Journal of Elementology ISSN 1644-2296

Kałużewicz A., Bosiacki M., Frąszczak B. 2016. *Mineral composition and the content of phenolic compounds of ten broccoli cultivars*. J. Elem., 21(1): 53-65. DOI: 10.5601/jelem.2015.20.2.915

MINERAL COMPOSITION AND THE CONTENT OF PHENOLIC COMPOUNDS OF TEN BROCCOLI CULTIVARS

Alina Kałużewicz[1], Maciej Bosiacki[2], Barbara Frąszczak[1]

[1]Chair of Vegetable Crops
[2]Chair of Plant Nutrition
Poznan University of Life Sciences

Abstract

Our objective was to determine the content of macro- and micronutrients, toxic heavy metals as well as total phenols in 10 broccoli (*Brassica oleracea* var. *italica*) cultivars. The experiment was designed at the Poznań University of Life Sciences, Poland, and completed during two plant growing seasons. Broccoli seedlings were planted in a field in early July and the plants were harvested between September and October. The content of general forms of nitrogen was measured by distillation with the Kjeldahl method. The content of potassium, calcium and sodium was assessed by flame photometry, and the content of magnesium, cadmium, lead, nickel, copper, zinc, manganese and iron was determined by flame atomic absorption spectroscopy (FAAS).

The content of heavy metals, macronutrients and sodium in the broccoli heads depended on a cultivar. Having analyzed the levels of macronutrients in ten broccoli cultivars, it was concluded that cv. Agassi and Tradition had the highest content of nitrogen and phosphorus. A very high amount of phosphorus was also found in cv. Beaumont. The highest concentrations of calcium and potassium were found in cv. Monte Carlo. The cultivars Agassi, Beaumont, Tiburon and Tradition were characterized by the highest content of magnesium. The highest content of sodium occurred in the cultivars Beaumont and Monopoly. With respect to micronutrients, the highest content of iron, copper, zinc and manganese was revealed in cv. Agassi. The highest content of nickel was determined in the cultivars Beaumont and Monte Carlo. In addition, the cultivar Monte Carlo was characterized by the highest content of lead, and Beaumont had the highest content of cadmium. However, the maximum permissible levels of cadmium and lead were not exceeded in the heads of the ten broccoli cultivars. In both years of the study, the highest content of phenols was found in cv. Steel and the lowest one appeared in cv. Agassi.

Keywords: *Brassica oleracea* var. *italica*, macronutrients, micronutrients, heavy metals

Alina Kałużewicz, Ph. D., Chair of Vegetable Crops, Poznań University of Life Sciences, Dąbrowskiego 159, 60-594 Poznań, Poland, e-mail: kalina@up.poznan.pl

INTRODUCTION

Recent research results have clearly reaffirmed the importance of fruit and vegetables as most probably the richest source of antioxidants, emphasizing the need to increase the proportion of these products in a diet. The major vegetable antioxidants are vitamins C and E, carotenoids and phenolic compounds, especially flavonoids (Sikora et al. 2008). Common Brassicaceae vegetables play an important role in supplying humans with these nutrients. They contain several bioactive compounds, therefore acting as antioxidants, but they also demonstrate other health-promoting properties (Moreno et al. 2006). Brassicaceae vegetables are an excellent dietary source of phytochemicals, such as glucosinolates (and glucosinolate-breakdown products), phenolics and other antioxidants including vitamins (C, K1, etc.) and essential dietary nutrients (Ca, Mg, Na, K, Fe, Zn, etc.) (Moreno et al. 2006).

However, it is not known to what extent the antioxidant capacity varies among broccoli genotypes (Kurilich et al. 2002, Farnham 2009). Apart from the plant's genetic traits, the environment conditions and individual plant organs have been shown to affect the antioxidant potential of different broccoli cultivars (Kaur et al. 2007). An examination of 50 varieties of broccoli showed that the levels of β-carotene varied more than six times, whereas α-tocopherol and ascorbate also varied, but less than β-carotene (Kurilich et al. 1999). The content of glucosinolates in the same 50 varieties of broccoli varied approximately 20 times (Kushad et al. 1999).

Broccoli is a good source of the main mineral elements such as Na, K, Ca, Mg, Cl, P and S, and trace elements such as Fe, Zn, Mn and Cu, which are essential to humans (House 1999). Broccoli is a particularly good vegetable source of Ca and Mg, and studies have shown that broccoli is an important alternative source of Ca in the segments of the population that consume limited amounts of dairy products (Farnham et al. 2000). It is important for human health that vegetables contain health-promoting compounds but are free from toxic substances like heavy metals. There is little information in literature on the accumulation of heavy metals like lead and cadmium in broccoli heads.

The present study was designed to evaluate the level of macro- and micronutrients and toxic heavy metals as well as the content of total phenols.

MATERIAL AND METHODS

Plant material and growth conditions

The experiment was conducted in two growing seasons at Marcelin Experimental Station, Poznań University of Life Sciences, Poland. The research comprised 10 cultivars of broccoli: Agassi, Beaumont, Ironman, Lord, Monaco, Monopoly, Monte Carlo, Stell, Tiburon, and Tradition. Broccoli seedlings were planted in a field in early July and the plants harvested between September and October. The heads were cut when the buds reached the size of about 2 mm. The experiment was arranged in a randomised block design with four replications. 26 broccoli were planted and spaced 0.5 x 0.5 m on each plot of 6.5 m^2.

