. *capitata* L. f. rubra) were treated with Na selenate. Cabbage was foliarly sprayed twice with 20 mg Se(VI) L^{-1}, while red cabbage was fertilized twice with 0.5 mg Se(VI) L^{-1}. Despite the high dose of Se, no toxic effects were observed on cabbage plants. The total Se concentration in cabbage leaves was 4.80 ± 0.25 μg Se g^{-1} (DM) and in red cabbage 0.96 ± 0.04 μg Se g^{-1} (DM). Soluble Se compounds were extracted from parts of cabbage with protease XIV, resulting in 49 % of soluble Se from roots, 59 % from leaves, and 65 % from stems. In red cabbage, the corresponding figures were 28 % of soluble Se in roots, 31 % in stems, and 43 % in leaves. Se species were determined in the enzymatic extracts using ion exchange high-performance liquid chromatography-inductively coupled plasma-mass spectrometry (HPLC-ICP-MS). The main Se species found in all parts of cabbage and red cabbage was selenomethionine (SeMet), which in roots represented 94 and 55 % of the soluble Se content in cabbage and red cabbage, respectively. In stems and leaves of cabbage, SeMet represented only 23 % of the soluble Se content. In stems of red cabbage SeMet represented 80 % and in leaves 41 % of the soluble Se content. We observed that traces of Se(VI) were present in upper parts of both plants.

Keywords: cabbage; high-performance liquid chromatography-inductively coupled plasma-mass spectrometry (HPLC-ICP-MS); selenomethionine (SeMet); Se species.

INTRODUCTION

Selenium (Se) is an essential nutrient for humans and animals. It is required for the functioning of some enzymes, such as glutathione peroxidase and thioredoxin reductase. However, this element can also be toxic in larger doses [1]. The daily intake of Se depends on its concentration levels in food and on the amount of food consumed. The recommended daily intake is 55 μg Se per day [2]. Deficiency of Se can weaken the immune system and cause hypothyroidism and heart disease [3]. Kahakachchi and co-workers [4] reported that Se has cancer-chemopreventive properties for humans.

In areas that are deficient in Se, Se-enriched plants could be used to supplement the human diet. The most often used techniques for enrichment are Se addition to soil [5], foliar treatment of plants with Se solution [6], soaking seeds in Se solution before sowing [7], and hydroponic [8] or aeroponic [9] cultivation in a nutrient solution containing Se.

Cabbage is an important vegetable grown worldwide, also commonly used in Slovenia. It is a member of the *Brassicaceae* family, which includes accumulator plant *Stanleya pinnata*, broccoli,

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cauliflower, and kale, and is cultivated for its large leafy head. The protective action of cruciferous vegetables has been attributed to the presence of antioxidant phytochemicals, particularly antioxidant vitamins, including ascorbic acid, α-tocopherol, and β-carotene [10]. Cabbage contains indole-3-carbinole (I3C), sulforaphane, and indoles. These compounds help activate and stabilize the body's antioxidant and detoxification mechanisms. The majority of antioxidant activity can be attributed to phenolic compounds such as flavonoids, isoflavones, flavones, anthocyanins, catechins, and isocatechins [11]. Red cabbage has a high content of anthocyanins with antioxidant activity [12], anticancer properties [13], neuroprotective effects [14], and antimicrobial activity [15], all of which makes it highly valued in human nutrition. Se-enriched cabbage is a good way to fulfil the daily Se requirement, but it is necessary to know in which form Se is present in the plant to determine its toxicity and nutritional importance.

The purpose of this work was to study Se distribution and to identify the Se species in different parts of Se-enriched cabbage and red cabbage after plants were exposed to foliar treatment or soil fertilization.

MATERIALS AND METHODS

Samples

Cabbage (*Brassica oleracea* var. *capitata* L., cv. Pandion) and red cabbage (*Brassica oleracea* var. *capitata* L. f. rubra, cv. Erfurtsko rano) plants were grown outdoors in Ljubljana, Slovenia (320 m above sea level, 46°35' N, 14°55' E), in Se-poor soil. Plants were randomly selected and then arranged in three blocks, where each block contained three basic plots, and each basic plot contained nine plants. Plants emerged on 20 April 2009 and were treated with Na selenate. To avoid contamination a pause between different treatments was made. When four leaves had grown, cabbage was foliarly sprayed twice with 20 mg Se(VI) L^{-1}, while red cabbage was fertilized twice with 0.5 mg Se(VI) L^{-1}.

