Dedicated to Professor Apolodor Aristotel Răduţă's 70th Anniversary

HEAVY METAL ACCUMULATION AND TRANSLOCATION IN DIFFERENT PARTS OF *BRASSICA OLERACEA L*

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The aim of this study was to quantify the concentration of seven heavy metals including (Cd, Fe, Mn, Cu, Zn, Pb, and Ni) in soil and to investigate the bioavailability of heavy metals from soil to different parts of *Brassica oleracea L*. var. *capitata*. The mobility of heavy metals from soil into the food chain and their bioaccumulation in cabbage has increased from safety point of view. The metal concentrations were determined by Flame Atomic Absorption Spectrometry technique. In this study the highest concentration of copper and iron in soil were obtained. This can be a consequence to the using excessively the fertilizers, pesticides and copper sulphate as treatment for cabbage protection. The manganese, nickel, zinc and cadmium concentrations in soil not exceed the normal values according with the Romanian Regulation. The bioaccumulation factor (BF) of seven heavy metals in cabbage revealed that this vegetable was a poor accumulators of Fe, Ni, Cu, Cd, and Pb (BF <1), and good accumulator of Mn (BF >1). Obviously, only with BF is no possible to establish if the cabbage may be considerate as accumulator species for a certain metals and from this reason the translocation factor (TF) was calculated.

Key words: *Brassica oleracea L.* var. *capitata*, heavy metal, flame atomic absorption spectrometry, accumulation factor, translocation factor.

1. INTRODUCTION

In Romania, from the point of view of cultivated land, *Brassica oleracea L.* var. *capitata* ranks the second place, which means approximately 21% of the total

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cultivated area with vegetables. Therapeutic properties of cabbage are known from antiquity and many peoples used this vegetable. The nutritional value [1] of the cabbage is emphasized by the high vitamins content, such as, vitamin A (5µg/100g) vitamin C (37 mg/100g), vitamin E (0.2 mg /100g), vitamin B6 (0.1 mg/100g), vitamin B3 (0.2 mg/100g), vitamin K (76µg/100g) and vitamin U. This vegetable has lower levels of saturated fat and cholesterol and is a good source of thiamin, calcium, iron, magnesium, phosphorus, potassium, dietary fiber, folate (vitamin B9) and manganese as well. In this respect the cabbage is a usefully food for the people of the whole world. From a traditional point of view, in many Eastern European counties, cabbage in the form of sauerkraut is one of appreciate traditional foods. A real matter of serious concern is the fact that the cabbage can be a prolific accumulator of heavy metals from soil, providing an easy entry into food chain of these toxic metals. It is well known that heavy metals appear in the soil in soluble form, as well as in combined forms. Certainly, only soluble exchangeable and chelated metal species in the soils are mobile and therefore available to the plants [2, 3]. However, metal can be accumulated in plant depending on vegetable species, growth stages, soil composition, geographic and atmospheric conditions, and type of metal [4-6].

The aim of this study was to investigate that *Brassica oleracea L.* var. *capitata*, can accumulate some soluble form of heavy metals from soil in different edible parts which can be a direct pathway for metals incorporation into the human food chain.

2. EXPERIMENTAL PART

2.1. SITE DESCRIPTION

The investigated area is one of the old villages from Southern of Dambovita County, namely Puntea de Greci, with traditional activities in agriculture and vegetable farming. In this area is cultivated especially cabbage and potatoes.

As pollution sources can be mentioned auto traffic (*i.e.* the highway A1 and other district roads – Figure 1), fertilizers and domestic wastes.

2.2. SAMPLING

The basic plant material of *Brassica oleracea L.* var. *capitata* used for investigation was obtained by sampling from seven well-established points (Fig. 1 and Table 1) which represent the most cultivated sites of Puntea de Greci village. The global positioning system (GPS) was used in recording the coordinates and geographical information system (GIS) was used to locate the map of the investigated sites (Table 1). The cabbage was collected according with [7] and [8].

Fig. 1 – Vegetable farming area Puntea de Greci, Dambovita County.

Table 1

Geographical information system (GIS) and sampling codes of cabbage and soil

Sampling points	*GIS coordinates*		*Altitude [m]*	*Soil sample*	*Component parts*	*Cabbage sample*
	N	*E*				
P1	44°38'54.73"	25°18'11.12"	168	S1	Outer leaf	V1
					Interior leaf	V2
					Core	V3
					Interior stem	V4
					Exterior stem	V5
					Root	V6
P2	44°39'01.33"	25°18'02.02"	174	S2	Outer leaf	V7
					Interior leaf	V8
					Core	V9
					Interior stem	V10
					Exterior stem	V11
					Root	V12
P3	44°38'57.97"	25°18'21.90"	170	S3	Outer leaf	V13
					Interior leaf	V14
					Core	V15
					Interior stem	V16
					Exterior stem	V17
					Root	V18

Table 1 (continued)

P4	44°38'58.71"	25°18'04.19"	173	S4	Outer leaf	V19
					Interior leaf	V20
					Core	V21
					Interior stem	V22
					Exterior stem	V23
					Root	V24
P5	44°38'54.61"	25°18'13.42"	165	S5	Outer leaf	V25
					Interior leaf	V26
					Core	V27
					Interior stem	V28
					Exterior stem	V29
					Root	V30
P6	44°38'55.10"	25°18'16.95"	172	S6	Outer leaf	V31
					Interior leaf	V32
					Core	V33
					Interior stem	V34
					Exterior stem	V35
					Root	V36
P7 (Blank)	44°38'23.97"	25°18'29.93"	164	S7	-	-

Each cabbage samples were coded from P1 to P6 and then were selected in component parts such as: outer leaf, interior leaf, core, interior stem, exterior stem and root, coded from V1 to V36 as well (*e.g.* Table 1). All the samples were washed with deionized water and dried at 60^0C in 72 hours. Then samples were powdered and weighed in order to determine the heavy metals concentrations by atomic absorption spectrometry. The sampling and preparation procedure of soil (*i.e.* S1–S7) were achieved according with [9, 10].