The plants were grown in mineral soil (loamy sand), where the content of organic carbon determined with the Tiurin's method was 11.5 g kg^{-1} (MOCEK, DRZYMAŁA 2010).

Pre-vegetation fertilisation (during the first and second year) with macro- and micronutrients was planned according to the initial content (in mg dm^{-3}) of components in the mineral soil, which were N-NH_4 – 4, N-NO_3 – 7, P – 69, K – 192, Ca – 544, Mg – 40, Na – 22, Cl – 49, S-SO_4 – 13, Fe – 94.1, Mn – 25, Zn – 10.4, Cu – 11.5, Ni – 1.17 in the first year of the research, and N-NH_4 traces, N-NO_3 – 11, P – 74, K – 168, Ca – 475, Mg – 72, Na – 21, Cl – 35, S-SO_4 – 21, Fe – 52.3, Mn – 15.9, Zn – 6.7, Cu – 8.7, Ni – 1.11 in the second year of the research, thus reaching the following levels (in mg dm^{-3}): N – 130, P – 80, K – 250, Mg – 120. Calcium and micronutrients were not entered into the mineral soil, because it was sufficiently abundant in these components. Nitrogen, phosphorus, potassium and magnesium were entered into the soil in the form of calcium magnesium nitrate, granular triple superphosphate and potassium salt. Additionally, top dressing of 150 kg ha^{-1} of ammonium nitrate was applied in the second and fifth week after the planting. The content of soluble cadmium in the soil was 0.19 mg dm^{-3} in the first year of the research and 0.21 mg dm^{-3} in the second year, whereas the content of lead was 3.21 mg dm^{-3} in the first year and 3.10 mg dm^{-3} in the second year.

Analysis of macro- and micronutrients in the soil and plant material

The nutrients in the soil were determined with the universal method in a CH_3COOH solution, concentrated at 0.03 mol dm^{-3} (KOZIK, GOLCZ 2011), and pH in water was measured by potentiometry (1:2 soil to water ratio) while EC was measured (mS cm^{-1}) by conductometry (1:2 soil to water ratio), (GOLCZ 2011).

The following techniques were applied to measure the nutrients: distillation to determine N-NH_4 and N-NO_3, the molybdenum vanadium colourimetric method to assy P, flame photometry to measure K, Ca and Na, atomic absorption spectrometry (AAS) to test Mg (KOZIK, GOLCZ 2011).

In the first and second year of the research, before the broccoli seedlings were planted, samples of mineral soil had been collected for extraction of Cd, Pb, Ni, Cu, Zn, Mn and Fe with Lindsay's solution (NOWOSIELSKI 1988). Afterwards, they were submitted to flame atomic absorption spectroscopy (FAAS) on an AAS-3 spectrophotometer (Zeiss).

After harvesting, the broccoli heads were dried in an exhaust dryer for 48 h. at a temp. of 105°C. Then the material was ground and 2.5 g of each sample was dry-mineralised in a Linn Elektro Therm furnace at a temp. of 450°C. The content of cadmium, lead, nickel, copper, zinc, manganese and iron in the plant material was measured by flame atomic absorption spectroscopy (FAAS) on an AAS-3 spectrophotometer (Zeiss). Heavy metals were also determined in certified plant material *Rye Grass* ERM®-CD281, (certified by the European Commission, Joint Research Centre, Institute for Reference Materials and Measurements IRMM, Geel BE) – Table 1.

Table 1

The content of heavy metals in reference material ERM®-CD281 *Rye grass* (mg kg^{-1} d.w.)

Metal	Reference material *Rye grass* certified content		Dry mineralisation			
	(Mg g^{-1})	+/-	content (mg kg^{-1})	recycled (%)	difference (mg kg^{-1})	difference (%)
Cd	0.120	0.007	0.12	100.00	0.00	0.00
Cu	10.2	0.5	8.98	88.03	1.22	11.97
Fe	180	-	172.37	95.76	7.63	4.24
Mn	82	4	78.56	95.80	3.44	4.20
Ni	15.2	0.6	14.31	94.14	0.89	5.86
Pb	1.67	0.11	1.49	89.22	0.18	10.78
Zn	30.5	1.1	28.80	94.43	1.70	5.57

The same plant material was wet-mineralised in concentrated H_2SO_4 (analytically pure grade), in which 30% H_2O_2 was used as an oxidant. After the mineralisation, the phosphorus content was measured by the colourimetric method with ammonium molybdate on a SPEKOL 210 apparatus. The content of potassium, calcium and sodium was measured by flame photometry, whereas the content of magnesium was measured by flame atomic absorption spectroscopy (FAAS) on a Zeiss AAS 3 apparatus (Kozik, Golcz 2011).

In order to determine the content of general forms of nitrogen, the plant material was subjected to mineralisation in sulphosalicylic acid, where sodium thiosulphate was applied as a reducer and a selenium mixture as a catalyser. Next, total nitrogen was measured by distillation, with the Kjeldahl method in a Parnas and Wagner apparatus.