After two months of an experiment, three plants from each basic plot were collected at the mature stage and separated into stems, leaves, and roots for further analysis. Roots were washed with water and cut into pieces. Samples were lyophilized at –44 °C and 0.050 mbar (ALPHA 1-4, Osterode am Herz, Germany), and milled (Fritsch, Pulverisette 7, Idar-Oberstein, Germany; 2600 rpm, 6 min).

Reagents and standards

The following chemicals were used: 96 % H_2SO_4 (Merck, Suprapur), 65 % HNO_3 (Merck, Suprapur), 30 % HCl (Merck, Suprapur), 36 % HCl (Merck, p.a.), 30 % H_2O_2 (Merck, p.a.), V_2O_5 (Merck, p.a.), NaOH (Merck, puriss p.a.), $NaBH_4$ (Fluka, Purum p.a.), $(NH_4)_2HPO_4$ (Fluka Chemie, puriss p.a.), pyridine (Fluka Chemie, puriss p.a.), diammoniumhydrogen citrate (Fluka Chemie, puriss p.a.), citric acid (Fluka Chemie, puriss p.a.), MeOH (Primar, Fischer Scientific U.K., trace analysis grade), and protease XIV from *Streptomyces griseus* (type XIV: bacterial, 4.4 units/mg of solid; Sigma-Aldrich).

For preparation of Se solutions, Na_2SeO_3 [Se(IV), Sigma-Aldrich, >98 %], Na_2SeO_4 [Se(VI), Sigma-Aldrich, SigmaUltra], selenomethionine (SeMet, Fluka Chemie, >99 %), selenocystine ($SeCys_2$, Fluka Chemie, >98 %), and selenomethylselenocysteine (SeMeSeCys, Fluka Chemie, >98 %) were used. Stock solutions of Se species containing about 1 mg of Se g^{-1} in water were prepared and kept at 4 °C. Daily working solutions containing 100 ng g^{-1} of each compound were prepared by dilution with ultrapure water (Milli Q, Millipore Corporation, Bedford, MA).

Determination of Se

To 0.200 g of homogenized and lyophilized sample, 1.5 mL HNO_3 and 0.5 mL H_2SO_4 were added and heated for 24 h at 80 °C in a closed vessel. The temperature was then increased to 130 °C and main-

tained there for 60 min. Then H_2O_2 and 0.1 mL 40 % HF were added to the cooled solution. After heating and cooling the samples again, 0.1 mL of V_2O_5 in H_2SO_4 was added. Se(VI) was reduced to Se(IV) by the addition of concentrated HCl and heating at 90 °C. The solution was diluted before determining the Se content, which was carried out by hydride generation atomic fluorescence spectrometry [16]. Working standard solutions of Se(IV) were prepared weekly by dilution of a standard stock solution with 0.5 M HCl [17]. Each sample was analyzed at least in duplicate. The method is described in detail by Smrkolj and Stibilj [16]. The accuracy of the method was checked with the certified reference material Spinach Leaves NIST 1570a, and good agreement was obtained between the analyzed, 113 ± 4 ng Se g^{-1} and certified, 117 ± 9 ng Se g^{-1} values.

Extraction and speciation

Samples were extracted in duplicate as described by Mazej et al. [9]. Water (8 mL) containing 60 mg of protease XIV was added to 0.6 g of sample and stirred at 200 rpm for 24 h at 37 °C. Extract was centrifuged at 11 000 rpm for 60 min at 4 °C (5804R, Eppendorf). The supernatant was filtered through 0.45 and 0.22 µm Millex GV filters (Millipore Corporation) and subjected to Se speciation analysis by high-performance liquid chromatography-inductively coupled plasma-mass spectrometry (HPLC-ICP-MS). Supernatants and sediments were stored at –20 °C until analysis. Se in sediments was determined as described in the paragraph "Determination of Se".

