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ARSENIC AND OTHER TRACE ELEMENTS IN BOVINE LIVER AND KIDNEY FROM A NATURALLY CONTAMINATED AREA IN ARGENTINA

Arsénico y otros elementos traza en hígado y riñón de bovinos de una zona naturalmente contaminada en Argentina

Cristina Viviana ALVAREZ GONÇALVEZ[1], Flavia Elisa ARELLANO[1,2,3]**, Simone BRAEUER[4], Walter GÖESSLER[5], Alicia FERNÁNDEZ CIRELLI[1,2,3] and Alejo Leopoldo PÉREZ CARRERA[1,2,3]*

[1] Centro de Estudios Transdiciplinarios del Agua (CETA- UBA). Facultad de Ciencias Veterinarias, Universidad de Buenos Aires. Avenida Chorroarín 280, CP C1427CWO, Buenos Aires, Argentina.
[2] Instituto de Investigaciones en Producción Animal (INPA). Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) -Universidad de Buenos Aires. Avenida Chorroarín 280, CP C1427CWO, Buenos Aires, Argentina.
[3] Cátedra de Química Orgánica de Biomoléculas. Facultad de Ciencias Veterinarias. Universidad de Buenos Aires. Avenida Chorroarín 280, CP C1427CWO, Buenos Aires, Argentina.
[4] BOKU University, Institute of Analytical Chemistry, Department of Natural Sciences and Sustainable Resources, Muthgasse 18, 1190 Vienna, Austria.
[5] Institute of Chemistry – Analytical Chemistry, University of Graz, Universitaetsplatz 1, 8010 Graz, Austria.

Author for correspondence: * alpc@fvet.uba.ar, ** farellano@fvet.uba.ar

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Key words: Cattle, tissue, trace elements, Latin America, human consumption, health risk.

ABSTRACT

In the South American Pampean Plain, high arsenic (As) concentrations are present in groundwater, exceeding, in some locations, 4 mg/L. Also, the concentrations of other elements, like selenium (Se), vanadium (V), molybdenum (Mo) or uranium (U), are elevated in this region. The elements could be taken up by crops, forages and animals, may be accumulated in tissues and have a negative impact on the health of the animals. Consumption of meat with elevated arsenic concentrations could be also a risk for human health. The aim of the present study was to determine the concentrations of As, Se, V, Mo and U in bovine liver and kidney samples and analyze the human health risk from its consumption. We found that the concentration of the elements present in liver and kidney samples were generally in accordance with the quality standards for food security set by national and international guidelines. Our results indicate that there is no health risk for consumers from the investigated elements, neither from kidneys nor from livers from the investigated regions.

Palabras clave: ganado, tejidos, elementos traza, Latinoamérica, consumo humano, análisis de riesgo.

RESUMEN

En las aguas subterráneas de la llanura pampeana sudamericana se encuentran presentes altas concentraciones de arsénico (As) , superando, en algunas localidades, los 4 mg/L. También en esta región son elevadas las concentraciones de otros elementos, como el selenio (Se), el vanadio (V), el molibdeno (Mo) o el uranio (U). Los elementos podrían ser absorbidos por cultivos, forrajes y animales, acumularse en los tejidos y tener un impacto negativo en la salud de los animales. El consumo de carne con concentraciones elevadas de arsénico también podría suponer un riesgo para la salud humana. El objetivo del presente estudio fue determinar las concentraciones de As, Se, V, Mo y U en muestras de hígado y riñón de bovinos y analizar el riesgo para la salud humana por su consumo. Encontramos que la concentración de los elementos presentes en las muestras de hígado y riñón estuvo en general de acuerdo con los estándares de calidad para la seguridad alimentaria establecidos por las directrices nacionales e internacionales. Nuestros resultados indican que no existe ningún riesgo para la salud de los consumidores a partir de los elementos investigados, ni de los riñones ni del hígado, de las regiones investigadas.

INTRODUCTION

The South American Pampean Plain is one of the largest pasturelands in the world, covering about 750 000 km^2 of fertile lowlands. Soil and weather conditions of the area turn this region into one of the most productive in South America from an agricultural point of view, but at the same time constitutes one of the largest regions of high arsenic (As) levels in groundwater on Earth, with up to more than 4 mg As /L (Bundschuh et al. 2004, Nicolli et al. 2012, Morales-Simfors et al. 2020, Bundschuh et al. 2021).

Arsenic is present in groundwater usually in its inorganic forms, arsenite or arsenate. In the Pampean aquifers its origin is related to tertiary loess deposits containing volcanic ash, and clastic sediments (Nicolli et al. 1989, Smedley et al. 1998, Smedley and Kinniburg 2002, Smedley et al. 2002, Bundschuh et al. 2004, Morales-Simfors et al. 2020, Bundschuh et al. 2021). Arsenic-contaminated groundwater is often used in the Argentinean Pampean Plain for livestock drinking water and to irrigate crops for both human and animal consumption. It can be taken up by plants and animals (Lei et al. 2013, Lei et al. 2015, Wu et al. 2016), which could potentially lead to As entering the human food chain. In animals, inorganic As can be methylated to organic arsenic species such as methylarsonate and dimethylarsinate. This methylation process reduces the acute toxicity and facilitates their excretion (Tseng 2009). There is evidence about the biotransference of arsenic to environmental matrices like plants (Wang et al. 2010, Perez-Carrera and Fernandez-Cirelli 2014). In the plant cell, the arsenic can be sequestered by vacuoles (Rosen 1999), complexed by phitoquelatines (Cullen et al. 1994), or methylated to less toxic forms (Maeda et al. 1992).

Arsenic is known to produce adverse health effects on animals and humans. It is one of the most relevant toxic elements present in Argentinian groundwater (Farias et al. 2003, Diaz et al. 2016, Blanco et al. 2017) and is classified as carcinogenic (IARC 2012, Roy et al. 2015, Li and Chen 2016, Khan et al. 2020). In this country, the endemic regional chronic hydroarsenicism (HACRE) due to the presence of high levels of As in water is an important health problem for the population (Lepori 2015). Also, it is thought to be related to diabetes (Maull et al. 2012, Park et al. 2016), cardiovascular dysfunction (Bianchi et al. 2013, Barchowsky et al. 2015), hepatoxicity (Hao et al. 2013, Bouaziz et al. 2015), neurotoxicity (Teng et al. 2015, Prakash et al. 2016), and nephrotoxicity (Jayasumana et al. 2013, Robles-Osorio et al. 2015).

