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Major, minor and trace metal composition of some selected vegetables

(Komposisi logam utama, minor dan surih dalam sayur-sayuran terpilih)

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Key words: major nutrients, toxic metals, root vegetables, stem vegetables, ICP-MS

Abstract

This paper describes the major, minor and trace metal composition of eight vegetables produced in the central region (CR) of Saudi Arabia. These vegetables, usually classified as modified stems or as modified roots, include potato, onion, string onion, garlic, carrot, radish, red radish and turnip. The dried samples of the vegetables were subjected to multi-element analysis using inductively coupled plasma mass spectrometry (ICP-MS) following microwave acid digestion in closed PTFE tubes.

In general, the vegetables contained higher amounts of potassium than that of sodium. The sum of the concentrations of Na, K, Ca, Fe, Mg and Mn was highest in garlic and lowest in peeled potato samples. The root vegetables (carrot, radish, red radish and turnip) were better sources of Ca and Na than the stem vegetables (potato, onion, and garlic) but the latter contained higher amounts of K, Fe, Mg and Mn. The average concentrations of Zn, Cu, Mo and V were higher in stem vegetables while Cr and Sr dominated in the root type vegetables. In terms of the toxic Pb, Cd and Ni contents, these vegetables were found to be much safer than those grown on the western region of Saudi Arabia and are well within the safety limits established by EEC standards. Further studies are highly essential in order to fully characterize the undesirable variations in the heavy metal content observed among vegetables grown in the two regions of Saudi Arabia.

Introduction

Foodstuffs of plant origin occupy the major part of human diet supplying energy, minerals and fibrous materials necessary for maintenance of proper metabolism and nutrition. Although the cereal grains are consumed as the main source of calorific input to human body, the inclusion of fruits and vegetables has been greatly emphasized to improve the amount as well as the bioavailability of essential minerals in the diet (Chiplonkar et al. 1993; Joshi and Agate 1995; Sanchez-Castillo et al. 1998). At the same time the vegetable foodstuffs may also become sources of non-essential toxic metals intake if the vegetables contain excessive amounts of those metals (Srikumar 1993). So, the analysis of heavy elements in various vegetables and other food items consumed by men is of primary

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importance. Determination of mineral constituents in individual foodstuffs also helps dietitians and nutritionists to compile national food composition tables and thus formulate special or modified diets.

Regular surveillance of trace elements in vegetables and other foodstuffs is carried out in developed countries in order to ensure food safety (MAFF 1998). In the last 10 years or so Saudi Arabia has started growing vegetables for its own consumption and presently a considerable portion of the vegetables and vegetable products consumed in the market are supplied by local farms (SAIR 1999). Unfortunately, there is a pronounced dearth of information pertaining to the proximate principals or elemental composition of vegetables grown in Saudi Arabia. Thus the present study was designed to initiate the process of evaluating vegetables and other foodstuffs in terms of mineral and toxic metal composition.

Inductively coupled plasma mass spectrometry (ICP-MS) has become a valuable instrumental method for trace and ultra-trace element analysis because of its high sensitivity, wide dynamic range and capability of multi-element analysis. This method has been widely used for multi-element characterization of various food items of both animal and plant origin (Shiraishi 1998; Falandysz et al. 2001; Thomas 2002). In the present study, eight varieties of vegetables produced in the central region of Saudi Arabia were analysed for their metal contents using ICP-MS. These vegetables, known as modified stems or as modified roots in botanical terms are grown in direct contact with the soil. The results were compared with data from other studies available in the scientific literature.

Materials and methods

Sample collection and handling

Eight vegetable species (2–5 kg each) were purchased from wholesale markets in Riyadh City during July–December 2002 and the sellers indicated on request the origin of the products. Vegetables other than potato were produced in the farming districts of Al-Kharj and Al-Qasim; potatoes were from Hail, all situated in the central region of Saudi Arabia. Potato, carrot, radish, red radish and turnip samples were washed three times with distilled water to remove surface contaminants and finally rinsed with deionised water. Dry skins of the onions and garlic were removed before washing.