Se species in supernatants were determined using an ion-exchange HPLC system (Agilent 1100, Waldbronn, Germany) coupled to ICP-MS (Agilent 7500ce, Tokyo, Japan). For soluble Se species determination, a Hamilton PRP-X 100 anion-exchange column (4.1 mm × 250 mm × 10 µm) and a Zorbax 300-SCX cation-exchange column (4.6 mm × 250 mm × 5 µm) were used. Citrate buffer (3 and 10 mM) in 2 % MeOH (pH 4.8) was used as the mobile phase for anion-exchange chromatography, and a 3 mM pyridine solution in 2 % MeOH (pH 2.1) was used as eluent for cation-exchange chromatography. The flow rate was 0.5 mL min^{-1} and the volume of the sample injected was 50 µL. The method and operating conditions (Table 1) were described in detail elsewhere [17]. Limits of detection for SeMet and SeMeSeCys were 0.9 ng g^{-1}, for $SeCys_2$ 0.2 ng g^{-1}, for Se(IV) 1.1 ng g^{-1} and for Se(VI) 0.1 ng g^{-1} [17]. The standard solution, which contained five Se compounds, was prepared in enzymatic extracts of control group. The identification of Se compounds was confirmed with standard addition method.

There is no reference material for Se speciation with a matrix similar to that of our samples. We therefore used Durum Wheat Flour NIST RM 8436, which has a literature value for SeMet [18]. Good agreement was obtained between the found (805 ± 55 ng g^{-1}) and literature (712 ± 72 ng g^{-1}) values.

Table 1 Operating conditions for determinations by HPLC-ICP-MS.

Parameter	Value
Nebulizer	Micro Mist
Plasma	
RF power (W)	1500
outer gas flow rate (L/min)	15.0
carrier gas flow rate (L/min)	0.80
make-up gas flow rate (L/min)	0.17
Octopole reaction cell	
H_2 gas flow rate (ml/min)	4.0
Measuring parameters	
m/*z* monitored	^{77}Se, ^{78}Se
integration time (s)	0.3

RESULTS AND DISCUSSION

During plant growth no toxic symptoms such as drying, leaf necrosis, or plant death were noticed. Se application did not affect the weight or mass of the plants [19]. Plants were able to absorb Se (Table 2), which is in line with other studies [19]. It is well known that plants from the *Brassicaceae* family are able to accumulate large amounts of Se [20,21]. It is assumed this is due to the high levels of sulfur (S) in the plants, whereby nonspecific binding of Se instead of S occurs [22].

Table 2 Se concentration, soluble and insoluble Se in cabbage, and red cabbage plants treated with selenate.

Samples	Treatment	Part of the plant	μg Se g^{-1} (DM)		
			Se in sample[a]	Insoluble Se	Soluble Se (% of soluble Se; mass balance %)
Cabbage	Foliar spraying 20 mg Se L^{-1}	Roots	5.51 ± 0.84	2.94 ± 0.97	2.68 ± 0.99 (49; 102)
		Stems	5.45 ± 0.87	1.69 ± 0.52	3.54 ± 0.46 (65; 96)
		Leaves	4.77 ± 0.25	1.99 ± 0.87	2.80 ± 1.66 (59; 100)
Red cabbage	Fertilization 0.5 mg Se L^{-1}	Roots	1.19 ± 0.31	0.37 ± 0.17	0.33 ± 0.08 (28; 59)
		Stems	0.81 ± 0.01	0.27 ± 0.08	0.25 ± 0.13 (31; 64)
		Leaves	0.96 ± 0.04	0.47 ± 0.17	0.41 ± 0.18 (43; 92)

*Means ± SD (n = 9). Each sample was measured in a duplicate.
[a]These data were published in Mechora et al. [19] and Mechora et al., submitted.

The concentrations of Se in cabbage plants foliarly sprayed twice with 20 mg Se(VI) L^{-1} were in the range from 4.77 μg Se g^{-1} in leaves to 5.51 μg Se g^{-1} (DM) in roots (Table 2). It was shown that foliarly sprayed Se was transported from leaves to roots. In radish sprouts treated with 10 mg Se L^{-1} [7] and in *Stanleya pinnata* [23], the concentration of Se was 20.8 and 534 μg Se g^{-1}, respectively (Table 3).