In the South American Pampean Plain As in groundwater is often correlated with other trace elements such as molybdenum (Mo), selenium (Se), antimony (Sb), vanadium (V) or uranium (U) (Edmunds and Smedley 1996, Farias et al. 2003, Fiorentino et al. 2007, Nicolli et al. 2008, Rosso et al. 2011, Machado et al. 2020). In ruminants, Mo depresses Cu availability and can lead to Cu deficiency (Ward 1978, Thorndyke et al. 2021). Se is an essential element for animal nutrition. A deficiency in Se reduces appetite, growth, production, and reproductive fertility, muscle weakness, nutritional muscular dystrophy, and retained placenta in ruminants (WHO 1996, Fordyce 2013). As well, excessive Se ingestion could cause several respiratory diseases, tremors, kidney failure, heart attacks, and heart failure (ATDRS 2003). Several studies, carried out on different animal species and cell lines, showed that V has different effects and biological roles, both beneficial and harmful. For cattle, some studies showed that chronic poisoning with V can be associated with wasting, chronic diarrhea, intestinal absorption disorders, immunosuppression, rhinitis, conjunctivitis, and decubitus, resulting occasionally in death (Gummow et al. 1994, Gummow et al. 2005). Other authors discuss the role of V as a micronutrient (Mukherjee et al. 2004, Kawachi et al. 2006). However, the V metabolic role and the effects on cattle health and production have not been well studied in depth yet. Concerning uranium, its chemical toxicity is higher than its radiotoxicity (Health Canada 1987, Alexander et al. 2009, ATSDR 2013). It is known that U activates oxygen species (WHO 2001), resulting in damage to proteins, nucleic acids, and lipids (Lourenço et al. 2010, Al Kaddissi et al. 2011). Also, it affects the kidneys, in particular damaging proximal tubules and, at high doses, also the glomerulus (COT 2006, EFSA 2009). Intake of U can increase cancer risk and liver damage (USEPA 2019). However, the long-term effect of environmental U exposure is little known (Kurttio et al. 2002). Uranium may be transferred to animal tissues and animal foodstuffs from drinking water, representing a potential risk to human health (Anke et al. 2009). A Brazilian study showed that the main contributors to U ingestion are meat, milk, and flour (Santos et al. 2004). Trace elements present in feed and water could be transferred to cattle tissues. The present study aimed to determine the content of trace elements in bovine liver and kidney samples from a highly contaminated and also a less contaminated part of the Pampean Plain and analyze the human health risk from their consumption. This work provides valuable information to guide food policies and contributes to safe food production practices.

MATERIAL AND METHODS

Study area

This study was carried out in the Pampean Plain (Argentina). The region under study (**Fig. 1**) is one of the most important livestock production areas. In previous studies within this region, several authors (Pérez Carrera et al. 2007, 2014, and 2016) reported high levels of As and other trace elements in groundwater, related to the phreatic layer. The sample areas are located in Buenos Aires and the southeast of Córdoba (**Fig. 1**). Conversely, in Buenos Aires Province, information about As levels in groundwater is scarce, but in general, levels are lower than in the southeast of Córdoba Province (Pérez Carrera et al. 2007, 2014, and 2016).

Samples collection and preparation

Bovine liver (n = 63; 11 from Buenos Aires and 52 from Córdoba province) and kidney samples (n = 37; 10 from Buenos Aires and 27 from Córdoba

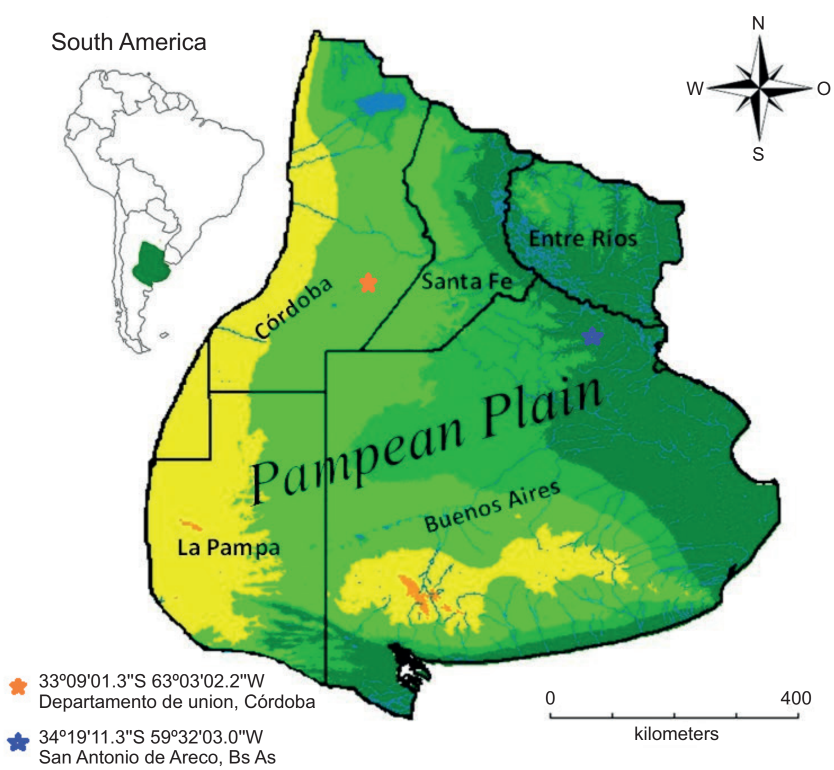

Fig. 1. Study area, Pampean Plain, Argentina. Map created with DIVA-GIS, GBIF.org. (2024) and software for images. Red star shows sampling sites.

province) were collected according to standard procedures directly after slaughter. All the slaughtered animals comply with the requirements of age, weight, and health established by the MAGyP, Resol. 32/2018.

The study areas were selected because they are regions of high livestock production. The samples were put in individual polypropylene bags and were conserved in darkness at 4ºC for transport to the laboratory. After that, the samples were freeze-dried with a lyophilizer (Labconco, USA) and stored at 4ºC until analysis. The water content was recorded.

Determination of element concentrations by inductively coupled plasma mass spectrometry (ICP-MS)

The concentrations of As, Mo, Se, U, and V were determined with inductively coupled plasma mass spectrometry (ICP-MS), using an Agilent 7500ce (Agilent, Waldbronn, Germany). As (m/z 75) and V (m/z 51) were measured in helium collision gas mode, Se (m/z 78) in hydrogen reaction gas mode, and Mo (m/z 98) and U (m/z 238) in no gas mode. The freeze-dried liver and kidney samples were pulverized in a coffee mill and digested in triplicate in a microwave-assisted digestion system (Milestone ultraCLAVE III, EMLS, Leutkirch, Germany) using 5 mL of concentrated nitric acid (Merck, Darmstadt, Germany) before being analyzed by ICPMS. For the quality control, DOLT-3, Dogfish Liver Certified Reference Material for Trace Metals, NRC-CNRC (Ottawa, Canada), SRM 1577b, Bovine Liver, NIST (Gaithersburg, USA), and BOVM-1, Bovine Muscle Certified Reference Material for Trace Metals and other Constituents, NRC-CNRC (Ottawa, Canada) were used. Limits of detection (LOD) were U: 2 µg/kg, V: 3 µg/kg, As: 2 µg/kg, Se: 4 µg/kg, and Mo: 2 µg/kg dry mass (dm). The median values of the corresponding digestion blanks were subtracted from the concentrations. Germanium, indium, and lutetium were used as internal standards. Mean, median, confidence interval, maximum, and minimum values were calculated for each element. A correlation analysis between trace elements was performed. The results are given for the wet samples (wet mass, wm). The average water content was 70% for livers and 80% for kidneys. The trueness of the investigated reference materials found was between 85 and 115% of the certified As concentrations, 92 to 106% in the case of Se, 80 to 92% of the certified V concentrations (only around 50% in BOVM-1, but it is only listed there as "information value") and between 84 and 108% in the case of Mo. U was certified with standard reference material SRM 1640a (trueness of 95 +/- 4%).

