

Accumulation of Arsenic and Cadmium in Foods of Animal Origin Collected from the Local Markets in Northeastern Region Thailand

¹P. Saipan, ²B. Tengjaroenkul and ³K. Prahkarnkaeo

¹Department of Veterinary Public Health,

²Department of Medicine, Faculty of Veterinary Medicine, Khonkaen University,
Khonkaen, 40002, Thailand

³Department of Clinical and Public Health Medicine, Faculty of Veterinary Science,
Mahidol University, Phutthamonthon, Nakhonpathom, 73170, Thailand

Abstract: Concentrations of arsenic and cadmium were determined in broiler chickens, cattle and swine collected from the local markets of the northeastern Thailand. Average concentrations of arsenic based on a wet weight basis in muscle, liver and kidney were 0.022 ± 0.008 , 0.068 ± 0.025 , 0.286 ± 0.073 $\mu\text{g/g}$ cattle; 0.045 ± 0.022 , 0.402 ± 0.096 , 0.812 ± 0.335 $\mu\text{g/g}$ chickens; and 0.116 ± 0.044 , 0.479 ± 0.142 , 1.012 ± 0.500 $\mu\text{g/g}$ swine, respectively. Cadmium levels in meat of cattle, chickens and swine samples were 0.024 ± 0.010 , 0.028 ± 0.006 and 0.042 ± 0.015 $\mu\text{g/g}$, respectively. In liver and kidney, average of cadmium levels was 0.286 ± 0.062 and 0.412 ± 0.074 $\mu\text{g/g}$ cattle; 0.312 ± 0.092 and 0.645 ± 0.068 $\mu\text{g/g}$ chickens and 0.368 ± 0.106 and 0.758 ± 0.120 $\mu\text{g/g}$ swine, respectively. Statistical analysis showed that chickens and swine levels were higher of these elements than in cattle. None of samples, however, exceeded the arsenic limits set by Thailand regulations and the average concentrations of cadmium in animal tissues were still within acceptable levels of Thailand standards.

Keywords: Arsenic, cadmium, foods of animal origin, Thailand

INTRODUCTION

Arsenic and cadmium are known to produce a range of toxic effects including carcinogenic and non-carcinogenic effects in both animals and humans (ATSDR (Agency for Toxic Substances and Disease Registry), 2007, 2008; Goyer and Clarkson, 2001). Environmental pollution from various sources, such as untreated municipal and industrial wastewater, leads to foodstuffs from animal origin contaminated with arsenic and cadmium. Animals can accumulate heavy metals via intake of contaminated feed, soil, water and then these animal tissue residues of heavy metals can be harmful to human health who consumes the meat and visceral organs. Arsenic and cadmium accumulation in the environment and foods of animal origin have become a problem of increasing concern due to their use in many industrial processes and anthropogenic activities and their potential toxicity on public health (WHO, 2001, 2002).

A number of studies have reported a large variability in arsenic and cadmium levels in foods and environments from differences countries. Recent studies of arsenic and cadmium problems have been reported in some areas of Thailand such as the Ronphibun area in the southern part and in the Tak province in the northern part (Ruangwises and Saipan,

2010; Simmons *et al.*, 2005; Swaddiwudhipong *et al.*, 2007; Teeyakasem *et al.*, 2007; Zwicker *et al.*, 2010). Thailand is administratively divided into 4 regions (77 provinces) with the approximately 63,878,267 inhabitants. The northeastern region is the largest area with an approximate population of 21,573,318 living in 20 provinces (NSO (National Statistical Office), 2012). The economic growth and increasing population of the northeastern part Thailand may lead to a large emission and contamination of heavy metals. Potential sources of arsenic and cadmium in this area are mining, industry, agriculture and urban sewage. At this time, there is little published data available regarding on the actual levels of arsenic and cadmium in foods of animal origin from the northeastern region. The production of cattle, broiler chickens and swine in this area are approximately 3,354,335, 66,763,425 and 1,520,591 head (NSO (National Statistical Office), 2012). Most of broiler chickens and swine are raised by business farmers while cattle are reared by local farmers. Generally, cattle are consumed locally and the other foods of animal origin sometimes are sold to nearby provinces. Heavy metals released from anthropogenic activities may be accumulated in the tissues of animals through the food chain. Internationally published reports on arsenic and cadmium levels in terrestrial animals from Thailand (Franke *et al.*, 2007;

Corresponding Author: P. Saipan, Department of Veterinary Public Health, Faculty of Veterinary Medicine, Khonkaen University, Khonkaen 40002, Thailand

Sridaoruang *et al.*, 2010; Yatmark *et al.*, 2010) are limited. Thus, this study was designed to determine the present arsenic and cadmium concentrations in cattle, broiler chickens and swine in northeastern Thailand.