The samples were then air dried on perforated plastic trays for 12 h. The edible part of each vegetable was collected on clean polyethylene sheet and cut into small pieces (1–2 cm) using a titanium knife. The mass was well mixed, 100–150 g portion was sampled by the method of quartering and weighed in a pre-cleaned porcelain crucible. The samples were finally dried (72 h) in a vacuum oven (VWR Scientific Model 1410) set at 40 ºC temperature and 65 kPa pressure. The dry residue was weighed, powdered in an agate mortar and stored in polypropylene bottles (Nalgene). Handling of vegetable samples at all stages in the laboratory was done by wearing appropriate hand gloves (rubber/vinyl). *Table 1* lists the vegetable species studied in this work.

Sample digestion

A representative portion (approx. 0.25–0.30 g) of the powdered sample was weighed in a PTFE tube (120 ml) and digested with 6.0 ml conc. HNO_3 and 1.0 ml 30% H_2O_2 using MILESTONE Model ETHOS 1600 Advanced Microwave Digestion System. The microwave heating programme was:

Step	1	2
Power (w)	250	400
Time (min)	5	10
Temp. (ºC)	165	195

After being cooled to ambient laboratory temperature, the digestion tube was opened inside a fume hood and the digest was quantitatively transferred to a 25 ml polypropylene flask and made to the mark with deionised water. Samples were digested

Table 1. Description of vegetable species studied

Common name	Scientific name	Vegetable type	Water content (%)
Potato	*Solanum tuberosum*	Modified stem	81.49
Onion	*Allium cepa*	Modified stem	92.26
String onion	*Allium porrum*	Modified stem	89.38
Garlic	*Allium sativum*	Modified stem	64.45
Garlic (China)*	*Allium sativum*	Modified stem	65.36
Radish	*Raphanus sativus*	Modified root	94.09
Red radish	*Raphanus sativus*	Modified root	95.07
Carrot	*Daucus carota*	Modified root	89.90
Turnip	*Brassica rapa* var. rapifera	Modified root	91.41

*Imported from China in Saudi Arabian market

Table 2. Typical operating conditions for ICP-MS measurement

Instrument	PE -SCIEX ELAN 6100
Sample introduction	
Nebulizer	Cross-flow type
Spray chamber	Scott-type
Sample uptake (ml/min)	1.2
Wash solution	1v/v% HNO_3
Plasma conditions	
RF frequency (MHz)	40
RF power (kW)	1.05
Outer gas flow (litre/min)	15.0
Auxiliary gas flow (litre/min)	1.0
Carrier gas flow (litre/min)	0.96
Mass analyzer	
Filter type	Quadruple rod
Scan mass range	2–242 a.m.u.
Number of points per peak	1
Number of scan sweeps	100
Dwell time per point	50 ms
Integration	100 times
Detection and data handling	
Lens voltage	Adjusted daily
Detector	26-segment dynode operating in both pulse and analogue modes
Data acquisition mode	Peak hopping
Instrument control and data analysis	ELAN 6000 software
Instrument tuning	Performed using a 10 mg/litre solution of Be, Mg, Cu, Pb and U

in a batch of six including at least one blank (acid mixture only) digestion. Each of the vegetable and Certified Reference Materials (CRM) samples was digested in triplicate.

Analysis

The vegetable digests obtained after microwave digestion were diluted 10 times with 1% HNO_3 and analysed for elemental concentration using a Perkin-Elmer Sciex 6100 ICP-MS spectrometer coupled with a *GILSON* peristaltic pump and a Perkin Elmer *AS-90* auto sampler unit. The optimized conditions for the ICP-MS operation are given in *Table 2.*

The instrument was set to run in the quantitative mode with 37 elements under the analysis scheme and each element was quantified against a 3-point calibration curve constructed with the responses from appropriate multi-element standard. A ^{103}Rh solution (20 mg/litre) previously mixed with each working solution was used as the internal standard. The resident software automatically made corrections for probable isobaric interference at certain mass numbers. The blank-corrected concentration data as given by the computer were further analysed to evaluate sample to sample variation and other statistical parameters using Microsoft Excel program. For some elements, standard addition calibration was adopted.

Chemicals and standards

All solutions were prepared with ultra-pure water (specific resistivity of 18 MW.cm) obtained from an E-pure (Barnstead, USA) purifier system. Super purity nitric acid (*SpA*, 68%) purchased from ROMIL Ltd., UK was used for sample digestion and dilutions. Hydrogen peroxide used in the digestion was of *Suprapur* grade (Merck, Germany). A multi-element standard solution (MES) containing 37 elements was prepared from Perkin-Elmer single element ICP-MS standards (1,000 or 10,000 mg/litre) and the working standards were prepared by serial dilution of the MES, immediately before use. The CRMs used for validating the analytical method were: 1) Tomato Leaves NIST-SRM 1573a, 2) Spinach Leaves NIST-SRM-1570a, and 3) Hay Powder IAEA-V-10, purchased from National Institute of Standards & Technology, USA or from International Atomic Energy Agency, Vienna, Austria. All digestion tubes and volumetric glassware used in this study were cleaned with acid (10% HNO_3/24 h) and washed several times with deionised water.