Human health risk assessment

The concentration of trace elements in liver and kidney was compared with recommended limits set by the Argentinean Food Códex (CAA in Spanish, 2017), the Argentinean National Waste Management and Health Food Plan (Plan CREHA in Spanish, 2000), and the World Health Organization (WHO 1996 and 2001). Human health risk assessment was approached through the estimation of mean, median, and maximum target hazard quotient (THQij), the target cancer risk (TR), and the hazardous index (HI) for both tissues. The calculations were performed for adults, and considering both mean and median values, this last value could be more representative for some elements due to the high dispersion of data. A third, worst-case scenario, with the highest determined concentrations, was also calculated. In every case, the quotients and hazard index were calculated per tissue and area (Buenos Aires and Córdoba provinces) and considering the reference dose of individual element (Rfd in mg/ kg.day) (IRIS 1991). (See **Table I**). In all cases, 100% absorption of each element is assumed.

TABLE I. REFERENCE DOSES (RfD) FOR EACH ELEMENT (IRIS 1991).

Element	RfD [mg/kg/day]
As	3.10^{-4}
Mo	5.10^{-3}
Se	5.10^{-3}
U	3.10^{-3}
V	9.10^{-3}

The THQ was calculated (for non-carcinogenic risk) by the following equation (USEPA 1991) (Eq. 1):

$$THQij = (EF \times C \times IR \times ED) / (RfD \times BW \times AT) \quad (1)$$

Exposure frequency (EF) = 365 days/ year
Concentration (C) = value in mg/kg (wm).
Ingestion rate of adults (IR) = 0.0074 kg/day for liver intake and 0.0025 kg/day for kidney intake (according to López 2012, 8.87 kg of bovine viscera are consumed on average in Argentina per person per year) and supposing that liver represents 30% of visceral intake and kidney about 10% according to Moos et al. 2013). It is important to mention that it is calculated with a general visceral intake rate. However, in some countries or population groups,

the mean intake could be lower or higher than these values. The ingested dose was assumed to equal the absorbed contaminated dose, and that cooking does not affect the contaminants.
RfD = reference dose of individual element (mg/kg.day) (IRIS, USEPA 1991, 2024). See Table I
Exposure duration (ED) = 30 years for non-carcinogens (USEPA 1991)
Body weight (BW) = 65 kg for adults – estimated (Del Pino et al. 2005)
Averaging time (AT) = ED x 365 days/year (USEPA 1991)
i = using median (M), mean (X) or maximum (max) concentration values.
j = element

The TR was calculated only for As, due to the fact that it presents a carcinogenic risk, by the following equation, Eq. 2 (USEPA 1991):

$$TR_{ij} = (EF \times C \times IR \times ED \times CPSo) / (BW \times AT) \quad (2)$$

Exposure frequency (EF) = 365 days/year
Concentration (C) = value in mg/kg (wm)
Ingestion rate of adults (IR) = 0.0074 kg/day for liver intake and 0.0025 kg/day for kidney intake (also see explanation for Eq. 1)
CPSo = cancer slope factor (USEPA 1991). As CPSo = 1.5 × x 1/(mg/kg/day)
Exposure duration (ED) = 70 years for carcinogens (USEPA 1991)
Body weight (BW) = 65 kg for adults (Del Pino et al. 2005)
Averaging time (AT) = ED × 365 days/year (USEPA 1991)
i = using median (M), mean (X) or maximum (Max) concentration values
j = element

With these values the hazard index (HI) was calculated, which is defined as the total risk, through the Eq. 3:

$$HI = \Sigma\, THQ_{i} \quad {}_{i = \text{element}} \quad (3)$$

Statistical analysis

Data processing and statistics (mean, median, confidence interval and correlations) were performed using INFOSTAT software, using Kruskall-Wallis test, $p \leq 0.05$ and Spearman correlation coefficients, $p \leq 0.05$.

RESULTS AND DISCUSSION

Trace element concentrations

Results obtained from each tissue type and sampling area are shown in **Table II**. Previously reported values are listed in **Table II** as well.

According to previous information, As content in some kidney and liver samples from Córdoba Province were higher than those reported by other authors. The presence of As and other associated trace elements in bovine liver and kidney were reported by several authors (**Table II**). The highest levels of As (68 µg/kg wm in kidney and 46 µg/kg wm in liver) were found by López Alonso et al. 2000. Similar As levels (43.8 µg/kg in kidney and 38.5 mg/kg in liver) were also found by our laboratory and reported previously (Pérez Carrera 2006).

Regarding Se concentration, only some kidney samples from Córdoba exceeded the values determined by other authors (Kramer et al.1983, Fordyce et al. 2013). In the case of the analyzed liver samples, they presented higher Se concentrations for both provinces. In the case of V concentrations, all samples presented values higher than previously described. The Mo values determined in this work were similar to those described by other authors. On the other hand, the U concentrations determined were higher than those previously reported by other authors (**Table II**).

Significant differences in trace element levels between study areas (Buenos Aires and Córdoba) were observed (according to Kruskall-Wallis test, $p \leq 0.05$) for As and V levels in kidney and for As and U in liver samples. Some samples of bovine liver and kidney had As levels above the maximum recommended level (MRL) for human consumption by SENASA (Plan CREHA 2012 and 2018) (MRL As < 1 mg/kg). There are no recommended levels for the other elements in this SENASA guide (Plan CREHA 2012 and 2018).