MATERIALS AND METHODS

Samples of muscle, liver and kidney from the cattle, broiler chickens and swine were purchased from the local markets in the 4 provinces of northeastern Thailand with the highest populations. Samples were collected five times from each province. The same part of each tissue, the upper hind right leg, right lobe of liver and right kidney tissues were collected from cattle and pigs and whole broiler chickens, were collected, kept in polyethylene bags, placed in iceboxes and transported to the laboratory. Each sample was dissected, connective tissue removed, homogenized and kept at -18°C until analysis. A total of 180 samples were analyzed in this study and samples were collected between February and October 2013.

Arsenic and cadmium in samples were determined by a modified method of Wlostowski *et al.* (2006). Briefly, 0.5 g of wet sample was digested overnight in 10 mL of concentrated nitric acid. Then, 2.5 mL of perchloric acid (70%, v/v) was added and evaporated on a hot plate and mineralized at 450°C in a muffle furnace for 3 h. The residue was left for 30 min; 10 mL of nitric acid (10%, v/v) was added and was then filtered through a Whatman no. 41 filter paper and adjusted to volume with nitric acid (10%, v/v). Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Agilent 7500C, Octopole Reaction System, Tokyo) at the Central Laboratory, Co. Inc., Thailand, was used to determine arsenic and cadmium in the solutions. Calibration standards were prepared by using samples fortified with certified stock solutions of arsenic and cadmium (Fluka, UK) with 0.1% HNO_3 at four different concentrations of each element and blank samples that were not fortified with elements. Standard stock solutions containing 1000 mg/L of each element were purchased from Fluka (UK) and were used to prepare calibration standards. HNO_3 and HClO_4 were purchased from Merck Chemicals (Darmstadt, Germany); other chemicals were obtained from Sigma-Aldrich (St. Louis, MO). Deionized water (18 M Ω cm) was used for preparation of standards, reagents and samples throughout the study. All glassware was treated with 10% (v/v) HNO_3 for 20-24 h and washed three times with deionized water.

Standard reference material (SRM 1577b bovine liver, NIST, USA) was used to verify the accuracy of the determinations. The recovery rates of arsenic and cadmium were ranges 90.86-102.50 and 89.45-98.20%. The relative standard deviations were less than 10% for all investigated elements. The analytical limit of detection of arsenic and cadmium were 0.02 and 0.004 $\mu\text{g/g}$. The concentrations of arsenic and cadmium found

in the standard reference material were 0.06 ± 0.02 and 0.52 ± 0.04 $\mu\text{g/g}$ ($n = 5$) which were in good agreement with the values of 0.05 (value not certified) and 0.5 ± 0.03 (value certified) $\mu\text{g/g}$. In this study, heavy metal levels were expressed as $\mu\text{g/g}$ wet weight.

One-way analysis of variance and the Turkey test were used to test for differences among the different tissues of the same species and among tissues of different species of animals by using SPSS Statistics version 17.0 for Windows (SPSS, Inc., Chicago, IL, USA). The level of significance accepted for all comparisons was $p < 0.05$.

RESULTS AND DISCUSSION

The age of cattle, swine and broiler chicken samples used in this study ranged from 3 to 6 years, 6 to 7 months and 40 to 50 days and average weights were 350 ± 38.25 kg for cattle, 110 ± 16.50 kg for swine and 2.05 ± 0.28 kg for broiler chickens. Kidney and liver samples of all animals detected arsenic and cadmium more than the limits of detection, while 4.44% (8 of 180 samples) and 3.89% (7 of 180 samples) of muscle samples were below the detection limits of arsenic and cadmium. Table 1 shows concentrations of arsenic on the basis of wet weight. None of samples exceeded the total arsenic limits set by Thai organization as 0.5 $\mu\text{g/g}$ muscle and 2 $\mu\text{g/g}$ offal (National Bureau of Agricultural Commodity and Food Standards of Thailand (ACFS, 2005).