Results and discussion

Validation of the analytical method

Mineral nutrients like Na, K, Ca, Mg, and Zn are usually present in vegetable samples at mg/kg (0.1–20,000) levels whereas trace and toxic elements (Cu, Cr, Mo, V, Pb, Cd etc.) occur at mg/kg or lower levels (Rains 1991). ICP-MS is well suited for a multi-element analysis of such samples (Shiraishi 1998; Falandysz et al. 2001). Under the given conditions of sample digestion and ICP-MS measurement the accuracy and precision of the multi-element analysis of the vegetable samples was tested by analysing samples of Certified Reference Materials, and the results are given in *Table 3*.

It can be seen from the results that majority of the nutrient and toxic metals expected in vegetables can be measured with acceptable accuracy (within ±20%) using the present ICP-MS method (Shiraishi 1998). However, Al (–5.9 to 53.4%), As (–79.4 to 175.0%) and Se (183.8 to 2844.4%) showed the widest variations of concentration from the certified values. In a view to improve the accuracy, the analysis of CRMs was repeated through standard addition calibration. The observed concentration values for Na, Al, Fe and Zn were improved to within ±6% of the certified or information values, for other elements the improvement was insignificant.

For the present analytical methodology, the detection limit values corresponding to 3 times the standard deviation of the analytical blank response (Long and Winefordner 1983) were found to be: 30–50 for Fe, Ca, Na; 5–10 for B, Al; 2–5 for Sn, Zn, Cu, K, Mg; 1–2 for Li, Ba; 0.1–1.0 for Zr, Se, Sc, Mo, Pb, Ni, Mn, Ti, Cr; 0.01–0.09 for As, V, U, Co, Sr; <0.01 for Cd, Cs, Bi, Th, Hf, Tl, Sm, La, and Rb, all expressed in mg/litre unit. These values are well below the concentrations of the concerned elements expected in the working digests of the vegetable samples and are highly suitable for the multi-element analysis programmme (Shiraishi 1998). Shiraishi (1998) reported the determination of 15 elements (Li, V, Cr, Mn, Co, Ni, Cu, Mo, Cd , Ba, Cs, Sr, Rb, Th and U) in various food groups (accuracy ±30%) using semi-quantitative ICP-MS. For Sr, Th and U, the results of semi-

Table 3. Multi-element analysis of Certified Reference Materials (CRM) using ICP-MS after closed vessel microwave digestion with HNO_3 and H_2O_2

Element	[a]Data for tomato leaves (NIST-SRM-1573a)			Data for spinach leaves (NIST-SRM-1570a)			Data for hay powder (IAEA-V-10)		
	Observed conc.	Certified conc.	[b]RPV	Observed conc.	Certified conc.	RPV	Observed conc.	Certified conc.	[b]RPV
Na	164	136	20.6	18100	18180	-0.4	464	500	-7.2
Mg	11800	12000	-1.7	8370	8900	-6.0	1150	1360	-15.4
Al	563	598	-5.9	207	310	-33.2	72.1	47	53.4
K	30700	27000	13.7	28400	29030	-2.2	18900	21000	-10.0
Ca	46900	50500	-7.1	14300	15270	-6.4	19000	21600	-12.0
V	0.918	0.835	9.9	0.598	0.570	4.9	0.219	–	–
Cr	2.33	1.99	17.1	1.950	–	–	6.53	6.5	0.5
Mn	271	246	10.2	78.2	75.9	3.0	48.1	47	2.3
Fe	422	368	14.7	297	–	–	199	186	7.0
Co	0.735	0.57	28.9	0.384	0.39	-1.5	0.147	0.130	13.1
Ni	1.32	1.59	-17.0	2.03	2.14	-5.1	3.79	4.20	-9.8
Cu	6.66	4.7	41.7	12.2	12.2	0.0	8.43	9.40	-10.3
Zn	36.1	30.9	16.8	76.7	82.0	-6.5	22.7	24	-5.4
As	0.308	0.112	175.0	0.014	0.068	-79.4	0.0135	–	–
Se	1.59	.054	2844.4	0.332	0.117	183.8	0.204	0.022	827.3
Rb	16.71	14.89	12.2	12.9	13	-0.8	6.88	7.60	-9.5
Sr	85.7	85	0.8	56.0	55.9	0.2	41.4	40	3.5
Mo	0.481	0.46	4.6	0.455	–	–	0.81	0.90	-10.0
Ag	0.0183	0.0170	7.6	0.0275	–	–	0.0121	–	–
Cd	1.53	1.52	0.7	2.61	2.89	-9.7	0.0332	0.0300	10.7
Cs	–	–		0.021	–	–	0.0182	0.0170	7.1
Ba	69.5	63	10.3	6.31	–	–	6.12	6.00	2.0
Pb	0.776	–		0.168	0.2	-16.0	1.47	1.60	-8.1
Th	–	–		0.0386	0.048	-19.6	.0769	–	–
U	0.0336	0.0350	-4.0	0.166	0.150	10.7	0.0052	–	–