2.3. ATOMIC ABSORBTION SPECTROMETRY AND SAMPLES PREPARATION PROCEDURES

Approximately 0.2 g of cabbage samples were digested with 8 mL of HNO_3 (65% Merck) and 10 mL H_2O_2 (30% Merck) in a Berghof MWS-2 microwave digestion system. The digestion was carried out at 220°C, at a pressure of 75 MPa for 20 minutes. The clear solutions were filtered and were brought in 50 mL volumetric bottle with distilled deionized water. The metal concentrations were determined by Flame Atomic Absorption Spectrometry (FAAS) technique [11-16]. All concentrations were reported as mg/kg dry weight of material. For the quality assurance, the results were checked by carrying out a triplicate analysis according to certified standard reference materials NIST SRM 1515 (Apple leaves) and was obtained a recovery between 95.9% and 101.2%. A quantity of approximately 0.5 g of soil samples were mineralized with 12 mL HNO_3 (65% Merck), 6 mL HCl (37% Aldrich), 4 mL HF (40% Aldrich) and 1 mL H_2SO_4 (96% Aldrich) according with 3051 EPA standard. Heavy metals concentrations were analysed by Flame Atomic

Absorption Spectrometry (FAAS). To check the analytical precision, randomly chosen samples (about 20% of the total numbers) were measured in triplicate according to International Standard Reference Material: NIST SRM 2709, 2710 and 2711 for soil. Average recoveries (n = 5) were between 85 and 99% for analysed heavy metals. Measurements of pH values of soil were carried out in deionized water ratio of 1:2 according to the NF ISO 10390/2005 procedure. pH determination was performed with Consort P501 pH-meter.

3. RESULTS AND DISCUSSION

The results obtained for pH of soil samples and soil reaction as well, are presented in Table 2. The pH values ranged from 6.56 to 7.53 (Table 2).

Table 2

Soil reaction at measured pH values

Soil	*pH*	*Soil reaction*
S1	7.54	weak alkaline
S2	7.43	weak alkaline
S3	7.09	neutral
S4	7.23	weak alkaline
S5	7.21	weak alkaline
S6	6.92	neutral
S7	6.56	weak acidic

These values are in concordance with the pH acceptable range for cabbage cultivation (*i.e.* pH 6.0 - 7.5).

Table 3

Mean of heavy metals concentrations in *Brassica oleracea L.* parts

Cabbage sample	*Component parts*	*Mean of heavy metals concentrations [mg/kg d.w.]*						
		Cu	*Fe*	*Mn*	*Ni*	*Zn*	*Cd*	*Pb*
V1	Outer leaf	9.43	226.08	78.20	2.37	22.66	0.98	1.09
V2	Interior leaf	13.90	202.24	48.45	2.24	55.76	0.82	0.92
V3	Core	14.09	184.49	48.84	2.06	67.60	0.61	0.88
V4	Interior stem	8.80	147.71	48.05	1.79	10.92	0.34	0.89
V5	Exterior stem	10.66	159.94	34.56	1.64	26.02	0.28	0.72
V6	Root	14.10	907.66	161.47	2.14	53.41	1.13	3.45
V7	Outer leaf	11.39	194.14	64.70	2.30	25.89	0.78	1.02
V8	Interior leaf	8.41	154.83	78.99	2.40	13.66	0.56	0.79
V9	Core	12.27	158.57	66.05	2.21	48.85	0.41	0.82
V10	Interior stem	8.44	141.99	57.10	1.99	11.23	0.36	0.98
V11	Exterior stem	9.59	136.90	52.82	1.81	16.81	0.11	0.44
V12	Root	11.28	1013.83	515.49	2.24	30.19	0.82	2.89

Table 3 (continued)

V13	Outer leaf	9.43	304.36	78.99	2.60	20.07	1.06	2.89
V14	Interior leaf	13.37	201.79	44.65	2.31	40.08	0.92	1.89
V15	Core	14.97	201.82	56.00	2.40	45.38	0.78	0.93
V16	Interior stem	9.62	136.75	48.40	1.77	12.33	0.83	0.94
V17	Exterior stem	10.77	143.89	26.38	1.88	15.51	0.76	0.57
V18	Root	9.56	5767.02	1615.1	1.36	44.09	1.25	4.67
V19	Outer leaf	9.87	213.28	110.57	2.74	22.84	1.10	2.11
V20	Interior leaf	13.86	206.34	59.63	2.28	43.33	1.02	1.05
V21	Core	15.20	229.77	70.38	2.43	65.01	0.89	1.03
V22	Interior stem	7.90	151.05	34.20	1.91	9.89	0.88	0.95
V23	Exterior stem	10.80	235.59	45.83	1.73	33.31	0.53	0.79
V24	Root	10.70	2543.56	1180.52	1.50	47.19	1,35	3.49
V25	Outer leaf	9.46	214.96	140.85	2.79	43.80	1.43	2.56
V26	Interior leaf	13.48	204.04	96.29	2.39	52.60	1.16	1.88
V27	Core	13.84	202.14	78.42	2.28	91.75	0.87	1.56
V28	Interior stem	8.73	172.79	50.15	1.71	18.82	0.74	0.92
V29	Exterior stem	10.08	145.27	25.95	1.49	63.88	0.65	0.81
V30	Root	13.33	963.61	362.18	2.13	108.13	2.19	3.21
V31	Outer leaf	7.07	195.43	53.86	2.40	13.72	1.01	1.84
V32	Interior leaf	14.23	179.76	44.81	2.20	38.55	0.84	1.05
V33	Core	14.90	193.25	61.60	2.28	54.00	0.76	0.84
V34	Interior stem	8.40	217.18	60.37	1.76	9.21	0.57	0.93
V35	Exterior stem	10.21	168.93	27.61	1.71	23.34	0.38	0.77
V36	Root	12.76	957.66	148.67	1.91	30.62	1.74	3.22
MAL for fresh or congealed vegetables / raw vegetable leaves (Ord. 975/1998 and JECFA 2005)		5.0	-	-	-	15.0	0.1 / 0.2	0.5
RSD [%]		1.0-3.4	2.3-7.8	1.4-5.6	0.3-1.1	2.4-5.3	0.1-0.5	0.1-0.7