Analyses of phenolic compounds

The phenolics were extracted in 80% methanol from homogenated and frozen broccoli heads and stems. The content of phenolic compounds was estimated by the Folin-Ciocalteu assay (Singleton, Rossi 1965), with quercetin used as a standard. Absorbances were read on a spectrophotometer at 725 nm.

Statistical analysis of data

The significance of the effect of a cultivar on the content of macronutrients, sodium, heavy metals and phenolic compounds was determined with the *F* test. Statistical analyses were carried out with the Stat program. Differences between the mean values were estimated with the Duncan test at the level of significance $P = 0.95$.

RESULTS AND DISCUSSION

Mineral composition

According to Moreno et al. (2006), broccoli is a good source of sodium, potassium, calcium, chlorides, phosphorus, sulphur, iron, zinc, manganese and copper.

The content of nitrogen ranged from 34.3 g kg^{-1} d.w. in the heads of cv. Monte Carlo (the first year of the research) to 45.1 g kg^{-1} d.w. in Agassi heads (the second year of the research) – Table 2. The highest mean content of nitrogen was found in the heads of the cultivars Agassi and Tradition and it did not differ significantly from the content of this component in the heads of the following cultivars: Monaco, Beaumont, Ironman, Lord, Monopoly, Tiburon. While the lowest content of nitrogen was found in the heads of cv. Stell, it did not differ significantly from the content found in the heads of Monte Carlo, Tiburon and Monopoly. In four broccoli cultivars, i.e. Shogun F_1, Pirate F_1, Marathon F_1 and Sultan F_1 the content of nitrogen ranged from 26.0 to 40.1 g kg^{-1} (Acikoz 2011).

The content of phosphorus ranged from 5.2 g kg^{-1} d.w. in the heads of the cultivar Stell (the second year of the research) to 6.8 g kg^{-1} d.w. in the heads of cv. Tradition (the second year of the research). The highest mean content of phosphorus was found in the heads of Agassi and Tradition and it did not differ significantly from the content of this component in the heads of the cultivar Beaumont. The lowest content of phosphorus was found in the heads of the Stell cultivar. In the eleven cultivars studied by Rosa et al. (2002), the content of phosphorus ranged from 4.9 to 9.6 g kg^{-1}, whereas in the broccoli cultivars studied by Acikoz (2011) the content of phosphorus ranged from 4.1 to 7.8 g kg^{-1}.

The content of potassium varied from 25.6 g kg^{-1} d.w. in the heads of cv. Monaco (the second year of the research) to 46.1 g kg^{-1} d.w. in the heads of cv. Monte Carlo (the first year of the research). The highest mean content of potassium was found in the heads of cv. Monte Carlo and the lowest one was found in the heads of the cultivars Monopoly and Monaco. In the eleven cultivars studied by Rosa et al. (2002), the content of potassium ranged from 23.9 to 33.6 g kg^{-1}, whereas in the broccoli cultivars studied by Acikoz (2011) the content of potassium ranged from 22.1 to 39.6 g kg^{-1}.

Table 2

The content of nutrients and sodium in heads of ten broccoli cultivars (g kg^{-1} d.w.)

Ingredient	Year of study	Cultivar									
		Agassi	Beau-mont	Ironman	Lord	Monaco	Mono-poly	Monte Carlo	Stell	Tiburon	Tradition
N	I	42.3 *bc**	42.7 *bc*	39.1 *abc*	41.2 *abc*	41.5 *abc*	39.4 *abc*	34.3 *a*	35.4 *ab*	37.3 *abc*	42.9 *bc*
	II	45.1 *c*	40.4 *abc*	43.7 *c*	40.3 *abc*	42.0 *abc*	41.8 *abc*	41.4 *abc*	35.7 *ab*	40.7 *abc*	44.3 *c*
Mean		43.7 *c*	41.6 *bc*	41.4 *bc*	40.8 *bc*	41.8 *bc*	40.6 *abc*	37.8 *ab*	35.5 *a*	39.0 *abc*	43.6 *c*
P	I	6.5 *efg*	6.3 *c-g*	5.7 *abc*	5.7 *abc*	6.0 *b-f*	5.6 *ab*	6.2 *b-g*	5.3 *a*	5.9 *b-e*	6.4 *d-g*
	II	6.7 *fg*	6.6 *fg*	6.4 *de*	5.6 *ab*	5.7 *a-d*	6.2 *b-g*	6.1 *b-f*	5.2 *a*	6.3 *c-g*	6.8 *g*
Mean		6.6 *e*	6.5 *de*	6.0 *bcd*	5.6 *b*	5.9 *bc*	5.9 *bc*	6.1 *cd*	5.2 *a*	6.1 *bcd*	6.6 *e*
K	I	33.4 *a*	30.6 *a*	28.5 *a*	28.5 *a*	27.7 *a*	26.9 *a*	46.1 *b*	27.6 *a*	29.3 *a*	31.0 *a*
	II	30.5 *a*	33.3 *a*	29.6 *a*	28.2 *a*	25.6 *a*	27.5 *a*	28.3 *a*	29.0 *a*	27.3 *a*	33.4 *a*
Mean		31.9 *ab*	31.9 *ab*	29.0 *ab*	28.3 *ab*	26.6 *a*	27.2 *a*	37.2 *b*	28.3 *ab*	28.3 *ab*	32.2 *ab*
Ca	I	3.2 *a-d*	3.8 *bcd*	3.5 *a-d*	2.6 *abc*	2.3 *ab*	2.8 *abc*	4.4 *d*	3.6 *a-d*	3.3 *a-d*	4.0 *cd*
	II	4.0 *cd*	3.7 *bcd*	3.7 *bcd*	3.1 *a-d*	2.1 *a*	2.4 *ab*	4.4 *d*	3.7 *bcd*	3.8 *bcd*	3.6 *a-d*
Mean		3.6 *cd*	3.7 *cd*	3.6 *cd*	2.8 *abc*	2.2 *a*	2.6 *ab*	4.4 *d*	3.7 *cd*	3.5 *bcd*	3.8 *cd*
Mg	I	2.95 *d*	2.85 *cd*	2.15 *ab*	2.05 *a*	1.95 *a*	1.95 *a*	3.10 *d*	2.05 *a*	2.65 *bcd*	3.05 *d*
	II	3.00 *d*	3.05 *d*	2.70 *cd*	2.35 *abc*	1.80 *a*	1.95 *a*	2.35 *abc*	2.05 *a*	2.95 *d*	2.75 *cd*
Mean		2.97 *d*	2.95 *d*	2.42 *bc*	2.20 *ab*	1.87 *a*	1.95 *a*	2.72 *cd*	2.05 *a*	2.80 *d*	2.90 *d*
Na	I	0.33 *a-d*	0.50 *e*	0.25 *a*	0.46 *cde*	0.44 *b-e*	0.54 *e*	0.47 *de*	0.22 *a*	0.30 *abc*	0.28 *ab*
	II	0.42 *b-e*	0.54 *e*	0.27 *ab*	0.43 *b-e*	0.51 *e*	0.47 *de*	0.30 *abc*	0.20 *a*	0.20 *a*	0.21 *a*
Mean		0.37 *b*	0.52 *c*	0.26 *a*	0.44 *bc*	0.47 *bc*	0.50 *c*	0.38 *b*	0.21 *a*	0.25 *a*	0.24 *a*