*RPV = Relative percent variance, calculated as $RPV = \frac{(\text{measured value} - \text{certified value})}{\text{certified value}} \times 100$

quantitative and the quantitative approaches agreed within ±10%. Falandysz et al. (2001) determined 33 elements including Th, U and the rare-earths in wild mushroom samples using double focused high resolution ICP-MS, the reported accuracy for CRMs being better than ±5%. In the present study, 23 elements could be determined in the CRMs within ±20% accuracy and the analytical performance of the present method may fall in between the semi-quantitative and the high-resolution modes of ICP-MS.

Macroelement composition of the vegetables

The vegetable samples studied in this work can be classified in two groups, namely, the modified stems (onions, potato and garlic) and the modified roots (carrot, radish, red radish and turnip). *Table 4* lists the concentrations of Na, K, Ca, Mg, Fe and Mn found in the vegetables grown in the central region of Saudi Arabia, on fresh weight basis. The concentration of those metals measured in garlic imported from China is also included for comparison. In general, all these vegetables contained higher concentration of potassium than that of sodium which is consistent with other reports (Marsh and Koons 1983; Srikumar 1993). The root vegetables are better sources of Ca (254.6–471.7 mg/kg) and Na (498.3–714.5 mg/kg) than the stem vegetables. On the contrary, the stem

Table 4. Concentration of major minerals in vegetables studied in this work on fresh weight basis

	Concentration in various vegetable species* (mg/kg)									
	Potato (unpeeled)	Potato (peeled)	Onion	String onion	Garlic (Saudi)	Garlic (China)	Radish	Red radish	Turnip	Carrot
Na	73.1	133.1	130.5	75.9	123.6	118.2	695.5	714.5	498.3	699.2
K	4363	1302	1593	2741	4835	5141	712	1481	2027	2949
Ca	74.3	87.2	279.7	206.2	138.5	120.7	353	254.6	471.7	325.1
Mg	204.2	177.8	118.6	143.4	216.2	262.9	107.9	123.3	87.1	83.5
Fe	14.01	6.12	2.70	3.09	9.88	9.93	1.73	2.56	2.24	4.95
Mn	1.56	1.36	0.78	1.65	2.87	4.41	0.61	0.56	1.34	0.79

*Each concentration value is the average of six individual samples. The relative standard deviation (RSD) for triplicate measurement of individual samples varied in the range 3.8–14.3% from the mean

Table 5. Minor and trace metals composition of vegetables produced in the central region of Saudi Arabia

Elements (conc. unit)	Concentration in various species									
	Potato (unpeeled)	Potato (peeled)	Onion	String onion	Garlic (Saudi)	Garlic (China)	Radish	Red radish	Turnip	Carrot
Zn (mg/kg)	3.61	3.09	2.23	4.56	8.86	8.48	1.41	1.21	1.51	3.17
Cu (mg/kg)	1.41	1.26	0.57	0.89	1.23	2.43	0.15	0.12	0.3	0.72
Mo (μg/kg)	80.1	62.5	31.5	40.1	186.4	72.7	89.4	47.8	16.6	29.3
Cr (μg/kg)	39.4	36.0	28.6	30.7	37.6	46.9	68.9	44.2	68.6	99.0
V (μg/kg)	11.5	7.7	5.5	7.4	34.4	27.1	10.0	15.7	8.2	3.8
Co (μg/kg))	36.5	52.3	6.5	8.7	8.1	3.2	4.6	10.4	11.6	4.6
Sr (mg/kg)	1.20	1.12	3.25	2.91	3.48	2.28	5.32	4.84	7.55	7.23
Ba (mg/kg)	0.19	0.15	0.15	0.16	0.12	1.61	0.06	0.07	0.45	0.75
Rb (mg/kg)	1.23	1.24	0.48	0.71	1.13	2.47	0.48	0.38	0.78	1.26