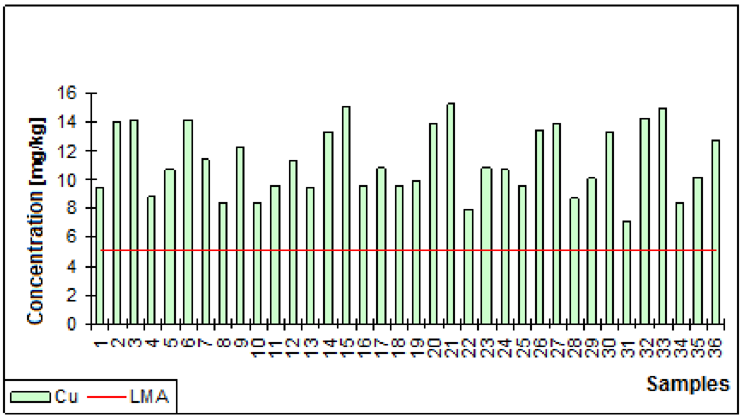


Fig. 2 – Copper concentration in *Brassica oleracea L.* samples.

The mean of heavy metals concentrations in *Brassica oleracea L.* parts are presented in Table 3. Usually copper is an essential element for the plant growing. This microelement reaches into the composition of many enzymes in plants, but the interval of positive actions being limited it may became very toxic in high concentrations. In this respect, it was analyzed copper concentrations in different parts of cabbage. From Table 3 and Figure 2 it can see that the copper concentration exceeded the maximum admitted limit (MAL) according with MAL (Ord. 975/1998 from Romanian legislation [18] and JECFA 2005) for fresh or congealed vegetables/raw vegetable leaves (5 mg/kg) in all analyzed samples. The highest levels were recorded on the interior and outer leaves, and this is a consequence of the application of foliar fertilizers with high copper content. A high concentration was found in the interior stem as well (Table 3). Lowest concentration of copper was found in the exterior stem of cabbage samples.

Iso-concentration curves (Figure 3) can be relevant for copper accumulation in different parts of *Brassica oleracea L.* var. *capitata*.

Therefore, Fig. 3a shows that the outer leaf collected from site P2 has a highest content of copper comparative with the other outer leaves. This can be explained by the using of fertilizers and treatment with copper sulphate near to the sampling period. Highest concentration of copper in core can be observed from Figure 3b for samples collected from P3, P4 and P6 sites. These samples accumulate copper from soil due to the treatments with copper sulphate applied to the cabbage to comb the disease called "fall seedlings". In these sites the copper concentrations in soil samples exceeded the MAL according with Ord. 956/1997 from Romanian Regulation. From Figure 3c it can see that the root collected from P1 site present the highest concentration of copper comparative with the other roots collected from P2, P3, P4, P5 and P6 sites. However, the soil sample presents the lowest concentration of copper (Table 3). The explication is the same: treatment with copper sulphate near to the sampling period.

Cadmium is a non-essential nutrient, and together with selenium, cesium, silver, lead and mercury, doesn’t yet a well-established biological role, being poisons for plants depending to the concentrations. Cadmium accumulation in plants depends by species and genus, as well as by the soluble form in soil. It is well-known the high cadmium bioavailability for plants and from this reason it can explain that the cadmium concentrations is so high in all cabbage samples (except V11 - exterior stem and V24 – root) comparative with MAL from Commission Regulation (EU) 1881/2006 [17] and Ord. 975/1998 from Romanian legislation [18] (Figure 4). The highest concentrations of cadmium were in V30 and V36 samples (*i.e.* root) (Table 3).

Zinc is a good nutrient for vegetable, which help the chlorophyll formation in cabbage leaves. The zinc concentration is exceeded the MAL value according with Ord. 975/1998 and JECFA 2005, in most of the samples (except V4, V10, V16, V22, V28, V34). A highest concentration of zinc was found in root and core cabbage samples (Table 3 and Figure 5).