Table 3 Se species found in leaves and sprouts of Se-enriched plants from *Brassicaceae* family.

Species	Treatment	Se content (μg g^{-1})	Se species (% of total Se)	Ref.
Indian mustard	1.97 mg L^{-1} Se(IV) hydroponically	9.4	SeMeSeCys, SeMet	[25]
Radish	1 mg Se L^{-1} Se(VI) hydroponically	120	$SeCys_2$ (8), SeMeSeCys (2), SeMet (4), Se(VI) (78)	[26]
Broccoli	1 mg Se L^{-1} Se(IV) hydroponically	27	SeMet (23), SeMeSeCys (13), Se(IV) (5)	[8]
Chinese cabbage sprouts	10 mg L^{-1} Se(IV) soaking seeds	6.6	Se(IV) (6), SeMeSeCys (91)	[7]
Broccoli sprouts		32.1	Se(IV) (2), SeMeSeCys (94)	
Radish sprouts	10 mg L^{-1} Se(VI) soaking seeds	20.8	SeMeSeCys (91.5), SeMet (8.5)	
Cabbage*	10, 20 mg m^2 Se(VI) foliar spray	11.9	Se(IV) (3), Se(VI) (13), SeCys (1)	[27]
Radish*		37.1	Se(IV) (>1), Se(VI) (3)	

(*continues on next page*)

Table 3 (*Continued*).

Species	Treatment	Se content (μg g^{-1})	Se species (% of total Se)	Ref.
Cabbage*	$H_2{}^{75}SeO_3$, conc. not reported fertilization	Not reported	**SeMeSeMet (3), SeMeSeCys (22), $SeHoCys_2$ (9), SeMet (15)	[28]
Indian mustard	1 mg L^{-1} Se(VI) hydroponically	1230	Se(VI) (91)	[29]
S. pinnata	474 μg L^{-1} Se(VI) seed treatment	534	SeMet + SeMeSeCys + $SeCys_2$ (80), Se(VI) (13)	[23]
Cabbage	20 mg L^{-1} Se(VI) foliar spray	4.8	SeMet (15), Se(IV) (3), Se(VI) (3)	Present study
Red cabbage	0.5 mg L^{-1} Se(VI) fertilization	1	SeMet (19), Se(IV) (5), Se(VI) (3)	

*Extraction with methanol-water.
**Regarding to activity of ^{75}Se in extracts.

Red cabbage readily absorbed Se that was applied, which was transported from roots to leaves. The addition of 0.5 mg Se(VI) L^{-1} to soil resulted in Se concentrations of red cabbage ranging from 0.81 to 1.19 μg Se g^{-1} (Table 2). On the contrary, in the experiment of Hamilton [24], cabbage fertilized with 3 mg Se kg^{-1} contained 160 μg Se g^{-1}, which is a much higher level of Se than found in our experiments.

To determine Se species, it is necessary to have them in soluble form. For this purpose we used the nonspecific enzyme protease XIV to release Se compounds in soluble forms. The mass balance for Se-enriched cabbage was around 100 % (Table 2). The mass balance for Se-enriched red cabbage was lower for roots and stems, around 62 % (Table 2). The roots and stems of red cabbage were hard to grind, and consequently the samples were not homogeneous. For this reason, the standard deviations of Se concentration were high. For Se-enriched broccoli the mass balance was between 70–100 % [30], and they suspected that there were losses of Se due to volatilization.

In cabbage, 60 % of Se was found in a soluble form (Table 2). In *S. pinnata*, soluble Se accounted for 60–70% of total Se [23], in chicory 64 % [9], and in potato 70 % [17], regardless of the way of Se(VI) addition. In red cabbage, there was only around 34 % of soluble Se (Table 2). It is shown that cabbage, treated with a higher dose of Se, could not transfer Se(VI) to insoluble organic form. In all parts of plants species much insoluble Se was found, which could be some kind of detoxification mechanism. Vogrinčič et al. [31] gave an explanation for the low solubility of Se in buckwheat leaves and stems, which could be the consequence of Se binding to phenolic or polyphenolic substances.