Cadmium concentrations were determined in all tissues and animals shown in Table 2. The ranges of cadmium levels were not detectable to 1.510 $\mu\text{g/g}$. The highest level of cadmium was detected in kidneys of pigs as 1.510 $\mu\text{g/g}$. Cadmium concentrations in muscle samples were no different among cattle, swine and broiler chicken ($p > 0.05$). An average of cadmium concentrations in liver samples was lower when compared with the residue levels in kidneys of all species. Similar to other studies, the kidney is the critical tissue of accumulated cadmium and generally cadmium levels in muscle of foods animal origin were low (Alonso *et al.*, 2000; Doganoc, 1996; Falandysz, 1993; Salisbury *et al.*, 1991). Yatmark *et al.* (2010) reported that cadmium levels in the kidneys of cattle and swine collected from cadmium-contaminated area of Maesot district, Tak province, Thailand ranged from 0.02 to 19.60 and 0.09 to 40.14 $\mu\text{g/g}$ wet wt and 51% of kidney samples contained cadmium levels higher than the maximum limits (1 $\mu\text{g/g}$ wet wt). The present study showed that cadmium levels were lower than those reported by Yatmark *et al.* (2010) but similar to the results found by Sridaoruang *et al.* (2010) study. Regulatory limits of cadmium in foods vary among countries. Thailand regulatory limits for cadmium in kidney, liver and muscle of all three animals are 1, 0.5 and 0.05 $\mu\text{g/g}$ wet wt (ACFS, 2005; DLD, 2006). From

Table 1: Arsenic concentrations in meat and visceral organs ($\mu\text{g/g}$, wet wt)

Animal	Tissue	Avg. \pm S.D.	Range	Number of samples <LOD	Number of samples >MRL
Cattle	Muscle (n = 20)	0.022 \pm 0.008 ^a	ND-0.075	4	-
	Liver (n = 20)	0.068 \pm 0.025 ^b	0.025-0.318	-	-
	Kidney (n = 20)	0.286 \pm 0.073 ^c	0.050-0.814	-	-
Chicken	Muscle (n = 20)	0.045 \pm 0.022 ^a	ND-0.129	2	-
	Liver (n = 20)	0.402 \pm 0.069 ^b	0.022-0.914	-	-
Swine	Kidney (n = 20)	0.812 \pm 0.335 ^c	0.026-1.625	-	-
	Muscle (n = 20)	0.116 \pm 0.064 ^a	ND-0.420	2	-
	Liver (n = 20)	0.479 \pm 0.142 ^b	0.028-1.250	-	-
	Kidney (n = 20)	1.012 \pm 0.500 ^c	0.069-1.815	-	-

ND: Not detected; LOD: Limit of detection; MRL: Maximum residue levels for total arsenic, 0.5 $\mu\text{g/g}$ (meat), 2 $\mu\text{g/g}$ (offal); Different letters within column in each animal type are significant at $p < 0.05$; Avg.: Average; S.D.: Standard deviation

Table 2: Cadmium concentrations in meat and visceral organs ($\mu\text{g/g}$, wet wt)

Animal	Tissue	Avg. \pm S.D.	Range	Number of samples <LOD	Number of samples >MRL
Cattle	Muscle (n = 20)	0.024 \pm 0.010 ^a	ND-0.038	3	-
	Liver (n = 20)	0.286 \pm 0.062 ^b	0.010-0.486	-	-
	Kidney (n = 20)	0.412 \pm 0.074 ^b	0.022-1.024	-	1
Chicken	Muscle (n = 20)	0.028 \pm 0.006 ^a	ND-0.034	3	-
	Liver (n = 20)	0.312 \pm 0.092 ^b	0.010-0.650	-	1
	Kidney (n = 20)	0.645 \pm 0.068 ^c	0.012-1.105	-	1
Swine	Muscle (n = 20)	0.042 \pm 0.015 ^a	ND-0.048	1	-
	Liver (n = 20)	0.368 \pm 0.106 ^b	0.018-0.852	-	2
	Kidney (n = 20)	0.758 \pm 0.120 ^c	0.034-1.510	-	2

ND: Not detected; LOD: Limit of detection; MRL: Maximum residue levels, 0.05 $\mu\text{g/g}$ (meat), 0.5 $\mu\text{g/g}$ (liver) and 1 $\mu\text{g/g}$ (kidney); Different letters within column in each animal type are significant at $p < 0.05$; Avg.: Average; S.D.: Standard deviation

Table 3: Comparison of arsenic and cadmium levels among tissues and animals ($\mu\text{g/g}$ wet wt)