vegetables are better in their K (1,302–4,835), Fe (2.7–14.0), Mg (118.6–216.2) and Mn (0.78–2.87 mg/kg) contents. As far as the nutritive value for human consumption is considered, the vegetables analysed in this work were found to be poor sources of Ca (74.3–471.7 mg/kg) and Fe (1.73–14.00 mg/kg) in comparison to cereals and leafy vegetables but rather better sources of K (0.712–5.141 g/kg) (Marsh and Koons 1983; Srikumar 1993). The major minerals content of the studied vegetables in terms of the sum of concentrations of Na, K, Ca, Mg, Fe and Mn decrease in the order: garlic (5.326 g/kg) > potato, unpeeled (4.730 g/kg) > carrot (4.063 g/kg) > string onion (3.171 g/kg) > turnip (3.088 g/kg) > red radish (2.577 g/kg) > onion (2.125 g/kg) > radish (1.870 g/kg) > potato, peeled (1.707 g/kg). Removal of the skin of the potato for cooking seems to greatly reduce the nutrient level, especially in terms of the K content. The concentrations of Na, Ca and some minor elements (to be found in later tables) are slightly higher in peeled potato compared to the unpeeled sample. This was also observed in previous studies (Sanchez-Castillo et al. 1998).

Minor and trace elements

The concentrations of Cu, Zn, Mo, Cr, Co, V, Sr, Ba and Rb found in the vegetable samples collected from Saudi Arabian markets (CR) are shown in *Table 5*. The four elements, zinc, copper, chromium and molybdenum are known to be essential in human nutrition at trace concentrations (Bowen 1979; Reusser and McCarron 1994; Türkdogan et al. 2002). The beneficial effect of chromium is derived only when it exists at its trivalent state, the hexavalent Cr being a potent carcinogen and extremely toxic to animals and humans (Gibb and Chen 1989; Zayed et al. 1998). The roles played by the trace elements like V, Co, Rb, Sr, Ba in human body are not known with certainty. Nevertheless, excessive concentration of any of the metals included in this group may have adverse effects on human health (Bowen 1979; Reusser and McCarron 1994).

The vegetable species analysed in this work show variable concentration of zinc ranging from 1.21 mg/kg in red radish to 8.86 mg/kg in garlic *(Table 5)*. The stem type vegetables contain higher Zn concentration (Ave = 4.47 ± 2.56 mg/kg) than the root vegetables (Ave = 1.83 ± 0.91 mg/kg). This may be due to organ specific mineral utilization in plant cells (Peterson 1979). The zinc values for the present vegetable species (1.21–8.86 mg/kg) were higher than those grown in India (0.8–1.0 mg/kg) (Srikumar 1993). Copper concentration also had the similar trend of variability, the stem vegetables possessing an average of 1.07 ± 0.34 mg/kg Cu. The average concentration for the root vegetables was 0.32 ± 0.28 mg/kg.

Chromium and molybdenum were found to occur at μg/kg level in the vegetables under study. The molybdenum content ranged widely from 16.6 μg/kg (turnip) to183.6 mg/kg (garlic). The stem vegetables showed higher Mo contents (Ave = 82.04 ± 59.80 μg/kg) than the root vegetables (Ave = 23.95 ± 7.04 μg/kg). The chromium concentration of the root vegetables (Ave = 70.18 ± 18.21) is substantially higher than that of stem vegetables (Average = 34.46 ± 4.61 μg/kg). This could be expected on the basis of the unique uptake and translocation properties of chromium ions in plant tissues as observed in the literature (Zayed et al. 1998).

The vanadium concentration of the stem vegetables ranged from 5.5 to 34.4 μg/kg (Ave = 14.70 ± 13.37). The range for the root vegetables was 3.8–15.7 μg/kg (Ave = 9.43 ± 4.93 μg/kg).