In the studied tissues, significant correlations were found between V-As and Se-As. The values of Spearman correlation for the elements in each sampling area and tissue are in **Table III**. In kidney samples from Buenos Aires province (low contamination area), a significant correlation was found between As-V only, while in liver samples for the same area, a significant correlation was found between U-Se only. In the samples of Córdoba (high contamination area), significant correlations were found in kidney between As-V, Se-As and Se-V. Several authors have studied the interactions between As and Se (Levander et al. 1977, Zeng et al. 2005, Sun et al. 2014, Ozoani

TABLE II. MEAN, CONFIDENCE INTERVALS (CI), MEDIAN AND CONCENTRATION RANGES CALCULATED FOR EACH TISSUE AND PROVINCE. DIFFERENT LETTERS IN A PAIR INDICATE SIGNIFICANT DIFFERENCES BETWEEN THEM (ACCORDING TO KRUSKALL-WALLIS TEST, $p \leq 0.05$). ALL VALUES GIVEN IN µg/kg OF WET MASS (wm). REFERENCE VALUES REPORTED BY OTHER AUTHORS

Element	Tissue	Province	Mean ± CI	Median	Range (min-max)	Reference values reported	Reference
As	kidney	Buenos Aires	27 ± 7^{a}	27	(12 - 40)		López Alonso et al. 2000
		Córdoba	55 ± 7^{b}	50	(22 - 100)	17-68	Kramer et al. 1983
	liver	Buenos Aires	16 ± 6^{a}	13	(7.3 - 45)		Salisbury et al. 1991
		Córdoba	33 ± 5^{b}	32	(6.7 - 74)	10-46	Kluge-Berge et al. 1992
Se	kidney	Buenos Aires	960 ± 160^{a}	850	(660 – 1 350)		López Alonso et al. 2004
		Córdoba	1100 ± 90^{a}	1070	(770 – 1 800)	1 000-1 400	Blanco Penedo et al. 2006
	liver	Buenos Aires	490 ± 330^{a}	320	(140 – 2 150)		Dermauw et al. 2014
		Córdoba	300 ± 50^{a}	260	(100 – 1 390)	200	Vos et al. 1987
V	kidney	Buenos Aires	46 ± 19^{a}	32	(32 - 113)		Carvalho et al. 2010
		Córdoba	105 ± 30^{b}	89	(21 - 300)	<0.3	Anke et al. 2009
	liver	Buenos Aires	43 ± 28^{a}	27	(20 - 180)		Pérez Carrera 2006
							Pérez Carrera et al. 2010
		Córdoba	98 ± 42^{a}	42	(7.4 – 670)	<0.3	Salim et al. 2023
Mo	kidney	Buenos Aires	350 ± 40^{a}	340	(280 - 490)		
		Córdoba	390 ± 35^{a}	380	(250 - 540)	300-500	
	liver	Buenos Aires	860 ± 160^{a}	920	(350 – 1 150)		
		Córdoba	1040 ± 50^{a}	1030	(570 – 1 480)	1 100-1 400	
U	kidney	Buenos Aires	4.9 ± 1.6^{a}	4.4	(2.4 – 11)		
		Córdoba	3.9 ± 1.2^{a}	3.4	(0.6 – 17)	<8.8	
	liver	Buenos Aires	1.7 ± 1.0^{a}	1.4	(< 0.6 – 6.3)		
		Córdoba	0.5 ± 0.3^{b}	0.2	(< 0.6 – 8.9)	0.3-4.5	

et al. 2024). This interaction can be antagonic or synergic and it depends on the dose and chemical form (Zeng et al. 2005). A possible explanation of these findings is that elevated As in the animals could increase dietary Se requirements (Villanueva et al. 2011). The correlation in bovine tissues found in the present study considers only the total amount of each element. Further studies should be done to deepen the knowledge about the chemical species present in the tissues and their interactions.

Regarding V, this element is present in high concentration in aquifers of Argentina usually associated with other trace elements like As (Fiorentino et al. 2007, Bavera 2011). Different studies in animals and cell lines show that this element is insulin-mimetic (Kawachi 2006) and an inhibitor of mammary carcinogenesis (Ray et al. 2005)

Human health risk assessment

THQ values and HI index per element and tissue, and all the TR values for As were calculated, and are shown in **table IV**. Median THQ obtained for adults per element for both tissues is shown in **figure 2**. All samples from the Pampean Plain were taken into account. The THQ and HI obtained for all tissues and sites suggest no risk for the population (THQ, HI < 1). No significant difference between HI from Buenos Aires and Córdoba Province was found for any tissue. TR values for both tissues and sites do not suggest any cancer risk for the population (TR < 1). It has to be added that the As toxicity and carcinogenicity are dependent on the element's chemical form. However, even if all As in the liver and kidney samples was present as arsenite (one of the most toxic forms), the concentrations are too low for an increased health risk for consumers. Thus, it was not necessary to determine the As speciation for the health risk assessment.

Despite these results, it is necessary to mention that the actual consumption rate of liver and kidney is not well studied. More consumption habit studies would be required to increase the accuracy of the estimation.

TABLE III. SPEARMAN COEFFICIENT CORRELATION FOR TOTAL LIVER AND KIDNEY SAMPLES, AND LIVER AND KIDNEY SAMPLES FROM BUENOS AIRES PROVINCE (BA, LOW CONTAMINATION) AND CÓRDOBA PROVINCE (CO, HIGH CONTAMINATION). BOLD NUMBERS = CORRELATION COEFFICIENTS ABOVE 0.7. *SIGNIFICANT CORRELATION ($p \leq 0.05$)

Liver Total	As	V	Se	Mo	U	Kidney Total	As	V	Se	Mo	U
As	1					As	1				
V	0.58*	1				V	0.43*	1			
Se	0.28*	0.47	1			Se	0.42*	0.19	1		
Mo	–0.16	–0.18	0.08	1		Mo	0.24	–0.07	0.05	1	
U	–0.18	0.01	0.03	–0.18	1	U	–0.13	0.2	–0.24	–0.12	1
Liver BA	**As**	**V**	**Se**	**Mo**	**U**	**Kidney BA**	**As**	**V**	**Se**	**Mo**	**U**
As	1					As	1				
V	**0.87***	1				V	0.35	1			
Se	–0.03	0.19	1			Se	–0.2	–0.33	1		
Mo	–0.39	–0.15	0.22	1		Mo	–0.39	0.36	–0.48	1	
U	0.28	0.34	0.41	–0.17	1	U	0.35	**0.7***	–0.41	–0.01	1
Liver CO	**As**	**V**	**Se**	**Mo**	**U**	**Kidney CO**	**As**	**V**	**Se**	**Mo**	**U**
As	1					As	1				
V	0.53*	1				V	0.17	1			
Se	0.4*	0.56*	1			Se	0.46*	0.29	1		
Mo	–0.26	–0.23	0.08	1		Mo	0.14	–0.37	0.03	1	
U	–0.06	0.12	–0.17	–0.11	1	U	0.02	0.35	0	–0.15	1

TABLE IV. MEAN, MEDIAN AND MAXIMUM (Max) THQ* OBTAINED FOR ADULTS.