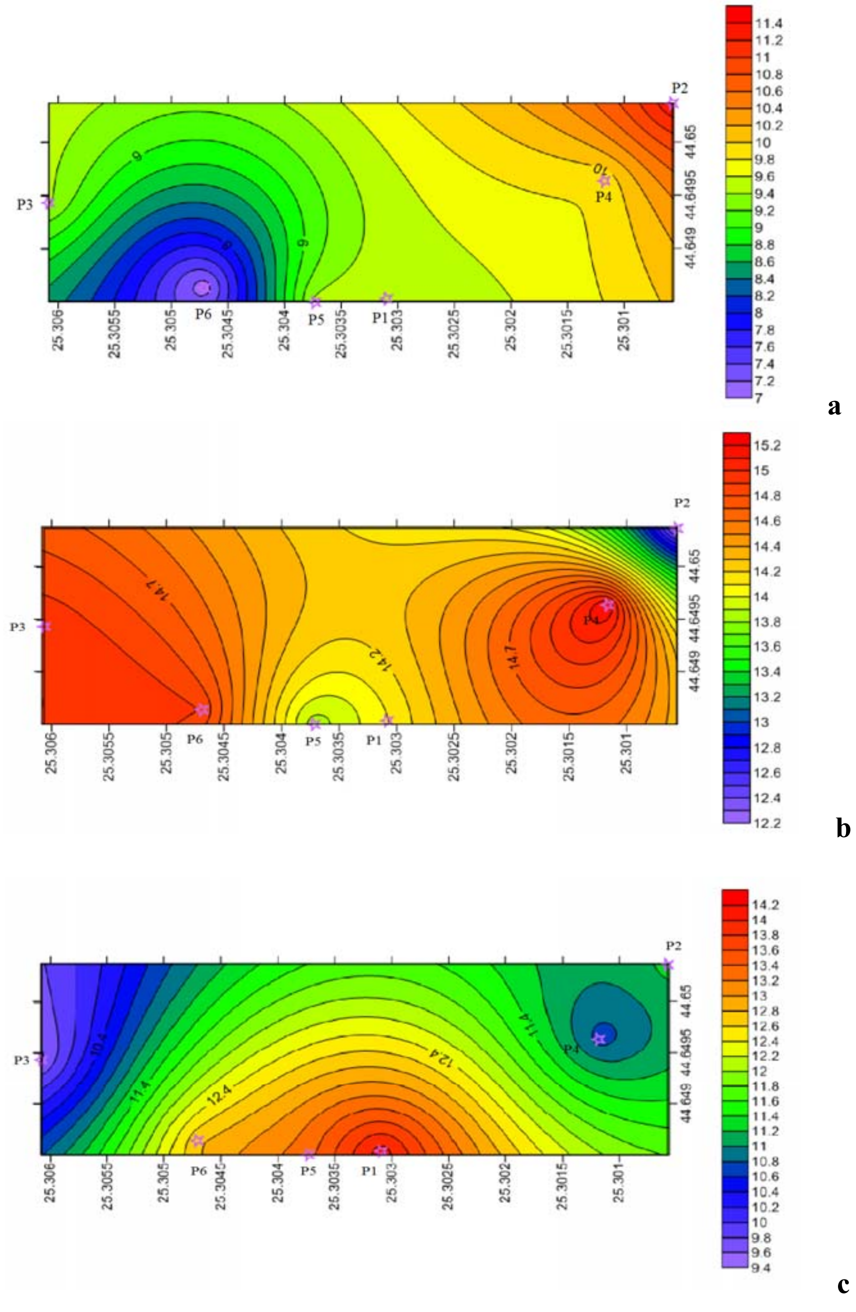


Fig. 3 – Copper concentration in Brassica oleracea L: outer leaf (a); core (b); root (c).

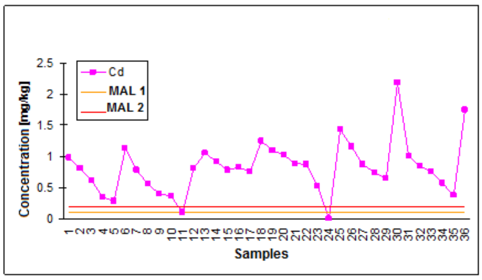


Fig. 4 – Cadmium concentration in *Brassica oleracea L.* samples.

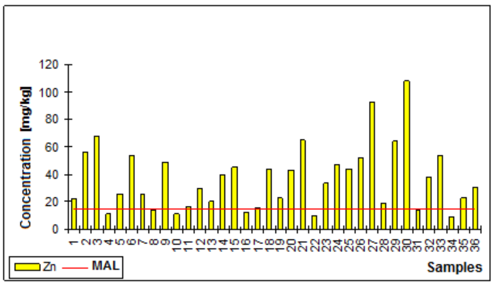


Fig. 5 – Zinc concentration in *Brassica oleracea L.* samples.

Lead is a toxic element for life and environment. The highest concentration of lead (Table 3 and Figure 6) was observed in all analyzed cabbage samples (except V11). The most important and alarming aspect was the highest concentrations of lead in all root samples which exceed by up to nine the MAL in Romanian legislation (*i.e.* 0.5 mg/kg) [18] and European Regulation (*i.e.* 0.3 mg/kg) [17]. It can be due by the historical pollution with lead provided from auto traffic (*e.g.* highway A1 and other county roads). In Romania the use of leaded petrol was banned completely only science January 2012.

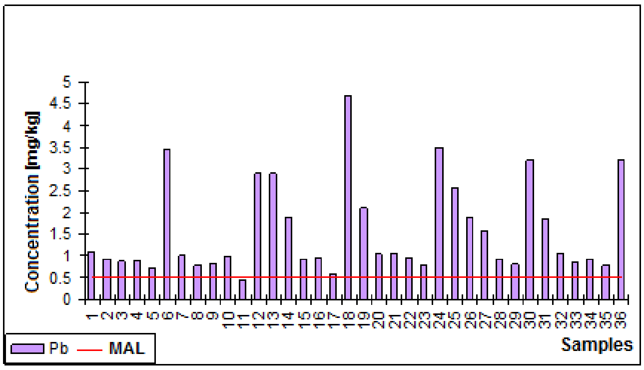


Fig. 6 – Lead concentration in *Brassica oleracea L.* samples.

The manganese is one of the most nutrients for vegetables and from this reason all fertilizers contain important quantities of manganese sulphate. In Romanian legislation is not specified the MAL for manganese in vegetables (*e.g.* 400 ppm of manganese are toxic for *Zea mays L*; 5 ppm of manganese is a toxic concentration for peanuts). In Table 4 are presented the obtained concentration of heavy metals in substrates comparative with the reference values from Romanian Regulation (Ord. 756/1997) [19] for heavy metals in soil.

Table 4

Heavy metals concentration in substrates of cabbage samples, comparative with the reference values from Romanian Regulation (Ord. 756/1997).