* means followed by the same letter do not differ significantly at $P = 0.95$

Farnham et al. (2000) claimed that broccoli was a good source of calcium and magnesium. In the broccoli cultivars studied by Acikoz (2011), the content of calcium ranged from 8.0 to 15.8 g kg^{-1}, whereas Rosa et al. (2002) observed the content of calcium ranging from 3.8 to 6.8 g kg^{-1} d.w. in the eleven cultivars grown in the spring-summer season; the analogous values ranged from 2.0 to 4.1 g kg^{-1} d.w. in the cultivars grown in the summer-winter season.

In the current research, the content of calcium ranged from 2.1 g kg^{-1} d.w. in the head of cv. Monaco (the second year of the research) to 4.4 g kg^{-1} d.w. in the head of cv. Monte Carlo (the first and second year of the research). The highest mean content of calcium was found in the head of cv. Monte Carlo and it did not differ significantly from the content of this component in the heads of such cultivars as Tradition, Beaumont, Stell, Agassi, Ironman, Tiburon. The lowest content of calcium was found in the head of cv. Monaco and it did not differ significantly from the content of this component in the heads of the cultivars Monopoly and Lord.

The content of magnesium ranged from 1.8 g kg^{-1} d.w. in the head of cv. Monaco (the second year of the research) to 3.1 g kg^{-1} d.w. in the head of cv. Monte Carlo (the first year of the research). The highest mean content of magnesium was found in the head of cv. Agassi and it did not differ significantly from the content of this component in the heads of such cultivars as Beaumont, Monte Carlo, Tiburon and Tradition. The lowest content of magnesium was found in the head of cv. Monaco and it did not differ significantly from the content of magnesium in the heads of such cultivars as Monopoly, Stell and Lord. In the study by Rosa et al. (2002), the content of magnesium in the dry weight of eleven broccoli cultivars ranged from 1.3 to 2.0 g kg^{-1}.

The content of sodium ranged from 0.20 g kg^{-1} d.w. in the heads of the cultivars Stell and Tiburon (the second year of the research) to 0.54 g kg^{-1} d.w. in the head of cv. Beaumont (the second year of the research) and cv. Monopoly (the first year of the research). The highest mean content of sodium was found in the head of the cultivars Beaumont and Monopoly. The lowest content of sodium was found in the head of the cultivars Stell, Tradition, Tiburon and Ironman.

As well as having a high nutritional value and macronutrients, vegetables may also be contaminated by heavy metals, which are variously toxic to humans. Different factors associated with cultivation (e.g. mineral fertilisation) and the environment may affect the accumulation of heavy metals in edible parts of vegetables. The proneness to the accumulation of heavy metals also depends on a plant species or even a variety (Bosiacki, Roszyk 2012, Bosiacki 2007, Bosiacki, Golcz 2004).

Heavy metal content

The content of iron ranged from 25.85 mg kg^{-1} d.w. in the head of cv. Lord (the first year of the research) to 54.14 mg kg^{-1} d.w. in the head of cv. Agassi (the second year of the research). The highest mean content of iron was found in the head of cv. Agassi, whereas the lowest content was observed in the head of cv. Lord, which did not differ significantly from the content of this metal in the heads of the cultivars Stell and Tiburon. In the research by Acikoz (2011), the content of iron in the broccoli heads ranged from 96.14 to 100.23 mg kg^{-1} d.w.