In the speciation study, around 55 % of total Se in cabbage roots and 30 % in stems and leaves were identified. In all parts of red cabbage, around 30 % were identified relative to total Se in the sample (Table 4). Se species were calculated based on results obtained by anion-exchange chromatography, except for unknown species W, which was calculated based on results obtained by cation-exchange chromatography (see notes to Table 4). Hamilton [28] reported that only 8 % of total Se in cabbage remained undetermined. Slekovec and Goesler [27] reported that 80 % of total Se in cabbage remained undetermined, which is higher than in our study, but they used only methanol-water extraction.

In the roots of cabbage plants, we identified practically all the soluble Se, but in stems and leaves only 45 % (Table 4). In red cabbage, roots and leaves 79 % of soluble Se species were identified, while in stems 93 % (Table 4). In beans, foliarly treated with 10 mg Se(VI) L^{-1}, 80 % of soluble Se was identified [6] and in chicory treated with 7 mg Se(VI) L^{-1} 90 % [9].

Table 4 Selenium species in cabbage and red cabbage treated with selenate.

Samples/ treatment	Part	ng Se g^{-1} of sample										
		Tot Se[a]	SeVI	SeIV	SeMeSeCys	U[b]	X[c]	Y[d]	W[e]	SeMet[f]	%SeMet according to soluble Se	%SeMet according to total Se
Cabbage,	Roots	5510 ± 840	tr	tr	67 ± 6	tr	38 ± 7	93 ± 35	tr	2520 ± 800	94	46
foliar spraying	Stems	5450 ± 8	702 ± 65	tr		91 ± 15		tr	118 ± 35	820 ± 290	23	15
20 mg Se L^{-1}	Leaves	4770 ± 246	146 ± 56	136 ± 47		140 ± 56	37 ± 6		tr	630 ± 290	23	13
Red cabbage,	Roots	1190 ± 308	tr	tr	tr	tr	tr	tr	tr	180 ± 60	55	15
fertilization	Stems	810 ± 2	tr			tr		tr	tr	200 ± 80	80	25
0.5 mg Se L^{-1}	Leaves	960 ± 40	34 ± 10	51 ± 15		32 ± 8			tr	170 ± 50	41	18

The sample was analyzed in duplicate. Tr = traces. Results are given as the average of 18 measurements ± SD (n = 9).

[a]These data were published elsewhere [19, Mechora et al., submitted].

[b]Unknown Se species with the same retention time as $SeCys_2$ (4.9 min), obtained on Hamilton PRP-X 100, estimated as Se in $SeCys_2$.

[c]Unknown Se species with retention time of 13.5 min, obtained on Hamilton PRP-X 100, estimated as Se in SeMet.

[d]Unknown Se species with retention time of 15.2 min, obtained on Hamilton PRP-X 100, estimated as Se in SeMet.

[e]Unknown Se species with retention time of 8.0 min, obtained on Zorbax 300-SCX, estimated as SeMeSeCys.

[f]Se as SeMet.

The most prevalent soluble Se species was SeMet (Table 4). The larger amounts were found in roots of both species. SeMet was confirmed by the standard addition method. The same results were found in upper parts of rice and barley [7]. In roots of red cabbage and cabbage, SeMet represented 15 and 46 % of total Se, respectively. In the roots of broccoli, the content of SeMet was 6.1 μg Se g^{-1} (23 %) and it was the major Se species [8]. SeMet in wheat grain represented 85 % of all Se species detected [32]. In contrast, in potato tubers only 30 % of Se was in the form of SeMet [17]. Lentils stems contained 35 μg Se g^{-1} (10 %) in the form of SeMet [33] and in chicory leaves, fertilized for 41 days to 7 mg Se L^{-1}, 40 μg Se g^{-1} (8 %) [9], which is a larger amount than in our plants (Table 4).