Soil sample	*Mean of heavy metals concentrations [mg/kg d.w.]*						
	Cu	*Fe*	*Mn*	*Ni*	*Zn*	*Cd*	*Pb*
S1	350.65*	7502.75**	420.99	9.52	299.66	4.33	10.64
S2	420.43*	6690.55*	402.23	5.59	353.93	3.78	8.44
S3	462.83*	8123.75**	578.68	9.23	368.80	4.47	19.35
S4	550.82**	6578.64*	413.75	8.38	280.85	4.68	9.21
S5	706.64**	6546.10*	401.60	16.79	282.14	5.03*	10.60
S6	532.26**	7969.47**	354.54	16.17	242.75	3.02	14.68
S7 (Witness)	261.35*	8603.45**	535.36	8.08	343.83	2.85	6.44
RDS	1.2-6.2	1.0-7.8	1.4-4.6	0.5-1.1	1.2-3.7	0.1-0.9	0.3-1.3
Normal value (VN)	20	3000	900	20	100	1	20
Maxim value (PM)	250	4500	2000	200	700	5	250
Intervention value (PI)	500	7000	4000	500	1500	10	1000

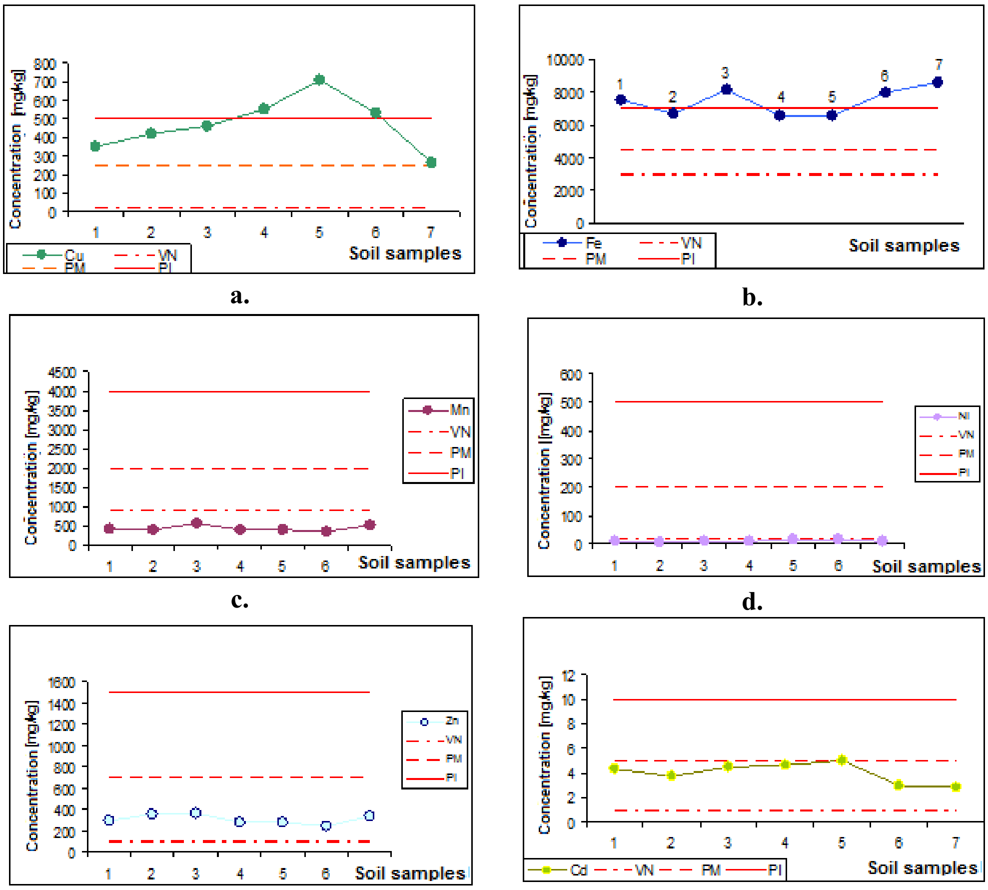
** Values which fall in the intervention threshold; ** Values which exceed the intervention threshold.*

Naturally without pollution, the copper concentration in soil is 20 ppm. This content is due to the presence of copper in minerals which can be released only by very slow disintegration processes. However this concentration of copper can increase significant under anthropogenic activities including non-ferrous metal processing, using the substances for plant protection and so on. Table 4 and Fig. 7 show that in all soil samples the copper concentration exceeded the maximum level to intervention threshold according with Romanian Regulation (Ord. 756/1997) [19]. The high concentrations of copper in soil are a consequence to use excessively the fertilizers, pesticides and copper sulphate as treatment for cabbage protection.

The manganese and nickel concentrations in soil not exceed the normal values according with Ord. 756/1997 such as 900 mg/kg and 20 mg/kg [19], respectively (Figure 7). For nickel, UK SHS (United Kingdom Soil and Herbage Survey) has reported concentrations between 1.16 and 216 mg/kg for rural soils with intensive farming activity, and 7.07–102 mg/kg for urban soils. The availability of nickel in soil increase with pH decrease, and most of nickel compounds are soluble at pH values lower than 6.5. The soils collected from Puntea de Greci village are weakly alkaline or neutral and this can explain the low concentration of nickel in soil. The fertilizers applied during the cultivation period of cabbage are poor in nickel and manganese.

In the case of iron concentrations in soil it can see that all values are situated around the intervention threshold. The soil concentration of samples S1, S3, S6 and

S7 exceed the values of intervention threshold according with Ord. 756/1997. The high concentration of iron for sample S7 *(i.e.* witness, Figure 7) can be explained by pH acid of soil useful for grassland.



a. b. c. d. e. f.

VN – normal value; PM – maxim threshold; PI – intervention threshold.

Fig. 7 – Heavy metals concentration in soil samples comparative with reference values:
a. Cu; b. Fe; c. Mn; d. Ni; e. Zn; f. Cd.

The zinc and cadmium concentrations in soil samples are between the normal value and maximum value provided in Ord. 756/1997. Zinc is one of the most available nutrients which can be accumulated by cabbage and then translocated in different parts of this vegetable. It is well-known that cadmium in association with zinc can be accumulated in high concentration by vegetables if the pH of soil is between 5.0 and 7.0, as well as if the pH is higher than 7.0. Thus can be explained the higher concentrations of zinc and cadmium as well.