The content of copper ranged from 3.69 mg kg^{-1} d.w. in the head of cv. Tiburon (the first year of the research) to 6.98 mg kg^{-1} d.w. in the head of cv. Agassi (the second year of the research). The highest mean content of copper was found in the head of cv. Agassi, whereas the lowest content was observed in the head of cv. Lord and it did not differ significantly from the content of copper found in the heads of such cultivars as Tradition, Tiburon, Stell, Monopoly, Monaco and Beaumont. Acikoz (2011) found the content of copper in the broccoli heads ranging from 3.96 to 5.33 mg kg^{-1}d.w, whereas Bosiacki and Golcz (2004) determined this value at 4.16 mg kg^{-1}d.w.

The content of zinc ranged from 42.32 mg kg^{-1} d.w. in the head of cv. Lord (the first year of the research) to 65.86 mg kg^{-1} d.w. in the head of cv. Agassi (the second year of the research). The highest mean content of zinc was found in the head of cv. Agassi, whereas the lowest content was observed in the head of cv. Lord and it did not differ significantly from the content of zinc found in the heads of the cultivars Tiburon and Stell. Acikoz (2011) observed a lower content of zinc (from 35.21 to 35.87 mg kg^{-1} d.w.) in four broccoli cultivars. On the other hand, Bosiacki and Golcz (2004) found 45.78 mg Zn kg^{-1} of dry weight in the broccoli heads.

The content of manganese ranged from 13.43 mg kg^{-1} d.w. in the head of cv. Monaco (the first year of the research) to 25.24 mg kg^{-1} d.w. in the head of cv. Agassi (the second year of the research). The highest mean content of manganese was found in the head of cv. Agassi and it did not differ significantly from the content of this metal in the head of cv. Ironman . The lowest content of manganese was found in the head of cv. Monaco and it did not differ significantly from the content in the heads of such cultivars as Beaumont, Lord, Tradition, Monopoly, Monte Carlo, Tiburon and Stell. Acikoz (2011) observed a higher content of manganese in the broccoli heads (from 30.11 to 39.21 mg kg^{-1} d.w.).

The content of nickel ranged from 0.51 mg kg^{-1} d.w. in the head of cv. Tiburon (first and second year of the research) to 1.32 mg kg^{-1} d.w. in the head of cv. Monte Carlo (the second year of the research). The highest mean content of nickel was found in the head of cv. Monte Carlo and it did not differ significantly from the content of this metal in the head of cv. Beaumont. The lowest content of nickel was found in the head of cv. Tiburon. Bosiacki and Roszyk (2012) observed that the content of nickel in vegetables varied depending on the plant organ which was its edible part. For example, they observed most nickel in vegetables with edible leaves, less in root vegetables, and the lowest nickel content in vegetables with edible fruit.

Kramářová et al. (2009) suggested that broccoli did not accumulate cadmium or lead. In our research, however, the content of cadmium ranged from 0.03 mg kg^{-1} d.w. in the head of cv. Tiburon (the first year of the research) to 0.54 mg kg^{-1} d.w. in the head of cv. Beaumont (the first year of the research). The highest mean cadmium content was found in the head of cv. Beaumont, whereas the lowest content of this metal was found in the head of cv. Tiburon.

The content of lead ranged from 0.58 mg kg^{-1} d.w. in the head of cv. Lord (the first year of the research) to 1.31 mg kg^{-1} d.w. in the head of cv. Monte Carlo (the first year of the research). The highest mean lead content was found in the head of cv. Monte Carlo and it did not differ significantly from the content of lead observed in the head of cv. Agassi. On the other hand, the lowest content of this metal was found in the head of cv. Lord and it did not differ significantly from the content of lead observed in the heads of the cultivars Tiburon and Monaco. Tyksiński et al. (1993) analysed the content of cadmium and lead in vegetables, noting that it was the highest in root vegetables and the lowest in the vegetables where fruit was the edible part. In the research by Bosiacki (2007), the lowest content of cadmium and lead was also found in the vegetables with edible fruit, whereas leaf vegetables had the highest content of these metals. The Official Journal of the Republic of Poland of 4 March 2003, as well as the Regulation of the Minister for Health of 13 January 2003 on the maximum acceptable levels of chemical and biological contamination in plant products state that the content of cadmium in fresh and frozen Brassicaceae vegetables should not exceed 0.05 and the content of lead should not exceed 0.30 mg kg^{-1} of fresh weight. In our research, the average content of the dry weight of broccoli heads was 9%. The results on the content of cadmium and lead in the broccoli heads were presented in milligrams per kilogram of dry weight. Therefore, in order to refer to the standard, they were converted into milligrams per kilogram of fresh weight. The acceptable content of cadmium in Brassicaceae vegetables is 0.55, and the acceptable content of lead is 3.33 mg kg^{-1} of dry weight. The maximum acceptable content of cadmium and lead was not exceeded in the heads of the broccoli cultivars under investigation (Table 3).