Element	Tissue	Mean	Median	Max
As	Kidney	$0.6*10^{-2}$	$0.5*10^{-2}$	$1.3*10^{-2}$
	Liver	$1.5*10^{-2}$	$1.1*10^{-2}$	$2.8*10^{-2}$
Se	Kidney	$0.8*10^{-2}$	$0.8*10^{-2}$	$1.3*10^{-2}$
	Liver	$0.7*10^{-2}$	$0.6*10^{-2}$	$4.8*10^{-2}$
V	Kidney	$0.4*10^{-3}$	$0.3*10^{-3}$	$1.2*10^{-3}$
	Liver	$1.1*10^{-3}$	$0.5*10^{-3}$	$8.4*10^{-3}$
Mo	Kidney	$0.3*10^{-2}$	$0.3*10^{-2}$	$0.4*10^{-2}$
	Liver	$2.3*10^{-2}$	$2.3*10^{-2}$	$3.3*10^{-2}$
U	Kidney	$0.5*10^{-4}$	$0.5*10^{-4}$	$2.1*10^{-4}$
	Liver	$0.3*10^{-4}$	$0.08*10^{-4}$	$3.3*10^{-4}$
HI*	Kidney	$0.2*10^{-2}$	$0.2*10^{-2}$	$0.3*10^{-2}$
	Liver	$4.2*10^{-2}$	$4.0*10^{-2}$	$12*10^{-2}$
TR* (As)	Kidney	$0.3*10^{-5}$	$0.2*10^{-5}$	$0.6*10^{-5}$
	Liver	$0.5*10^{-5}$	$0.5*10^{-5}$	$1.3*10^{-5}$

* Target hazard quotient (THQ_{iJ}), hazardous index (HI) and the target cancer risk (TR).

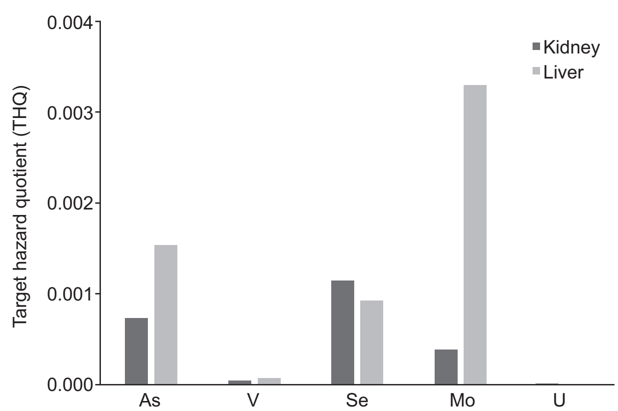

Fig. 2. Median THQ obtained for adults per element for both investigated tissues.

CONCLUSION

Trace elements are not well studied in some bovine tissues. In many cases, there are no guidelines indicating the permitted levels in bovine visceral tissues. However, these are part of the diet in countries like Argentina or China (Hong Kong, Republic of

China special administrative region). The potential effects of the presence of trace elements in greater levels in bovine liver and kidney, both for animal health and production, and the impact on consumer health are poorly studied. Our results show that it can be important to look not only at As in areas like the South American Pampean Plain. In our study, Se and Mo had similar or even higher THQ values than As and should thus also be considered in health risk analyses. There were differences in the element concentrations between samples from Buenos Aires and Córdoba province, especially in the case of As and V.

Still, the element concentrations in samples from both study areas were under the quality standards for food security set by national and international guidelines. The health risk calculated in the present study indicates that the consumption of liver and kidney from little-contaminated Buenos Aires province and also from the highly contaminated Córdoba province is safe, considering an average intake of livers and kidneys.

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REFERENCES

Al Kaddissi S., Legeay A., Gonzalez P., Floriani M., Camilleri V., Gilbin R. and Simon O. (2011). Effects of uranium uptake on transcriptional responses, histological structures and survival rate of the crayfish *Procambarus clarkii*. Ecotoxicology and Environmental Safety 74 (7), 1800-1807. https://doi.org/10.1016/j.ecoenv.2011.06.010

Alexander J., Benford D. and Cockburn A. (2009). Scientific opinion of the panel on contaminants in the food chain on a request from German Federal Institute for Risk Assessment (BfR) on uranium in foodstuffs, in particular mineral water. European Food Safety Authority. EFSA Journal 1018, 1- 59.

Anke M., Seeber O., Müller R., Schäfer U. and Zerull J. (2009). Uranium transfer in the food chain from soil to plants, animals and man. Geochemistry 69, 75-90. https://doi.org/10.1016/j.chemer.2007.12.001

ATSDR (2013). CAS#: 7440-61-1. Toxicological profile for uranium. Agency for Toxic Substances and Disease Registry. Atlanta, G.A., USA, 448 pp.

ATSDR (2003). CAS#: 7782-49-2. Toxicological profile for selenium. Agency for Toxic Substances and Disease Registry. Atlanta, G.A., USA, 418 pp.

Barchowsky A. and States J.C. (2015). Arsenic-Induced cardiovascular disease. In: Arsenic: Exposure sources, health risks, and mechanisms of toxicity. (J.C. States, Ed.). John Wiley and Sons, Inc. Hoboken, New Jersey, USA, pp. 455-467. https://doi.org/10.1002/9781118876992.ch20

Bianchi F., Cori L. and Sicari R. (2013). Arsenic and cardiovascular diseases. Proceedings of the 16th International Conference on Heavy Metals in the Environment. E3S Web of Conferences 1 (40002) 1-2. https://doi.org/10.1051/e3sconf/20130140002

Blanco M.D.C., Amiotti N.M., Diaz S.L. and Esposito M.E. (2017). Arsénico en aguas del sudoeste bonaerense: del medioambiente al ser humano. Agro Universidad Nacional del Sur 26, 17-20.

Blanco-Penedo I., Cruz J.M., López-Alonso M., Miranda M., Castillo C., Hernández J. and Benedito J.L. (2006). Influence of copper status on the accumulation of toxic and essential metals in cattle. Environment International 32, 901-906. https://doi.org/10.1016/j.envint.2006.05.012

Bouaziz H., Soudania N., Essafia M., Amara I.B., Hakim A., Jamoussi K., Zeghal K. and Zeghal N. (2015). Hepatotoxicity induced by arsenic trioxide in adult mice and their progeny. International Journal of Environmental and Ecological Engineering 9 (3), 236-241.

Bundschuh J., Farias B., Martin R., Storniolo A., Bhattacharya P., Cortes J., Bonorino G. and Albouy R. (2004). Groundwater arsenic in the Chaco-Pampean Plain, Argentina: case study from Robles country, Santiago del Estero province. Applied Geochemistry 19 (2), 231-243. https://doi.org/10.1016/j.apgeochem.2003.09.009

Bundschuh J., Armienta M.A., Morales-Simfors N., Alam M.A., López D.L., Delgado Quezada V., Dietrich S., Schneider J., Tapia J., Sracek, O., Castillo E., Marco Parra L.M., Altamirano Espinoza M., Guimarães Guilherme L.R., Sosa N.N., Khan Niazi N., Tomaszewska B., Allende K.L., Bieger K., Alonso D.L., Brandão P.F.B., Bhattacharya P., Litter M.I. and Ahmad A. (2021). Arsenic in Latin America: New findings on source, mobilization and mobility in human environments in 20 countries based on decadal research 2010-2020. Critical Reviews in Environmental Science and Technology 51 (16), 1727-1865.