Element	Animal	Muscle	Liver	Kidney
Arsenic	Cattle	0.022 \pm 0.008 ^a	0.068 \pm 0.025 ^a	0.286 \pm 0.073 ^a
	Chicken	0.045 \pm 0.022 ^a	0.402 \pm 0.069 ^b	0.812 \pm 0.335 ^b
	Swine	0.116 \pm 0.044 ^b	0.479 \pm 0.142 ^b	1.012 \pm 0.500 ^b
Cadmium	Cattle	0.024 \pm 0.010 ^a	0.286 \pm 0.062 ^a	0.412 \pm 0.074 ^a
	Chicken	0.028 \pm 0.006 ^a	0.312 \pm 0.092 ^a	0.645 \pm 0.068 ^b
	Swine	0.042 \pm 0.015 ^a	0.368 \pm 0.106 ^a	0.758 \pm 0.120 ^b

Different letters within columns in each element are significant as $p < 0.05$

Table 2, the levels of cadmium in muscle samples of all animals were lower than the permitted level set by Thailand organizations except for cadmium in some kidney (4 of 60 samples, 6.67%) and liver (3 of 60 samples, 5%) samples were above the acceptable levels, similar to Miranda *et al.* (2001). They suggested that 1 to 15% of kidney samples in many countries studied have cadmium levels above 1 $\mu\text{g/g}$.

Statistical analysis showed that arsenic levels in liver and kidney samples of chickens and swine were significantly ($p < 0.05$) higher than those in cattle samples. Cadmium levels measured in the meat and liver of the three animals were not significantly different among them but significant differences in kidney samples ($p < 0.05$). The highest cadmium concentrations were found in swine. The other details of statistical analysis are shown in Table 3.

In a report from, Franke *et al.* (2007), they reported the arsenic concentrations in poultry meat collected from Thailand. The reported average level of arsenic was 0.141 \pm 0.042 $\mu\text{g/g}$ wet wt (n = 3). In this present study, concentrations of arsenic found in poultry meat were 0.045 \pm 0.022 $\mu\text{g/g}$ wet wt, lower than the level reported by Franke *et al.* (2007). Lopez-Alonso *et al.* (2002) and Miranda *et al.* (2005) studies showed that arsenic levels in the cattle samples ranged of 0.004 to

0.055 and were non-detectable to 0.593 $\mu\text{g/g}$ wet wt, similar or slightly below those levels found in the present study. Delgado-Andrade *et al.* (2003) presented high levels of arsenic in bovine samples (non-detectable to 3.249 $\mu\text{g/g}$) when compared with the results in this study. Arsenic in broiler chicken samples in the present study were higher than those levels in the U.S.A. report by Tao and Bolger (2009), (0.030 to 0.086 $\mu\text{g/g}$ wet wt), but lower than those concentrations found in Shah *et al.* (2009) who reported levels of 2.15 to 7.17 $\mu\text{g/g}$ wet wt. Jorhem *et al.* (1991) presented average arsenic concentrations in swine meat, liver and kidney were 0.024, 0.023 and 0.019 $\mu\text{g/g}$ wet wt, respectively below the levels arsenic were determined in this study. Additionally, arsenic in chickens and porcine samples were about 7 to 12 times higher than average concentrations found in the other species reported by Salisbury *et al.* (1991) and similar to the present study, arsenic levels in chickens and swine were 3.54 to 7.04 times higher than mean levels of arsenic presented in cattle tissues.

When compared to the cadmium levels reported from other countries, Cai *et al.* (2009), Miranda *et al.* (2005) and Sedki *et al.* (2003) reported that cadmium levels in bovine organs ranged in the not detectable range to 38.3 $\mu\text{g/g}$. In swine and broiler chicken

studies, cadmium concentrations varied between non-detectable and 40.14 µg/g (Doganoc, 1996; Ihedioha and Okoye, 2012; Kumar *et al.*, 2007; Swaileh *et al.*, 2009; Tomovic *et al.*, 2011; Villar *et al.*, 2005; Yatmark *et al.*, 2010). The present results obtained from foods of animal origin were comparable to those found in other studies. It is difficult, however, to directly compare arsenic and cadmium concentration data because the residue magnitude can be influenced by the type and age of the animals and concentrations and rates of exposure to the elements. In general, arsenic and cadmium levels in tissues of food animal origin may be increased with age and related to those concentrations in feedstuffs. Environmental contamination has an effect on heavy metal levels in tissues of animals who ingested contaminated water and feedstuffs (Farmer and Farmer, 2000; Miranda *et al.*, 2005; Sedki *et al.*, 2003). The differences of heavy metals levels in soil and surface water will result in differences in contamination levels of plants and feedstuffs. Limited data, however, on heavy metals levels in animals and feedstuffs from the different environmental areas of Thailand are available. Thus, further monitoring of the foods of animal origin, feedstuffs, soil and water to assess the status of heavy metals contamination is necessary.