The content of total phenolic compounds

In both years of the experiment, there were significant differences between the cultivars in the content of phenolic compounds. In the first year of experiment, the highest content of phenols was noted in the broccoli cultivars Tradition and Steel (above 1000 mg kg^{-1} f.w.), and in the second year the cultivars Steel and Tiburon proved the richest in these compounds (930--940 mg kg^{-1} f.w). In both years, the lowest content of phenols was found in cv. Agassi (566 mg kg^{-1} f.w in first year and 593 mg kg^{-1} f.w in second year) – Table 4.

In the study conducted by Kaur et al. (2007), which comprised 8 cultivars, the content of phenols was very low and ranged from 166 to 414 mg

Table 3

The content of heavy metals in heads of ten broccoli cultivars (mg kg^{-1} d.w.)

Metal	Year of study	Cultivar									
		Agassi	Beaumont	Ironman	Lord	Monaco	Monopoly	Monte Carlo	Stell	Tiburon	Tradition
Fe	I	43.62 *e**	31.45 *abc*	28.86 *ab*	25.85 *a*	31.23 *abc*	32.71 *bc*	28.90 *ab*	29.21 *abc*	28.89 *ab*	32.54 *bc*
	II	54.14 *f*	40.40 *de*	38.81 *de*	32.31 *bc*	39.6 *de*	42.30 *e*	39.74 *de*	35.5 *cd*	35.36 *cd*	41.88 *e*
Mean		48.88 *d*	35.93 *bc*	33.84 *bc*	29.08 *a*	35.40 *bc*	37.50 *c*	34.32 *bc*	32.34 *ab*	32.13 *ab*	37.21 *c*
Cu	I	5.52 *efg*	4.28 *a-d*	4.59 *a-e*	3.89 *ab*	4.07 *abc*	3.95 *abc*	4.72 *b-f*	3.85 *ab*	3.69 *a*	3.70 *a*
	II	6.98 *h*	5.61 *fg*	5.90 *g*	4.61 *a-f*	5.46 *efg*	5.36 *efg*	5.85 *g*	5.40 *efg*	5.13 *d-g*	4.91 *c-g*
Mean		6.25 *c*	4.95 *ab*	5.25 *b*	4.25 *a*	4.77 *ab*	4.65 *ab*	5.29 *b*	4.62 *ab*	4.41 *a*	4.30 *a*
Zn	I	64.90 *f*	52.42 *cde*	48.81 *a-e*	42.32 *a*	51.93 *b-e*	55.63 *e*	53.76 *e*	44.91 *a-d*	44.46 *abc*	55.49 *e*
	II	65.86 *f*	55.05 *e*	49.55 *a-e*	44.36 *ab*	52.53 *de*	52.72 *de*	54.20 *e*	44.73*a-d*	43.45 *a*	51.69 *b-e*
Mean		65.38 *d*	53.73 *c*	49.18 *bc*	43.34 *a*	52.232 *c*	54.18 *c*	53.98 *c*	44.82 *ab*	43.95 *a*	53.59 *c*
Mn	I	19.94 *cd*	13.57 *a*	17.64 *abc*	14.68 *ab*	13.43 *a*	16.93 *abc*	17.28 *abc*	17.16 *abc*	16.82 *abc*	16.32 *abc*
	II	25.24 *e*	17.22 *abc*	22.97 *de*	17.91 *a-d*	17.07 *abc*	19.08 *bcd*	19.00 *bcd*	20.38 *cd*	20.01 *cd*	18.62 *a-d*
Mean		22.59 *c*	15.40 *a*	20.30 *bc*	16.30 *a*	15.25 *a*	18.01 *ab*	18.14 *ab*	18.77 *ab*	18.41 *ab*	17.47 *ab*
Ni	I	0.98 *bc*	1.22 *de*	0.86 *bc*	0.92 *bc*	0.94 *bc*	0.88 *bc*	1.24 *de*	1.06 *cd*	0.51 *a*	0.90 *bc*
	II	1.04 *cd*	1.24 *de*	0.86 *bc*	0.76 *b*	0.94 *bc*	0.88 *bc*	1.32 *e*	1.04 *cd*	0.51 *a*	0.87 *bc*
Mean		1.01 *cd*	1.23 *e*	0.86 *b*	0.84 *b*	0.94 *bcd*	0.88 *bc*	1.28 *e*	1.05 *d*	0.51 *a*	0.88 *bc*
Cd	I	0.39 *fgh*	0.54 *i*	0.35 *fg*	0.30 *efg*	0.22 *cde*	0.21 *cde*	0.34 *fg*	0.31 *efg*	0.03 *a*	0.13 *abc*
	II	0.40 *fgh*	0.49 *hi*	0.28 *def*	0.40 *fgh*	0.16 *bcd*	0.20 *cde*	0.42 *ghi*	0.30 *efg*	0.04 *ab*	0.12 *abc*
Mean		0.39 *e*	0.51 *f*	0.31 *de*	0.35 *de*	0.19 *bc*	0.21 *c*	0.38 *de*	0.30 *d*	0.03 *a*	0.12 *b*
Pb	I	1.06 *de*	1.01-*cde*	1.01 *cde*	0.58 *a*	0.68 *abc*	0.97 *b-e*	1.31 *e*	0.97 *b-e*	0.63 *ab*	0.79 *a-d*
	II	1.10 *de*	1.01 *cde*	1.00 *cde*	0.59 *a*	0.68 *abc*	1.00 *cde*	1.28 *e*	1.06 *de*	0.66 *abc*	0.88 *a-d*
Mean		1.09 *de*	1.01 *cd*	1.00 *cd*	0.58 *a*	0.68 *ab*	0.98 *cd*	1.29 *e*	1.01 *cd*	0.64 *ab*	0.83 *bc*