In cabbage, *B. juncea*, and *S. pinnata*, the most prevalent Se species were SeMet and SeMeSeCys [23,25,28] (Table 3). We detected SeMeSeCys only in the roots of both species (Table 4). In studies where selenite was used, it was reported that SeMeSeCys is present in the *Brassicaceae* family in large amounts [8,25]. In the studies of Montes-Bayon et al. [25] and Pedrero et al. [26] a hydroponic solution was used and the plants were exposed to Se for a longer period than in our study. Cabbage and red cabbage plants were treated in the beginning of the experiment, and there was time to metabolize Se(VI) to SeMet and other organic forms by harvest time. There are reports that below a concentration of 333 μg Se g^{-1} Se is incorporated mainly as γ-Glu-SeMeSeCys and SeMet, but above this value it is converted to SeMeSeCys [34]. In plants from the *Brassicaceae* family SeMeSeCys was found [7,8,23,25,26,28], while we did not detect SeMeSeCys in above-ground parts of cabbage and red cabbage (Tables 3 and 4).

We also identified traces of Se(IV) and Se(VI) (Table 4). Se(VI) was the most obvious in stems of cabbage (Table 4). We observed that added Se(VI) was always mainly transformed to organic forms of Se, as was reported in *S. pinnata* [23]. Different results were seen in radish by Slekovec and Goesler [27] and Pedrero et al. [26] (Table 3). Pedrero et al. [26] found that 16 % of Se was present in organic forms, with the remainder as Se(VI), while Slekovec and Goesler [27] found only inorganic Se in methanol-water extracts.

In cabbage and red cabbage supernatants, some Se species were observed at trace level and not identified (Table 4). On the anion-exchange column unknown species X and Y occurred, with retention times of 13.5 and 15.4 min, respectively (Figs. 1 and 2). On the cation-exchange column, unknown species W occurred, with a retention time of 8.0 min (Fig. 2). On the anion-exchange column, we observed a peak with the same retention time as $SeCys_2$ (Figs. 1 and 2), but on the cation-exchange column we did not confirm $SeCys_2$. Therefore, we conclude that this is an unknown species U. Unknown species altogether accounted for 7 % in red cabbage stems, 2 % in cabbage stems, and 5 % in leaves and roots, regarding total Se.

Considerable proportions of unknown Se species were found in buckwheat, barley sprouts, rice, and soybean [7]. Unknown Se species were detected in Chinese cabbage [7] around 5 min after injection. Sugihara et al. [7] under their experimental conditions gave an explanation for this species; it may be an intermediate in the pathway from SeCys to SeMet.

There is much confusion about interpretation of the results regarding Se-cysteine (SeCys) or Se-cystine ($SeCys_2$) and their actual presence in plants. Cubadda et al. [32], Pedrero et al. [26], and Ximénez-Embún et al. [29] reported the presence of $SeCys_2$ in wheat grain, radish, and lupins. Slekovec and Goesler [27] reported finding SeCys in cabbage (Table 3), but they used only $SeCys_2$ as a standard. Also, Hamilton [28] reported finding Se-containing cysteine or cystine-type compounds, but the presence or absence of $SeCys_2$ in the cabbage extract could not be definitely established. Wróbel et al. [35] referred to these substances as the $SeCys_2$/SeCys couple because of the easy interconversion between $SeCys_2$ and SeCys during sample handling. So the confusion really exists.