Carvalho F.P. and Oliveira J.M. (2010). Uranium isotopes in the Balkan's environment and foods following the use of depleted uranium in the war. Environment international 36 (4), 352-360. https://doi.org/10.1016/j.envint.2010.02.003

COT (2006). Statement on uranium levels in water used to reconstitute infant formula. Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment, London [online]. https://cot.food.gov.uk/sites/default/files/cot/cotstatementuranium06.pdf 06/03/2020

Cullen W.R., Harrison L.G., Li H. and Hewitt G. (1994). Bioacummulation and excretion of arsenic compounds by a marine unicellular alga, *Polyphhysa peniculus.* Applied Organomethalic Chemistry 8 (4), 313-324. https://doi.org/10.1002/AOC.590080406

Dermauw V., Alonso M.L., Duchateau L., Du Laing G., Tolosa T., Dierenfeld E., Clauss M. and Janssens G.P.J. (2014). Trace element distribution in selected edible tissues of zebu (*Bos indicus*) cattle slaughtered at Jimma, SW Ethiopia. PloS One 9 (1), e85300. https://doi.org/10.1371/journal.pone.0085300

Del Pino M., Bay L., Lejarraga H., Kovalskys I., Berner E. and Rausch Herscovici C. (2005). Peso y estatura de una muestra nacional de 1.971 adolescentes de 10 a 19 años: las referencias argentinas continúan vigentes. Archivos Argentinos de Pediatría 103 (4), 323-330.

Diaz S.L., Esposito M.E., Blanco M. del C., Amiotti N.M., Schmidt E.S.Ñ., Sequeira M.E., Paolon J.D. and Nicolli H.B. (2016). Control factors of the spatial distribution of arsenic and other associated elements in loess soils and waters of the southern Pampa (Argentina). Catena 140, 205-216. https://doi.org/10.1016/j.catena.2016.01.013

Edmunds W.M. and Smedley P.L. (1996). Groundwater geochemistry and health: An overview. Geological Society, London, Special Publications 113 (1), 91-105. http://dx.doi.org/10.1144/GSL.SP.1996.113.01.08

Farías S.S., Casa V.A., Vázquez C., Ferpozzi L., Pucci G.N. and Cohen I.M. (2003). Natural contamination with arsenic and other trace elements in ground waters of Argentine Pampean Plain. Science of The Total Environment 309 (1-3), 187-199. https://doi.org/10.1016/s0048-9697(03)00056-1

Fiorentino C.E., Paolini J.D., Sequeira M.E. and Arosteguy P. (2007). The presence of vanadium in groundwater of southeastern extreme the Pampean region Argentina. Relationship with other chemical elements. Journal of Contaminant Hydrology 93, 122-129. https://doi.org/10.1016/j.jconhyd.2007.02.001

Fordyce F.M. (2013). Selenium deficiency and toxicity in the environment. Springer Netherlands 16, 375-416. https://doi.org/10.1007/978-94-007-4375-5_16

Gummow B., Bastianello S.S., Botha C.J., Smith H.J.C., Basson A.J. and Wells B. (1994). Vanadium air pollution: a cause of malabsorption and immunosuppression in cattle. Onderstepoort Journal of Veterinary Research 61, 303-316. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=cdc1b6c2dbd36980c7474b11c8457940a9d5363c

Gummow B., Botha C., Noordhuizen J. and Hesterbeek J. (2005). The public health implication of farming cattle in areas with high background concentration of vanadium. Preventive Veterinary Medicine 72, 281-290. https://doi.org/10.1016/j.prevetmed.2005.07.012

Hao L., Zhao J., Wang X., Wang H., Wang H. and Xu G. (2013). Hepatotoxicity from arsenic trioxide for pediatric acute promyelocytic leukemia. Journal of Pediatric Hematology/Oncology 35 (2), e67-e70. https://doi.org/10.1097/mph.0b013e31827e91bc

Health Canada (1987). Uranium. Guidelines for Canadian drinking water quality: Supporting documentation [online] https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-uranium.html 06/08/2019

IARC (2012). Monographs on the evaluation of carcinogenic risks to humans volume 100C. Arsenic, metals, fibres, and dusts. International Agency for Research on Cancer, World Health Organization, Geneva, Switzerland, 466 pp.

IRIS (1991). Integrated Risk Information System. United States Environmental Protection Agency. Washington, D.C., [online] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=278. 08/08/2020

Jayasumana M.A.C.S., Paranagama P.A., Amarasinghe M.D., Wijewardane K.M. R.C., Dahanayake K.S., Fonseka S.I., Rajakaruna K.D.L.M.P., Mahamithawa, A.M.P., Samarasinghe U.D. and Senanayake V.K. (2013). Possible link of chronic arsenic toxicity with chronic kidney disease of unknown etiology in Sri Lanka. Journal of National Science Research 3 (1), 64-73.

Kawachi H. (2006). Micronutrients affecting adipogenesis in beef cattle. Animal Science Journal 77, 463-471. https://doi.org/10.1111/j.1740-0929.2006.00373.x

Khan K.M., Chakraborty R., Bundschuh J., Bhattacharya P. and Parvez F. (2020). Health effects of arsenic exposure in Latin America: An overview of the past eight years of research. Science of The Total Environment 710, 136071. https://doi.org/10.1016/j.scitotenv.2019.136071

Khandare V. and Rao N. (2015). Effects of strontium and fluoride ions on bone mechanical and biochemical indices in guinea pigs (*Cavia porcellus*). Fluoride 48 (2), 149-159.

Kluge-Berge S., Skjerve E., Sivertsen T. and Godal A. (1992). Lead, cadmium, mercury and arsenic in Norwegian cattle and pigs. Proceedings of the 3rd World Congress Foodborne Infections and Intoxications (Germany: Berlin). World Congress of foodborne infections and intoxication, June 19th 1992, Institute of Veterinary Medicine, Berlin, Germany, pp. 745-748.

Kramer H., Steiner J. and Vallely P. (1983). Trace element concentration in the liver, kidney and muscle of Queensland cattle. Bulletin of Environmental Contamination and Toxicology 30, 588-594. https://www.cabidigitallibrary.org/doi/full/10.5555/19832226651

Kurttio P., Auvinen A., Salonen L., Saha H., Pekkanen J., Mäkeläinen I., Väisänen S.B., Penttilä I.M. and Komulainen H. (2002). Renal effects of uranium in drinking water. Environmental Health Perspectives 110 (4), 337. https://doi.org/10.1289/ehp.02110337

Lei B., Chen L., Hao Y., Cao T., Zhang X., Yu Y. and Fu J. (2013). Trace elements in animal-based food from Shanghai markets and associated human daily intake and uptake estimation considering bioaccessibility. Ecotoxicology and Environmental Safety 96, 160-167. https://doi.org/10.1016/j.ecoenv.2013.06.032

Lei B., Zhang K., An J., Zhang X. and Yu Y. (2015). Human health risk assessment of multiple contaminants due to consumption of animal-based foods available in the markets of Shanghai, China. Environmental Science and Pollution Research 22 (6), 4434-4446. https://doi.org/10.1007/s11356-014-3683-0

Lepori V. and Cristina E. (2015). Hidroarsenicismo crónico regional endémico en Argentina. Acta Bioquímica Clínica Latinoamericana 49 (1), 00-00.