Potato contains much higher amount of cobalt (52.3 mg/kg) than the other vegetables analyzed in this study. The average concentration of the other six vegetables was found to be 7.21 ± 3.49 μg/kg. The root vegetables showed higher concentration of Sr (Ave = 6.24 ± 1.35 mg/kg) than the stem vegetables (Ave = 2.39 ± 1.14 mg/kg).

The barium concentration of the stem vegetables was fairly homogeneous with an average of 0.15 ± 0.03 mg/kg. The root vegetables on the other hand greatly varied in their Ba content, the average being 0.33 ± 0.33 mg/kg. The concentration of rubidium in the indigenous vegetables ranged from 0.38–1.26 mg/kg with an average of 0.80 ± 0.36 mg/kg.

Toxic metals

Table 6 gives the concentration of trace elements that are known to possess definite toxic effects on human health when ingested beyond permissible levels. These include Al, Ni, Ag, Cd, Pb and also two naturally occurring radioactive elements, U and Th.

Table 6. Toxic elements concentration in vegetable samples analysed in this study

	Potato (unpeeled)	Potato (peeled)	Onion	String onion	Garlic (Saudi)	Garlic (China)	Radish	Red radish	Turnip	Carrot
Al (mg/kg)	4.77	2.45	3.54	2.48	4.79	6.11	1.11	1.04	1.81	2.55
Ni (μg/kg)	85.6	96.8	35.0	244.9	131.1	91.9	32.9	29.2	67.1	114.9
Ag (μg/kg)	2.5	1.9	1.7	1.4	4.7	6.6	0.6	0.9	1.6	1.4
Cd (μg/kg)	39.8	19.7	11.1	10.6	12.7	9.6	7.2	11.5	25.7	6.9
Pb (μg/kg)	17.6	13.3	29.9	15.3	14.8	29.7	9.6	7.9	5.6	15.9
Th (μg/kg)	0.021	0.07	0.014	0.033	0.039	0.081	0.082	0.045	0.048	0.034
U (μg/kg)	0.119	0.201	0.280	0.254	0.261	0.226	0.412	0.083	0.521	0.126

There are plenty of data available in the scientific literature on the concentration of toxic lead, cadmium, uranium and thorium and much less information on toxic nickel, aluminum and silver content in various foodstuffs (Shiraishi 1998; Lopez et al. 2000).

Aluminum was present in the studied vegetable species in rather small amounts ranging from 1.1 mg/kg (radish) to 4.79 mg/kg (garlic), the average being 2.50 ± 1.17 mg/kg. López et al. (2000) reported the aluminum contents of 12 vegetables of Spanish produce including potato, carrot and garlic. The range of Al concentration was 0.311–6.973 mg/kg fw with an average concentration of 2.12 ± 1.95 mg/kg. The highest concentration was found in garlic. The variation of Al concentration found in the present study (garlic>potato>carrot) closely resembles pattern observed by López et al. (2000).

The nickel concentration varied widely among the Saudi grown vegetables in the range 29.2 (red radish) to 244.9 µg/kg (string onion) with the average of the eight vegetables at 93.1 ± 67.8 µg/kg. The silver concentrations in the vegetables were low having an average of 2.33 ± 1.88 µg/kg.

Among the Saudi grown vegetables studied in this work, the highest concentration of toxic lead was found in onion (29.9 µg/kg) and the lowest in turnip (5.6 µg/kg). The average for the eight varieties comes out to be 14.58 ± 7.52 µg Pb/kg. Cadmium concentration had a range of 6.90 (carrot) to 39.8 (unpeeled potato) µg/kg in the eight vegetables and the average was 16.13 ± 10.72 µg/kg fw. The concentration values of both lead and cadmium found for the studied vegetables were well below the limit (100 µg/kg) proposed by European Commission Regulation (ECR 1995).

Thorium was present in the range of 0.021–0.082 µg/kg (Ave = 0.043 ± 0.021) while uranium was found to occur at 0.083–0.521 µg/kg (Ave = 0.221 ± 0.143) in the studied vegetable species.

Elemental composition data of vegetables and vegetable foodstuffs produced in Saudi Arabia has been very rare in the scientific literature. A report by Mohamed et al. (2003) describing concentrations of 12 elements (Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Zn) in 15 vegetables grown in the Al-Taif district situated in the western region (WR) of Saudi Arabia has recently appeared in the literature. The concentrations of metal nutrients (Na, K, Ca, Mg, Fe, Cu and Zn) in three vegetable species commonly studied by Mohamed et al. (2003) and by us are compared in *Table 7,* along with data reported for similar vegetables of German, Mexican and UK origin.