The bioaccumulation factor (BF) from soil to component parts of cabbage, expressed as the ratio of metal concentration in part divided by the concentration of metal in soil, may be an indicator of the cabbage accumulation behavior. In this study it is estimated and compared the values of the bioaccumulation factor (BF) of Cd, Zn, Ni, Cu, Pb, Fe and Mn (Tables 5) from soil to different part of cabbage.

Table 5

The bioaccumulation factor (BF) of metals from soil to different parts of *Brassica oleracea L*

Cabbage sample	*Component part*	*Bioaccumulation factor, BF*						
		BF_{Cu}	BF_{Fe}	BF_{Mn}	BF_{Ni}	BF_{Zn}	BF_{Cd}	BF_{Pb}
V1	Outer leaf	0.027	0.030	0.186	0.249	0.076	0.226	0.102
V2	Interior leaf	0.040	0.027	0.115	0.235	0.186	0.189	0.086
V3	Core	0.040	0.025	0.116	0.216	0.226	0.141	0.083
V4	Interior stem	0.025	0.020	0.114	0.188	0.036	0.079	0.084
V5	Exterior stem	0.030	0.021	0.082	0.172	0.087	0.065	0.068
V6	Root	0.040	0.121	0.384	0.225	0.178	0.261	0.324
V7	Outer leaf	0.027	0.029	0.161	0.411	0.073	0.206	0.121
V8	Interior leaf	0.020	0.023	0.196	0.429	0.039	0.148	0.094
V9	Core	0.029	0.024	0.164	0.395	0.138	0.108	0.097
V10	Interior stem	0.020	0.021	0.142	0.356	0.032	0.095	0.116
V11	Exterior stem	0.023	0.020	0.131	0.324	0.047	0.029	0.052
V12	Root	0.027	0.152	**1.282**	0.401	0.085	0.217	0.342
V13	Outer leaf	0.020	0.037	0.137	0.282	0.054	0.237	0.149
V14	Interior leaf	0.029	0.025	0.077	0.250	0.109	0.206	0.098
V15	Core	0.032	0.025	0.097	0.260	0.123	0.174	0.048
V16	Interior stem	0.021	0.017	0.084	0.192	0.033	0.186	0.049
V17	Exterior stem	0.023	0.018	0.046	0.204	0.042	0.170	0.029
V18	Root	0.021	0.710	**2.791**	0.147	0.120	0.280	0.241
V19	Outer leaf	0.018	0.032	0.267	0.327	0.081	0.235	0.229
V20	Interior leaf	0.025	0.031	0.144	0.272	0.154	0.218	0.114
V21	Core	0.028	0.035	0.170	0.290	0.231	0.190	0.112
V22	Interior stem	0.014	0.023	0.083	0.228	0.035	0.188	0.103
V23	Exterior stem	0.020	0.036	0.111	0.206	0.119	0.113	0.086
V24	Root	0.019	0.387	**2.853**	0.179	0.168	0.288	0.379
V25	Outer leaf	0.013	0.033	0.351	0.166	0.155	0.284	0.242
V26	Interior leaf	0.019	0.031	0.240	0.142	0.186	0.231	0.177
V27	Core	0.020	0.031	0.195	0.136	0.325	0.173	0.147

Table 5 (continued)

V28	Interior stem	0.012	0.026	0.125	0.102	0.067	0.147	0.087
V29	Exterior stem	0.014	0.022	0.065	0.089	0.226	0.129	0.076
V30	Root	0.019	0.147	***0.902***	0.127	0.383	0.435	0.303
V31	Outer leaf	0.013	0.025	0.152	0.148	0.057	0.334	0.125
V32	Interior leaf	0.027	0.023	0.126	0.136	0.159	0.278	0.072
V33	Core	0.028	0.024	0.174	0.141	0.222	0.252	0.057
V34	Interior stem	0.016	0.027	0.170	0.109	0.038	0.189	0.063
V35	Exterior stem	0.019	0.021	0.078	0.106	0.096	0.126	0.052
V36	Root	0.024	0.120	0.419	0.118	0.126	0.576	0.219

Bioaccumulation factor is calculated with relation:

$$BF = C_p/C_s$$

where: C_p is the mean metal concentration in cabbage sample (mg/kg) and C_s is the mean metal concentration in soil sample (mg/kg). If the BF > 1 then the plants can be accumulators; BF = 1 is no influences and if the BF < 1 then the plant can be an excluder. The bioaccumulation factors (BF) of Cd, Zn, Ni, Cu, Pb, Fe and Mn for cabbage samples are given in Table 5. From this table it can see that in six of the seven elements the accumulation factor has the maximum value in the root samples (*i.e.* 0.04 at Cu and 2.853 at Mn). However, a plant can be considered accumulator if BF > 1. In Figure 8 is presented the BF for Mn in root samples of cabbage, because the BF value for Mn exceed in root for samples collected from P2, P3, P4 and P5 sites.

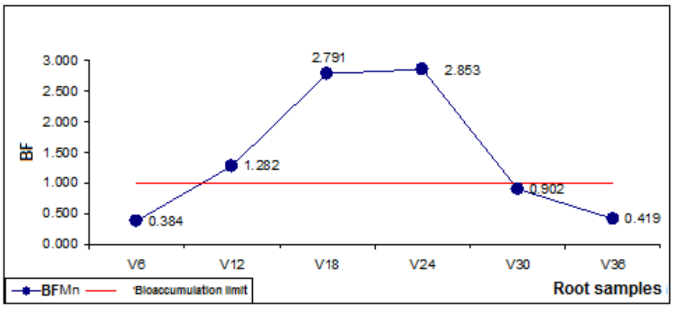


Fig. 8 – Bioaccumulation factor in cabbage root samples.