Li L. and Chen F. (2016). Oxidative stress, epigenetics, and cancer stem cells in arsenic carcinogenesis and prevention. Current Pharmacology Reports 2, 57-63. https://doi.org/10.1007%2Fs40495-016-0049-y

López Alonso M., Benedito J.L., Miranda M., Castillo C., Hernandez J. and Shore R.F. (2000). Toxic and trace elements in liver, kidney and meat from cattle slaughtered in Galicia (NW Spain). Food Additives and Contaminants 17 (6), 447-457. https://doi.org/10.1080/02652030050034028

López Alonso M., Prieto Montaña F., Miranda M., Castillo C., Hernández J. and Benedito J.L. (2004). Interactions between toxic (As, Cd, Hg and Pb) and nutritional essential (Ca, Co, Cr, Cu, Fe, Mn, Mo, Ni, Se, Zn) elements in the tissues of cattle from NW Spain. Biometals 17, 389-397. https://doi.org/10.1023/b:biom.0000029434.89679.a2

López G. (2012). Perfil de mercado: despojos y menudencias de la especie bovina refrigeradas, congeladas y procesadas. Subsecretaria de Ganadería Dirección Nacional de Estudios y Análisis Económico del Sector Pecuario. Ministerio de Agricultura, Ganadería y Pesca, Ciudad Autónoma de Buenos Aires, Argentina, 101 pp.

Lourenço J., Castro B.B., Machado R., Nunes B., Mendo S., Gonçalves F. and Pereira R. (2010). Genetic, biochemical, and individual responses of the teleost fish *Carassius auratus* to uranium. Archives of Environmental Contamination and Toxicology 58 (4), 1023-1031

Machado I., Falchi L., Bühl V. and Mañay N. (2020). Arsenic levels in groundwater and its correlation with relevant inorganic parameters in Uruguay: A medical geology perspective. Science of The Total Environment 721, 137787. https://doi.org/10.1016/j.scitotenv.2020.137787

Maeda S., Ohki A., Kusadome K., Kuroiwa T., Yoshifuku I. and Naka K. (1992). Bioacummulation of arsenic and its fate in a freshwater food chain. Applied Organometallic Chemistry 6 (2), 213-219. https://doi.org/10.1002/aoc.590060216

MAGyP (2018). Resolución 32/2018. Criterio de clasificación y tipificación de res bovina. Boletín Oficial. Ministerio de Agricultura, Ganadería y Pesca de la Nación. Argentina [online] https://www.argentina.gob.ar/normativa/nacional/316048/texto 05/05/2019

Maull E.A., Ahsan H., Edwards J., Longnecker M.P., Navas-Acien A., Pi J., Silbergeld E.K., Styblo M., Tseng C.H., Thayer K.A. and Loomis D. (2012). Evaluation of the association between arsenic and diabetes: a National Toxicology Program workshop review. Environmental Health Perspectives 120 (12), 1658. https://doi.org/10.17615/2fbv-4a11

Moos A., Bertolotto P., Rupérez C., Gallerano R. and Asaduroglu A. (2013). Alimentos cárnicos y huevos: perfil de consumo en adultos mayores ambulatorios. Diaeta 31 (142), 7-14. http://www.scielo.org.ar/scielo.php?script=sci_arttext&pid=S1852-73372013000100001

Morales-Simfors N., Bundschuh J., Herath I., Inguaggiato C., Caselli A.T., Tapia J., Erlingtton Apaza Choquehuayta F., Armienta M. A., Ormachea M., Erouscilla J. and López D.L. (2020). Arsenic in Latin America: A critical overview on the geochemistry of arsenic originating from geothermal features and volcanic emissions for solving its environmental consequences. Science of The Total Environment 716, 135564. https://doi.org/10.1016/j.scitotenv.2019.135564

Mukherjee B., Patra B., Mahapatra S., Banerjee P., Tiwari A. and Chatterjee M. (2004). Vanadium-an element of atypical biological significance. Toxicology Letters 150, 135-143. https://doi.org/10.1016/j.toxlet.2004.01.009

Nicolli H.B., Suriano J.M., Gomez Peral M.A., Ferpozzi L.H. and Baleani O.A. (1989). Groundwater contamination with arsenic and other trace elements in an area of the pampa, province of Córdoba, Argentina. Environmental Geology and Water Sciences 14 (1), 3-16.

Nicolli H.B., Tineo A., Falcón C.M., García J.W., Merino

M.H., Etchinery M.C., Alonso M.S. and Tofalo O.R. (2008). Arsenic hydrogeochemistry in groundwater from the Burruyacú basin, Tucumán Province. In: Natural Arsenic in Groundwaters of Latin America (J. Bundschuh, M. A. Armienta, P. Birkle, P. Bhattacharya, J. Matschullat, A. B. Mukherjee, Eds.). CRC Press Balkema, London, UK 1, 47-59.

Nicolli H.B., Bundschuh J., Blanco M.D.C., Tujchneider O.C., Panarello H.O., Dapeña C. and Rusansky J.E. (2012). Arsenic and associated trace-elements in groundwater from the Chaco-Pampean plain, Argentina: Results from 100 years of research. Science of The Total Environment 429, 36-56. https://ri.conicet.gov.ar/handle/11336/20698

Park S.K., Peng Q., Bielak L.F., Silver K.D., Peyser P.A. and Mitchell B.D. (2016). Arsenic exposure is associated with diminished insulin sensitivity in non-diabetic Amish adults. Diabetes Metabolism Research and Reviews 32 (6), 565-571. https://doi.org/10.1002/dmrr.2769

Pérez Carrera A. (2006). Evaluación de elementos traza en agua, suelo, forraje y leche. PhD Thesis. Facultad de Ciencias Veterinarias, Universidad de Buenos Aires. Cuidad Autónoma de Buenos Aires, Argentina, 321 pp.

Pérez Carrera A. and Fernández Cirelli A. (2007). Problemática del arsénico en la llanura sudeste de la provincia de Córdoba. Biotransferencia a leche bovina. Revista InVet 9, 132-135.

Pérez Carrera A., Pérez Gardiner M.L. and Fernandez Cirelli A. (2010). Presencia de arsénico en tejidos de origen bovino en el sudeste de la provincia de Córdoba, Argentina. Revista InVet 12 (1), 59-67.

Pérez Carrera A., Alvarez Gonçalvez C.V. and Fernández Cirelli A. (2014). Vanadio en agua de bebida animal de tambos del sudeste de Córdoba, Argentina. Revista InVet 16 (1), 39-47.