It is seen that the vegetables grown in Al-Taif are extremely deficient in their potassium, zinc and copper contents compared to those produced in the central region of Saudi Arabia (this study), Germany, Mexico and UK. An unusual observation in the elemental data provided by Mohamed et al. (2003) is the unexpectedly lower values for K:Na concentration ratios in the Al-Taif vegetables; 12 out of 15 species studied by them showed this ratio to be <1. In vegetables and other plant materials the concentration of K is usually much higher than that of Na (Marsh and Koons 1983; Srikumar 1993) as is seen for German, Mexican and British products in *Table 7.* Occurrence of higher K contents (K:Na = 10–40) in plant materials is also supported in other studies (Udoessin and Aremu 1991; Falandysz et al. 2001).

It can be easily envisaged that the vegetable species from Al-Taif area (as reported by Mohamed et al. 2003) contain exceedingly higher amounts of toxic Pb, Cd and Ni compared to those produced in the central region of Saudi Arabia (this study). Similar situation also holds for Al-Taif species when compared with the data for German (Brüggemann et al. 1995) and British (MAFF 1998) products *(Figure 1).* The Cd concentration values reported by

Table 7. Comparison of mineral contents among vegetables of different origin

Element	Concentration (mg/kg) in potatoes				
	This study	Saudi (Al-Taif)[1]	German[2]	Mexican[3]	
Na	476	2720	–	562	
K	28405	1700	–	26966	
Ca	484	384	290	–	
Mg	1329	1668	1200	1011	
Fe	39.9	48.2	27.0	22.5	
Zn	23.5	4.5	14.0	11.2	
Cu	9.2	0.88	4.9	3.9	
K:Na ratio	60	< 1	–	48	
	Concentration (mg/kg) in carrots				
	This study	Saudi (Al-Taif)[1]	Mexican[3]	German[4]	UK[4]
Na	6919	6540	5200	5100	2500
K	28181	1980	22596	24600	16700
Ca	3217	5634	3215	3500	2500
Mg	826	1736	1513	1500	300
Fe	49.0	29.4	9.5	–	–
Zn	31.3	9.6	ND	–	–
Cu	7.1	0.98	5.6	–	–
K:Na ratio	4	< 1	4	5	6.68
	Concentration (mg/kg) in onions				
	This study	Saudi (Al-Taif)[1]	Mexican[3]	German[4]	UK[4]
Na	1686	280	900	700	300
K	20580	2360	20900	14100	14500
Ca	3614	7450	3600	2500	2300
Mg	1531	2000	2500	900	400
Fe	34.8	93.6	30.0	–	–
Zn	28.8	17.6	11.0	–	–
Cu	7.34	2.81	5.0	–	–
K:Na ratio	12.2	8.4	23.2	20.1	48.3

Source: [1]Mohamed et al. (2003); [2]Brüggemann et al. (1995); [3]Sanchez-Castillo et al. (1998); [4]Data quoted by Sanchez-Castillo et al. (1998)

Mohamed et al. (2003) for potato, carrot and onion are 3.3, 11.9 and 5.3 times higher than values found in this study. The Cd concentration in Al-Taif potato is 7.9 times higher than that in German potatoes. The Pb concentrations found by Mohamed et al. (2003) in the 3 vegetables are 24.4, 50.6 and 26.7 times higher than our values. Their value for Pb in potato is likewise 46.1 higher than potatoes produced in Germany.

It is clear from the comparison that the vegetables grown in the central region of Saudi Arabia are much safer than those produced in the western region (Al-Taif) for human consumption in terms of Pb, Cd, Ni and Co and are comparable to those of German and British origin. The concentration of the four toxic metals in potato, carrot and onion produced in the central region of Saudi Arabia are well within the limit set by EEC regulations (ECR 1995).