CONCLUSION

In the present study, arsenic and cadmium concentrations were comparable to those found in other country studies and it may be concluded that the average concentration of arsenic and cadmium in foods of animal origin from northeastern Thailand were still within acceptable levels. Arsenic and cadmium contents in all tissues of broiler chicken and swine tended to higher levels than cattle. A lack of data published in Thailand, however, has resulted in difficulty to compare of the magnitude of the problem of residues in foodstuffs from the different terrestrial animals.

ACKNOWLEDGMENT

This study was supported by the Research Group, Toxic Substances in Livestock and Aquatic Animals, Khonkaen University. The authors thank Professor Dr. James A. Will, University of Wisconsin-Madison, USA, for editing this manuscript.

REFERENCES

ACFS, 2005. Thai Agricultural Commodity and Food Standard: TACFS 9007-2005. Safety Requirements for Agricultural Commodity and Food. National Bureau of Agricultural Commodity and Food Standards of Thailand, Ministry of Agriculture and Cooperatives, Thailand, pp: 1-25.

Alonso, M.L., J.L. Benedito, M. Miranda, C. Castillo, J. Hernandez and R.F. Shore, 2000. Arsenic, cadmium, lead, copper and zinc in cattle from Galicia, NW Spain. *Sci. Total Environ.*, 246: 237-248.

ATSDR (Agency for Toxic Substances and Disease Registry), 2007. Toxicological Profile for Arsenic. U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA, USA.

ATSDR (Agency for Toxic Substances and Disease Registry), 2008. Toxicological Profile for Cadmium. U.S. Department of Health and Human Services, Atlanta, GA, USA.

Cai, Q., M.L. Long, M. Zhu, Q.Z. Zhou, L. Zhang and J. Liu, 2009. Food chain transfer of cadmium and lead to cattle in a lead-zinc smelter in Guizhou, China. *Environ. Pollut.*, 157: 3078-3082.

Delgado-Andrade, C., M. Navarro, H. Lopez and M.C. Lopez, 2003. Determination of total arsenic levels by hydride generation atomic absorption spectrometry in foods from south-east Spain: Estimation of daily dietary intake. *Food Addit. Contam.*, 20(10): 923-932.

DLD, 2006. Notification of the Department of Livestock Development No. 2/2 (B.E. 2549). Regulation of the Permissible Levels of Harmful Substances in Animal Foods. Department of Livestock Development, Ministry of Agriculture and Cooperatives, Thailand.

Doganoc, D.Z., 1996. Lead and cadmium concentrations in meat, liver and kidney of Slovenian cattle and pigs from 1989-1993. *Food Addit. Contam.*, 13: 237-241.

Falandysz, J., 1993. Some toxic and essential trace metals in cattle from the northern part of Poland. *Sci. Total Environ.*, 136: 177-191.

Farmer, A.A. and A.M. Farmer, 2000. Concentrations of cadmium, lead and zinc in livestock feed and organs around a metal production centre in Eastern Kazakhstan. *Sci. Total Environ.*, 257: 53-60.

Franke, B.M., M. Haldimann, J. Reimann, B. Baumer, G. Gremaud, R. Hadorn, J.O. Bossel and M. Kreuzer, 2007. Indications for the applicability of element signature analysis for the determination of the geographical origin of dried beef and poultry meat. *Eur. Food Res. Technol.*, 225: 501-509.

Goyer, R.A. and T.W. Clarkson, 2001. Toxic Effects of Metals. In: Klaassen, C.D. (Ed.), 6th Edn., Casarett and Doull's Toxicology: The Basic Science of Poisons. McGraw-Hill, New York, pp: 811-867.

Ihedioha, J.N. and C.O.B. Okoye, 2012. Cadmium and lead levels in muscles and edible offal of cow reared in Nigeria. *B. Environ. Contam. Tox.*, 88: 422-427.

Jorhem, L., S. Slorach, B. Sundstrom and B. Ohlin, 1991. Lead, cadmium, arsenic and mercury in meat, liver and kidney of Swedish pigs and cattle in 1984-1988. *Food Addit. Contam.*, 8: 201-212.