* means followed by the same letter do not differ significantly at $P = 0.95$

Table 4

The content of total phenolic compounds (mg kg^{-1} f.w.) in flower buds and stems of the broccoli

Cultivar	Buds		Mean	Stems		Mean
	I year	II year		I year	II year	
Agassi	566 *a**	593 *a*	580 *b*	340 *a*	452 *a*	396 *a*
Beaumont	930 *bc*	784 *bc*	857 *bcd*	503 *b*	497 *ab*	500 *ab*
Ironman	797 *ab*	859 *bcd*	828 *bcd*	458 *ab*	657 *a*	558 *ab*
Lord	982 *bc*	734 *ab*	858 *bcd*	470 *ab*	458 *a*	464 *a*
Monaco	975 *bc*	837 *bcd*	906 *bc*	520 *b*	479 *a*	500 *ab*
Monopoly	876 *bc*	768 *b*	822 *bcd*	435 *ab*	520 *a*	478 *ab*
Monte Carlo	595 *a*	704 *ab*	650 *ab*	413 *ab*	493 *a*	453 *a*
Steel	1036 *bc*	945 *d*	991 *d*	511 *b*	744 *b*	628 *b*
Tiburon	823 *ab*	932 *cd*	878 *bc*	469 *ab*	566 *ab*	518 *ab*
Tradition	1114 *c*	713 *ab*	914 *bc*	502 *b*	493 *a*	498 *ab*
Mean	869	787	828	462	536	499

* means followed by the same letter do not differ significantly at $P = 0.95$

kg^{-1} f.w. The phenolic content was expressed as mg GAE kg^{-1} f.w. A higher content of phenolics was reported by Kaur and Kapoor (2002) – 875 mg kg^{-1} f.w and Chu et al. (2002) – 808 mg kg^{-1} f.w. These data coincide with our results concerning the cultivars Monaco and Ironman in the second year, and the cultivars Monopoly, Tiburon and Ironman in the first year. Koh et al. (2009) described large variation in the total phenolic content, i.e. from 151.8 to 1213.8 mg kg^{-1} f.w.

Differences in the content of phenolic compounds are said to depend on cultivars, growing conditions (Gliszczyńska-Świgło et al. 2007), agronomic factors (Vallejo et al. 2003), different extraction methods (Kaur and Kapoor 2002). Another source of discrepancies is the different ways in which results are expressed. For instance, Chu et al. (2002) and Koh et al. (2009) expressed the total phenolic content as the mean values of milligrams of gallic acid equivalents per kg of vegetables; Kaur and Kapoor (2002) presented their results as mg catechol kg^{-1} of fresh weight material and our results were expressed as mg quercetin kg^{-1} f.w.

In our research, the content of total phenols in broccoli stems was lower (499 mg kg^{-1} f.w.) than in buds (828 mg kg^{-1} f.w.). This is consistent with the results demonstrated by Horbowicz and Babik (2005), who noted that the values for broccoli buds were almost twice as high as those for stems.

CONCLUSIONS

The results reported in this paper clearly show that the content of heavy metals, macronutrients and sodium in broccoli heads depend on a cultivar. The content of macronutrients and sodium in broccoli heads formed the following sequence: N > K > P > Ca > Mg > Na. The content of micronutrients in broccoli heads can be arranged as follows: Zn > Fe > Mn > Cu > Ni. The maximum acceptable content of cadmium and lead, which is established in the Regulation of the Minister for Health, was not exceeded in the heads of the broccoli cultivars under investigation. There were significant differences between the cultivars in the content of total phenols. A higher total content of phenols (a two-year average) was found in broccoli buds than in stems.

REFERENCES

Acikoz E.F. 2011. *Influence of different sowing times on mineral composition and vitamin C of some broccoli (Brassica oleracea var. italica) cultivars*. Scientific Res. Essays, 6(4): 760-765.

Bosiacki M., 2007. *The lead and cadmium content in edible parts of vegetables sold in the area of city of Poznań*. Rocz. AR Pozn., Ogrodn., 41: 427-432.

Bosiacki M., Golcz A., 2004. *Zinc and copper content in vegetables grown near communication routes in Środa Wielkopolska commune*. Rocz. AR Pozn., Ogrodn., 37: 13-17.

Bosiacki M., Roszyk J., 2012. *Nickel and chromium content in the edible parts of selected vegetables mineralised according to two methods*. Bromat. Chem. Toksykol., 2: 125-130. (in Polish)

Chu Y.F., Sun J., Wu X., Liu R. H., 2002. *Antioxidant and antiproliferative activities of common vegetables*. J. Agric. Food Chem., 50: 6910-6916. DOI: 10.1021/jf020665f

Farnham M.W., Grusak M.A., Wang M. 2000. *Calcium and magnesium concentration of inbred and hybrid broccoli heads*. J. Am. Soc. Hortic. Sci., 125: 344-349.

Farnham M.W., Kopsell D.A. 2009. *Importance of genotype on carotenoid and chlorophyll levels in broccoli heads*. Hort. Sci., 44(5): 1248-1253.