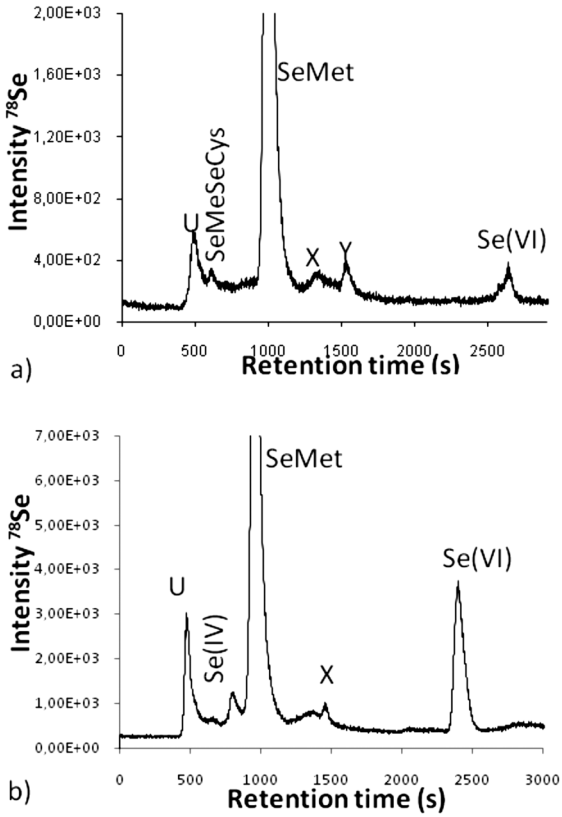

Fig. 1 Chromatogram of enzymatic extracts of cabbage (a) roots and (b) leaves obtained after separation on Hamilton PRP-X 100 (anion-exchange column) connected to ICP-MS.

In *B. juncea*, the author also found an unknown Se-species eluting at about 3 min [25]. In Indian mustard, Ximénez-Embún and co-workers [29] found an unknown species at about 5 min. In chicory, an unknown Se species at a retention time of 6 min represented 2 % of total Se in leaves [9]. In our study, unknown Se species U in roots of cabbage and red cabbage represented less than 1 %, while in stems it represented around 1.7 % and in leaves 3.3 % of the total Se content.

Se-enriched red cabbage could be a suitable source of Se for human consumption, while a concentration around 0.1 mg kg^{-1} represents an appropriate amount of Se in consumed vegetables [36]. An edible portion of red cabbage contained about 11 or 2 μg Se in the form of SeMet, while same portion of cabbage contained 41 or 5.4 μg Se in the form of SeMet. On the other hand, Se-enriched cabbage has a higher content of Se and would be suitable for using it for food supplements.

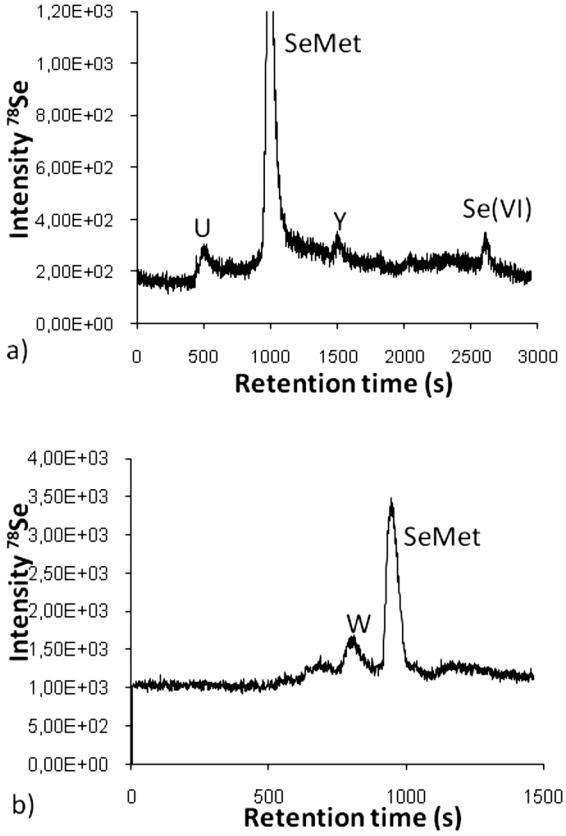

Fig. 2 Chromatogram of enzymatic extracts of red cabbage (a) steams obtained after separation on Hamilton PRP-X 100 (anion-exchange column) and (b) roots obtained after separation on Zorbax 300-SCX (cation-exchange column) connected to ICP-MS.

CONCLUSION

Cabbage, foliarly sprayed twice with selenate, and red cabbage twice fertilized with selenate solution, took up large amounts of Se in roots, stems, and leaves. Following enzymatic hydrolysis, the main soluble species in both cabbage plants was SeMet. In edible parts of cabbage, SeMet represented 17 % of total Se. We identified almost all of the soluble Se in roots of cabbage, while in other parts of cabbage and red cabbage there were some other species, which could not be identified with the method used. There are still major amounts of Se in insoluble form (31–53 %), and this could be a part of a detoxification mechanism. Se-enriched red cabbage could be a suitable source of Se for human consumption to enhance low dietary intakes.

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