The root is adapted to carry out the main functions: one for fixing plant in soil and one for absorption water and dissolved minerals. The root contributes to the metabolism of cabbage feeding the whole plant and often serves to store minerals. This ability of roots to accumulate heavy metals is considered to be a way that the aerial parts of the plant are protected. Adsorption of heavy metals and their transport to the cabbage part depend mainly on the type of metal, in the second on the biological role in cabbage, and the metal ability to form some complexes with the sap components. On the second place is found the outer leaf, being the old leaf, when the accumulation period of heavy metals is much longer than the other leaves. Obviously, the outer leaf is the first which is in contact with fertilizers and pesticides, as well as with acid rain or pollutants from air. Third place in this "ranking" is occupied by the core. It is composed from the youngest leaves of the cabbage. Minerals are found in highest quantity in young leaves in growing, observing some migration of these from mature to the young leaves. The total BF for each cabbage collected from P1-P6 sites were presented in Table 6 and Figure 9.

The BF > 1 demonstrates that the manganese is the most assimilated element on *Brassica oleracea L.* In five from six samples, the percentage exceeds value 1. Therefore the root accumulates and stores manganese providing a constant amount required by the plant. In addition, all foliar fertilizers contain manganese in order to stimulate the biosynthesis of phytohormones. Manganese and iron are the most important catalysts oxidoreducătoare for oxido-reducing processes of plant. As a component of the chloroplast, manganese is involved in photolysis of water, having an essential role to donor the electron in photosystem II from photosynthesis process. Thus, after roots, the outer leaves are green and contain the highest quantities of manganese.

Table 6

The amount of bioaccumulation factor for each sample

Site	BF_{Cu}	BF_{Fe}	BF_{Mn}	BF_{Ni}	BF_{Zn}	BF_{Cd}	BF_{Pb}
P1	0.202	0.244	0.997	1.285	0.789	0.961	0.747
P2	0.146	0.269	2.076	2.316	0.414	0.803	0.822
P3	0.146	0.832	3.232	1.335	0.481	1.253	0.614
P4	0.124	0.544	3.628	1.502	0.788	1.232	1.023
P5	0.097	0.290	1.878	0.762	1.342	1.399	1.032
P6	0.127	0.240	1.119	0.758	0.698	1.755	0.588

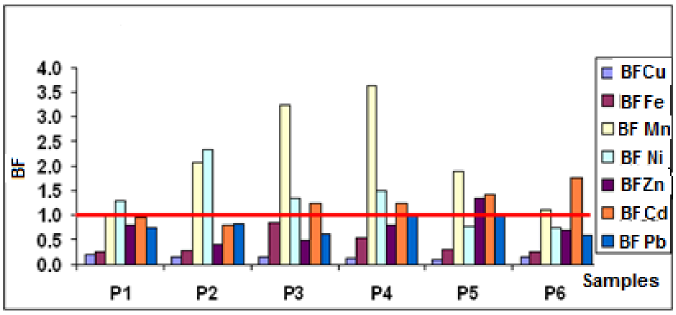


Fig. 9 – Bioaccumulation factor of heavy metals in cabbage samples.

The BF for zinc and cadmium registered values less than 1.0 in parts of cabbage, but they amount exceeds this value. This fact depend both by the pH of soil (weakly alkaline or neutral) and the zinc concentration in analyzed soil.

Obviously, only with BF is no possible to establish if the cabbage may be considerate as accumulator species for a certain metals and these can be poisonous for people life. However these data can be used with other data resulted by calculus of translocation factor (TF) using the next formula:

$$TF = C_{\text{cabbage part}} / C_{\text{root}}$$

where: $C_{\text{cabbage part}}$ is mean metal concentration in outer leaf or other parts of cabbage (mg/kg); C_{root} is mean metal concentration in root (mg/kg). Translocation factor were presented in Table 7 and Figure 9.

The iron is a metals which is uniform distributed in all parts of cabbage because the value of TF_{Fe} is less than 1 (*i.e.* 0.024 – 0.249). Translocation factor of copper present values between 0.554 and 1.566. Figure 10a shows that copper migrate from outer leaves to interior leaves and core, as well as from external stem to internal stem and core. The highest value of translocation factor for copper was in core samples. Similar with copper is the comportment of iron (Figure 10c). TF_{Mn} is less than 1 in all samples, and the value gradually decreases from outer leaf to interior leaf, core and stem (Figure 10b). Translocation factor of nickel present values between 0.7 and 1.912. It can observe the same decreases of nickel from outer leaf to interior leaf, core and stem (Figure 10b).

Table 7

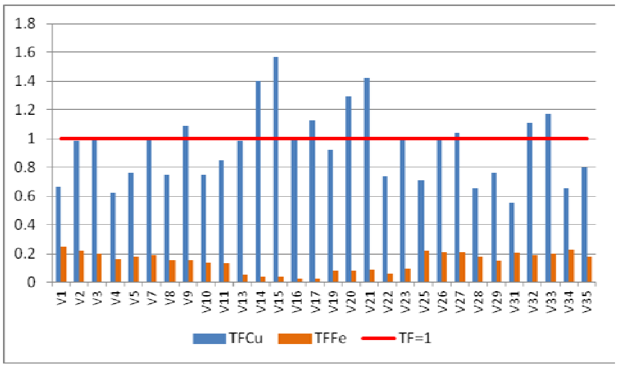
Translocation factor (TF) of metals from root to different parts of cabbage