Gliszczyńska-Świgło A., Kałużewicz A., Lemańska K., Knaflewski M., Tyrakowska B. 2007. *The effect of solar radiation on the flavonol content in broccoli inflorescence*. Food Chem., 100: 241-245. DOI: 10.1016/j.foodchem.2005.09.048

Golcz A. 2011. *Soil salinity and acidity*. *Research methods in plant sciences*. Vol. 3. *Soil sickness*. Narwal S.S., Politycka B., Fengzhi Wu, Sampietro D.A. (eds). Studium Press LLC, Huston USA., 43-53.

Horbowicz M., Babik I. 2005. *Sulforaphane and flavonoid contents in chosen broccoli cultivars*. Veg. Crops Res. Bull., 61: 127–136.

House W.A., 1999. *Trace element bioavailability as exemplified by iron and zinc*. Field Crops Res., 60: 115-141.

Kaur C., Kumar K., Anil D., Kapoor H.C. 2007. *Variations in antioxidant activity in broccoli (Brassica oleracea* L.*) cultivars*. J. Food Biochem., 31: 621-638.DOI: 10.1111/j.1745-4514. 2007.00134.x

Kaur C., Kapoor H.C. 2002. *Anti-oxidant activity and total phenolic content of some Asian vegetables*. Int. J. Sci.Tech., 37: 153-161. DOI: 10.1046/j.1365-2621.2002.00552.x

Koh E., Wimalasiri K.M.S., Chassy A.W., Mitchell A.E. 2009. *Content of ascorbic acid, quercetin, kaempferol and total phenolics in commercial broccoli*. J. Food Comp. Anal., 22: 637-643. DOI: 10.1016/j.fca.2009.01.019

KOZIK E., Golcz A. 2011. *Plant nutrients. Research methods in plant sciences.* Vol. 3. *Soil sickness.* NARWAL S.S., POLITYCKA B., FENGZHI WU, SAMPIETRO D.A. (eds). Studium Press LLC, Huston USA, 2-141.

KRAMÁŘOVÁ D., ALTNGEREL B., LAZARKOVÁ Z. 2009: *Determination of heavy metals and nutrition values in broccoli.* Ecol. Chem. Eng. A, 16(12): 1585-1590.

KURILICH A.C., TSAU G.J., BROWN A., HOWARD L., KLEIN B.P., JEFFERY E.H., KUSHAD, M., WALLIG M.A., JUVIK J.A. 1999. *Carotene, tocopherol, and ascorbate contents in subspecies of Brassica oleracea.* J. Agric. Food Chem., 47(4): 1576-1581.

KURILICH A.C., JEFFERY E.H, JUVIK J. A., WALLIG M.A., KLEIN B.P. 2002. *Antioxidant capacity of different broccoli (Brassica oleracea) genotypes using the oxygen radical absorbance capacity (ORAC) assay.* J. Agric. Food Chem., 50: 5053-5057. DOI: 10.1021/jf025535l

KUSHAD M.M., BROWN A.F., KURILICH A.C., JUVIK J.A., KLEIN B.P., WALLIG M.A., JEFFERY E.H. 1999. *Variation of glucosinolates in vegetable crops of Brassica oleracea.* J. Agric. Food Chem., 47: 1541-1548. DOI: 10.1021/jf980985s

MOCEK A., DRZYMAŁA S. 2010. *The genesis, analysis, classification of soils.* Publishing company by Poznan University of Life Sciences. (in Polish)

MORENO D.A., CARVAJAL M., LÓPEZ-BERENGUER C., GARCIA-VIGUERA C. 2006. *Chemical and biological characterization of nutraceutical compounds of broccoli.* J. Pharm. Biom. Anal., 41(5): 1508-1522.

NOWOSIELSKI O. 1988. *The principles developed in gardening fertilizer recommendations.* Issue III supplemented, State Farm and Forest Publisher Warsaw. (in Polish)

ROSA E.A.S., HANEKLAUS S.H., SCHNUG E., 2002. *Mineral content of primary and secondary inflorescences of eleven broccoli cultivars grown in early and late seasons.* J. Plant Nutr., 25(8): 1741-1751. DOI: 10.1081/PLN-120006055

SIKORA E., CIEŚLIK E., LESZCZYŃSKA T., FILIPIAK-FLORKIEWICZ A., PISULEWSKI P.M. 2008. *The antioxidant activity of selected cruciferous vegetables subjected to aquathermal processing.* Food Chem., 107: 55-59. DOI: 10.1016/j.foodchem.2007.07.023

SINGLETON V. L., ROSSI J. JR. 1965. *Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents.* Amer. J. Enol. Vitic., 16: 144-158.

TYKSIŃSKI W., BREŚ W., GOLCZ A., KOMOSA A., KOZIK E., ROSZYK J. 1993. *The contents of Pb, Cd and other heavy metals in vegetables sold in Poznan.* Biul. Warzywn, 40: 25-31. (in Polish)

VALLEJO F., THOMAS-BARBERAN F.A., GARCIA-VIGUERA C. 2003. *Effect of climatic and sulphur fertilization conditions, on phenolic compounds and vitamin C, in the inflorescences of eight broccoli cultivars.* Eur. Food Res. Technol., 216: 395-401.