Perez Carrera A. and Fernandez Cirelli A. (2014). Arsenic biotransference to alfalfa (*Medicago sativa*). International Journal of Environment and Health 7 (1), 31-40. https://doi.org/10.1504/IJENVH.2014.060123

Pérez Carrera A., Arellano F.E. and Fernández-Cirelli A. (2016b). Concentration of trace elements in raw milk from cows in the southeast of Córdoba province, Argentina. Dairy Science Technology 96, 591-602. https://doi.org/10.1007/s13594-016-0290-5

Plan CREHA (2000). Resolución 119/2000. Plan Nacional de Control de Residuos e Higiene en Alimentos. [online]

https://www.argentina.gob.ar/senasa/programas-sanitarios/plan-creha/plan-creha-animal 10/10/2020

Poon R., Chu I., Lecavalier P., Valli V.E., Foster W., Gupta S. and Thomas B. (1998). Effects of antimony on rats following 90-day exposure via drinking water. Food and Chemical Toxicology 36 (1), 21-35. https://doi.org/10.1016/S0278-6915(97)80120-2

Prakash C., Soni M. and Kumar V. (2016). Mitochondrial oxidative stress and dysfunction in arsenic neurotoxicity: A review. Journal of Applied Toxicology 36 (2), 179-188. https://doi.org/10.1002/jat.3256

Robles-Osorio M.L., Sabath-Silva E. and Sabath E. (2015). Arsenic-mediated nephrotoxicity. Renal Failure 37 (4), 542-547. https://doi.org/10.3109/0886022X.2015.1013419

Rossen BP (1999). Families of arsenic transporters. Trends in Microbiology 7 (5), 207-212. https://doi.org/10.1016/S0966-842X(99)01494-8

Rosso J.J., Troncoso J.J. and Fernández-Cirelli A. (2011). Geographic distribution of arsenic and trace metals in lotic ecosystems of the Pampa Plain, Argentina. Bulletin of Environmental Contamination and Toxicology 86 (1), 129-132. https://doi.org/10.1007/s00128-010-0177-8

Roy R.V., Son Y.O., Pratheeshkumar P., Wang L., Hitron J.A., Divya S.P., Rakesh D., Donghern K., Yuanqin Y., Zhuo Z. and Shi X. (2015). Epigenetic targets of arsenic: emphasis on epigenetic modifications during carcinogenesis. Journal of Environmental Pathology, Toxicology and Oncology 34 (1). https://doi.org/10.1615/JEnvironPatholToxicolOncol.2014012066

Salim S.A., Dana Z., Hashami Z., Afrah A., Sadeghi E. and Bashiry M. (2023). A comprehensive image of environmental toxic heavy metals in red meat: A global systematic review and meta-analysis and risk assessment study. Science of The Total Environment (889), 164100. https://doi.org/10.1016/j.scitotenv.2023.164100

Salisbury C., Chan W. and Saschenbreker P. (1991). Multi-element concentrations in liver and kidney tissues from five species of Canadian slaughter animals. Journal of the Association of Official Analytical Chemists 74, 587-591. https://doi.org/10.1093/jaoac/74.4.587

Santos E.E., Lauria D.C. and Porto da Silveira C.L. (2004). Assessment of daily intake of trace elements due to consumption of foodstuffs by adult inhabitants of Rio de Janeiro city. Science of The Total Environment 327, 69-79. https://doi.org/10.1016/j.scitotenv.2004.01.016

Smedley P.L. and Kinniburgh D.G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. Applied Geochemistry 17 (5), 517-568. https://doi.org/10.1016/S0883-2927(02)00018-5

Smedley P.L., Nicolli H.B., Barros A.J. and Tullio, J.O. (1998) Origin and mobility of arsenic in groundwater from the Pampean Plain, Argentina. En: Water-rock interaction. Proceedings of the 9th International Symposium on Water-Rock Interaction: WRI-9/Taupo/New Zealand/30 March - 3 April 1998. (G. B. Arehart, J. R. Hulston, Eds.) Rotterdam, Netherlands, pp. 275-278.

Smedley P.L., Nicolli H.B., Macdonald D.M.J., Barros A.J. and Tullio J.O. (2002). Hydrogeochemistry of arsenic and other inorganic constituents in groundwaters from La Pampa, Argentina. Applied Geochemistry 17 (3), 259-284. https://doi.org/10.1016/S0883-2927(01)00082-8

Sun H.J., Rathinasabapathi B., Wu B., Luo J., Pu L.P. and Ma Q. (2014). Arsenic and selenium toxicity and their interactive effects in humans. Environment International 69, 148-158. https://doi.org/10.1016/j.envint.2014.04.019

Thorndyke M.P., Guimaraes O., Kistner M.J., Wagner J.J. and Engle T. E. (2021). Influence of molybdenum in drinking water or feed on copper metabolism in cattle-a review. Animals 11 (7), 2083. https://doi.org/10.3390/ani11072083

Teng Y.C., Jeng C.J., Huang H.J. and Lin A.M.Y. (2015). Role of autophagy in arsenite-induced neurotoxicity: the involvement of α-synuclein. Toxicology Letters 233 (3), 239-245. https://doi.org/10.1016/j.toxlet.2015.01.018

Tseng C.H. (2009). A review on environmental factors regulating arsenic methylation in humans. Toxicology and Applied Pharmacology 235 (3), 338-350. https://doi.org/10.1016/j.taap.2008.12.016

USEPA (2019). 40 CFR Part 141. National Primary Drinking Water Regulations – Code of Federal Regulations 40. United States Environmental Protection Agency, Washington, D.C., USA, 258 pp.

USEPA (1991). Risk Assessment Guidance for Superfund (RAGS): Part B, Chapter 3: Calculation of Risk-Based Preliminary Remediation Goals. United States Environmental Protection Agency. Wahington, D.C., USA, 64 pp.

Vos G., Hovens J. and Van Delft W. (1987). Arsenic, cadmium, lead and mercury in meat, livers and kidneys of cattle slaughtered in the Netherlands during 1980-1985. Food Additives and Contaminants 4, 73-88. https://doi.org/10.1080/02652038709373617

Ward G.M. (1978). Molybdenum toxicity and hypocuprosis in ruminants: A review. Journal of Animal Science 46 (4), 1078-1085. https://doi.org/10.2527/jas1978.4641078x

Wang H., Wong M., Lan C., Qin Y., Shu W., Qiu R., Ye Z. (2010). Effect of arsenic on flavonoid contents in *Pteris* species. Biochemical Systematics and Ecology 38 (4), 529-537. https://doi.org/10.1016/j.bse.2010.05.009

WHO (1996). Trace elements in human nutrition and health. World Health Organization, Geneva, Switzerland, 343 pp.

WHO (2001). Depleted uranium, sources, exposure and health effects. World Health Organization, Geneva, Switzerland, 209 pp.

Wu Y., Zhang H., Liu G., Zhang J., Wang J., Yu Y. and Lu S. (2016). Concentrations and health risk assessment of trace elements in animal-derived food in southern China. Chemosphere 144, 564-570. https://doi.org/10.1016/j.chemosphere.2015.09.005

Zeng H., Uthus E.O. and Combs G.F. Jr. (2005). Mechanistic aspects of the interaction between selenium and arsenic. Journal of Inorganic Biochemistry 99 (6), 1269-1274. https://doi.org/10.1016/j.jinorgbio.2005.03.006