In view of the unusually low K:Na concentration ratios and exceedingly high abundance of toxic metals (Pb, Cd, Ni) observed by Mohamed et al. (2003) for vegetables grown in Al-Taif it appears deem necessary to undertake immediate and extensive studies on the vegetables and other foodstuff produced in that area to ensure

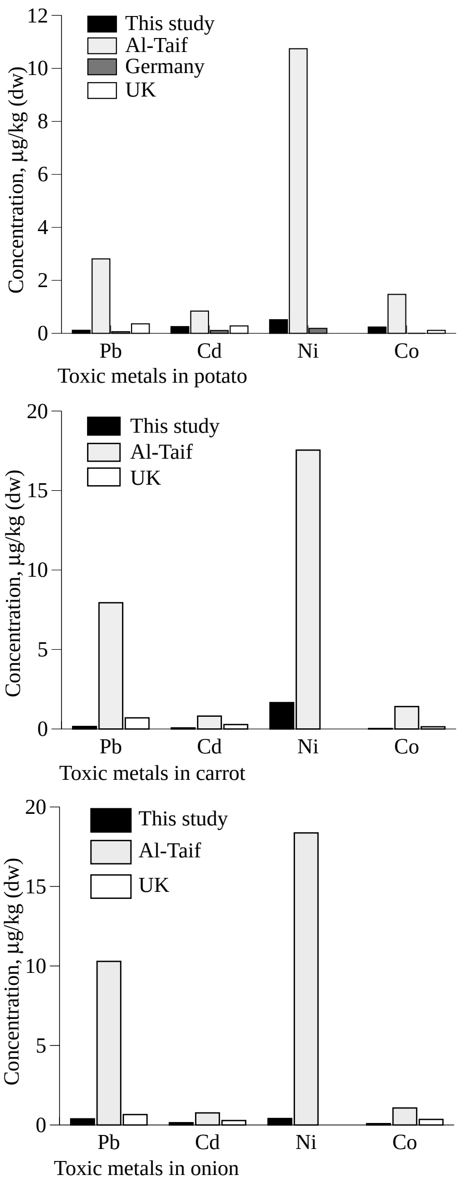

Figure 1. Comparison of potatoes, carrots and onion of different origin in terms of toxic metal (Pb, Cd, Ni, Co) composition

safety of the population consuming those products. In fact, the elemental composition for some vegetables reported by Mohamed et al. (2003) resembles those of the endemic upper gastrointestinal cancer region of Turkey (Türkdogan et al. 2002). More importantly, the district of Al-Taif is well-known for production of some exotic fruits of Saudi Arabia.

Conclusion

This study provided the concentration of 22 elements in 8 vegetables grown in the central region of Saudi Arabia. While dietary intake of major nutrients like Na, K, Ca, Mg and Fe can be supplemented by other food items, the assessment of toxic metals is important even in individual foodstuffs. In this respect, the vegetables studied in this work are quite safe for human consumption in terms of toxic metal (Pb, Cd, Ni, Al) contents. In view of wide and undesirable variations in the heavy metal composition observed between vegetables grown in the central and the western regions of Saudi Arabia, the immediate need for further study is evident.

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Abstrak
Artikel ini membincangkan komposisi logam utama, minor dan surih dalam lapan jenis sayur yang ditanam di wilayah tengah (CR) Arab Saudi. Sayur-sayuran termasuklah kentang, bawang, string onion, bawang putih, lobak merah, radish, red radish dan turnip. Sampel kering dianalisis menggunakan ICP-MS selepas melalui sistem pencernaan asid ketuhar gelombang di dalam tiub PTFE yang tertutup.

Secara amnya, sayuran ini mengandungi jumlah K yang lebih tinggi daripada Na. Jumlah kepekatan Na, Ca, Fe, Mg dan Mn adalah tinggi dalam bawang putih dan paling rendah dalam kentang yang sudah dibuang kulit. Sayur berubi (lobak merah, radish, red radish dan turnip) merupakan sumber Ca dan Na yang lebih baik daripada sayur batang (kentang, bawang dan bawang putih) tetapi sayur batang ini mempunyai jumlah K, Fe, Mg dan Mn yang tinggi. Kepekatan purata Zn, Cu, Mo dan V adalah tinggi dalam sayur batang manakala Cr dan Sr lebih banyak dalam sayur berubi. Dari segi kandungan toksik Pb, Cd dan Ni, sayuran ini adalah lebih selamat daripada sayur yang ditanam di wilayah barat Arab Saudi. Sayuran ini juga adalah dalam had keselamatan mengikut standard EEC. Kajian lanjut diperlukan untuk mencirikan variasi kandungan logam berat yang terdapat di dalam sayur yang ditanam di dua wilayah Arab Saudi ini.

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