Cabbage sample	*Component part*	*Translocation factor (TF)*						
		TF_{Cu}	TF_{Fe}	TF_{Mn}	TF_{Ni}	TF_{Zn}	TF_{Cd}	TF_{Pb}
V1	Outer leaf	0.669	0.249	0.484	1.107	0.424	0.867	0.316
V2	Interior leaf	0.986	0.223	0.300	1.047	1.044	0.726	0.267
V3	Core	0.999	0.203	0.302	0.963	1.266	0.540	0.255
V4	Interior stem	0.624	0.163	0.298	0.836	0.204	0.301	0.258
V5	Exterior stem	0.756	0.176	0.214	0.766	0.487	0.248	0.209
V7	Outer leaf	1.010	0.191	0.126	1.027	0.858	0.951	0.353
V8	Interior leaf	0.746	0.153	0.153	1.071	0.452	0.683	0.273
V9	Core	1.088	0.156	0.128	0.987	1.618	0.500	0.284
V10	Interior stem	0.748	0.140	0.111	0.888	0.372	0.439	0.339
V11	Exterior stem	0.850	0.135	0.102	0.808	0.557	0.134	0.152
V13	Outer leaf	0.986	0.053	0.049	1.912	0.455	0.848	0.619

Table 7 (continued)

V14	Interior leaf	1.399	0.035	0.028	1.699	0.909	0.736	0.405
V15	Core	1.566	0.035	0.035	1.765	1.029	0.624	0.199
V16	Interior stem	1.006	0.024	0.030	1.301	0.280	0.664	0.201
V17	Exterior stem	1.127	0.025	0.016	1.382	0.352	0.608	0.122
V19	Outer leaf	0.922	0.084	0.094	1.827	0.484	0.815	0.605
V20	Interior leaf	1.295	0.081	0.051	1.520	0.918	0.756	0.301
V21	Core	1.421	0.090	0.060	1.620	1.378	0.659	0.295
V22	Interior stem	0.738	0.059	0.029	1.273	0.210	0.652	0.272
V23	Exterior stem	1.009	0.093	0.039	1.153	0.706	0.393	0.226
V25	Outer leaf	0.710	0.223	0.389	1.310	0.405	0.653	0.798
V26	Interior leaf	1.011	0.212	0.266	1.122	0.486	0.530	0.586
V27	Core	1.038	0.210	0.217	1.070	0.849	0.397	0.486
V28	Interior stem	0.655	0.179	0.138	0.803	0.174	0.338	0.287
V29	Exterior stem	0.756	0.151	0.072	0.700	0.591	0.297	0.252
V31	Outer leaf	0.554	0.204	0.362	1.257	0.448	0.580	0.571
V32	Interior leaf	1.115	0.188	0.301	1.152	1.259	0.483	0.326
V33	Core	1.168	0.202	0.414	1.194	1.764	0.437	0.261
V34	Interior stem	0.658	0.227	0.406	0.921	0.301	0.328	0.289
V35	Exterior stem	0.800	0.176	0.186	0.895	0.762	0.218	0.239

For cadmium and lead the maximum values of TF are in outer leaves (TF_{Cd} = 0.915 and TF_{Pb} = 0.798) and minimum values of TF are in stem (TF_{Cd} = 0.134 and TF_{Pb} = 0.122).



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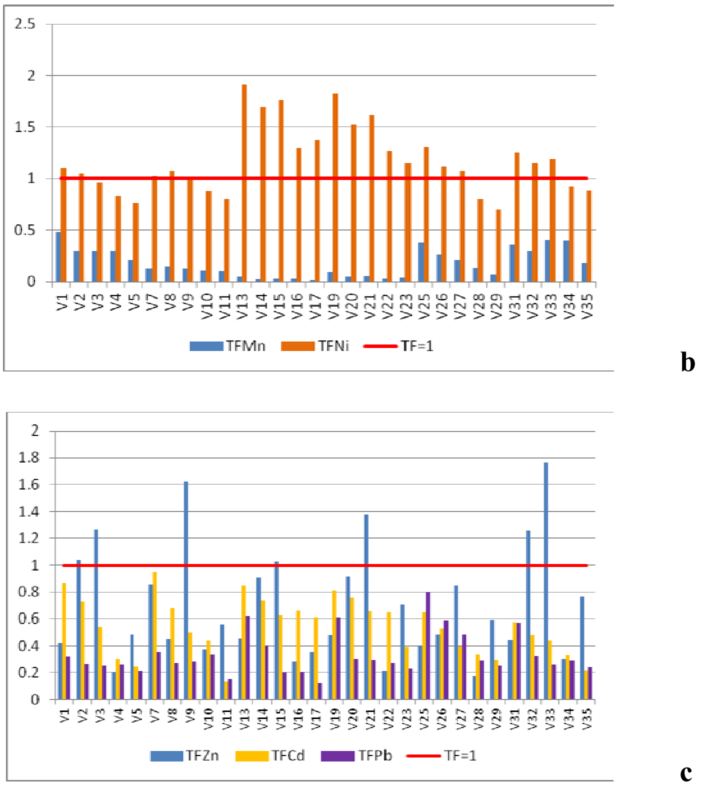

Fig. 10 – Translocation factor of metals from root in other parts of cabbage : a. TF_{Cu} and TF_{Fe}; b. TF_{Mn} and TF_{Ni}; TF_{Zn}, TF_{Cd} and TF_{Pb}.

4. CONCLUSIONS

Cabbage is interesting from both marketing and dietary points of view because cabbage has many beneficial effects on health. Atomic absorption spectrometry technique of high sensitivity can be successfully applied in the analysis of heavy metals of *Brassica oleracea* var. *capitata*. Cabbage can take up heavy metals by their roots, or even *via* their stems and leaves, and accumulate them in their organs. By this study can concluded that the cabbage take up elements selectively. Accumulation and distribution of heavy metals in the cabbage depends on the component parts, metal type, bioavailiability of metal, pH and temperature of soil, and secretion of roots. In conclusion, fresh cabbage from the production area of Puntea de Greci is a good raw material for fresh use and biological fermentation. The climatic and pedological characteristics of the typical and traditional production area favor the production of late cabbage cultivars, suitable for this purpose.

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