- Kumar, P., Y. Prasad, A.K. Patra and D. Swarup, 2007. Levels of cadmium and lead in tissues of freshwater fish (*Clarias batrachus* L.) and chicken in Western UP (India). *B. Environ. Contam. Tox.*, 79: 396-400.
- Lopez-Alonso, M., J.L. Benedito, M. Miranda, C. Castillo, J. Hernandez and R.F. Shore, 2002. Cattle as biomonitors of soil arsenic, copper and zinc concentrations in Galicia (NW Spain). *Arch. Environ. Con. Tox.*, 43(1): 103-108.
- Miranda, M., M. Lopez Alonso, C. Castillo, J. Hernandez and J.L. Benedito, 2001. Cadmium levels in liver, kidney and meat in calves from Asturias (North Spain). *Eur. Food Res. Technol.*, 212: 426-430.
- Miranda, M., M. Lopez Alonso, C. Castillo, J. Hernandez and J.L. Benedito, 2005. Effects of moderate pollution on toxic and trace metal levels in calves from a polluted area of northern Spain. *Environ. Int.*, 31: 543-548.
- NSO (National Statistical Office), 2012. Thailand Statistical Yearbook. National Statistical Office of Thailand, Ministry of Information and Communication Technology, Thailand.
- Ruangwises, S. and P. Saipan, 2010. Dietary intake of total and inorganic arsenic by adults in arsenic-contaminated area of Ron Phibun District, Thailand. *B. Environ. Contam. Tox.*, 84: 274-277.
- Salisbury, C.D.C., W. Chan and P.W. Saschenbrecker, 1991. Multi element concentrations in liver and kidney tissues from five species of Canadian slaughter animals. *J. Assoc. Off. Anal. Chem.*, 74: 587-591.
- Sedki, A., N. Lekouch, S. Gamon and A. Pineau, 2003. Toxic and essential trace metals in muscle, liver and kidney of bovines from a polluted area of Morocco. *Sci. Total Environ.*, 317: 201-205.
- Shah, A.Q., T.G. Kazi, M.B. Arain, M.K. Jamali, H.I. Afridi, N. Jalbani, G.A. Kandhro and J.A. Baig, 2009. Comparison of electrothermal and hydride generation atomic absorption spectrometry for the determination of total arsenic in broiler chicken. *Food Chem.*, 113: 1351-1355.
- Simmons, R.W., P. Pongsakul, D. Saiyasitpanich and S. Klinpholap, 2005. Elevated levels of cadmium and zinc in the paddy soils and elevated levels of cadmium in rice grain downstream of zinc mineralized area in Thailand: Implications for public health. *Environ. Geochem. Hlth.*, 27: 501-511.
- Sridaoruang, N., S. Meesok and P. Saipan, 2010. Cadmium accumulation in beef and kidney of cattle from the northeastern region of Thailand. Proceedings of the 22nd Annual Meeting of the Thai Society for Biotechnology International Conference on Biotechnology for Healthy Living. Prince of Songkla University, Trang Campus, Thailand, pp: 89-92.
- Swaddiwudhipong, W., P. Limpatanachote, P. Mahasakpan, S. Krintratun and C. Padungtod, 2007. Cadmium-exposed population in Mae Sot District, Tak Province: 1. Prevalence of high urinary cadmium levels in the adults. *J. Med. Assoc. Thai.*, 90: 143-148.
- Swaileh, K.M., A. Abdulkhalik, R.M. Hussein and M. Matani, 2009. Distribution of toxic metals in organs of local cattle, sheep, goat and poultry from the West Bank, Palestinian Authority. *B. Environ. Contam. Tox.*, 83: 265-268.
- Tao, S.S. and P.M. Bolger, 2009. Dietary arsenic intakes in the United States: FDA total diet study, September 1991-December 1996. *Food Addit. Contam.*, 16: 465-472.
- Teeyakasem, W., N. Muneko, H. Ryumond, S. Soisungwan, S. Witaya and R. Werawan, 2007. Monitoring of cadmium toxicity in a Thai population with high-level environmental exposure. *Toxicol. Lett.*, 169: 185-195.
- Tomovic, V.M., L.S. Petrovic, M.S. Tomovic, Z.S. Kevresan, M.R. Jokanovic, N.R. Dzinic and A.R. Despotovic, 2011. Cadmium levels of kidney from 10 different pig genetic lines in Vojvodina (northern Serbia). *Food Chem.*, 129: 100-103.
- Villar, T.C., J. Elaine, P. Kaligayahan and M.E. Flavier, 2005. Lead and cadmium levels in edible internal organs and blood of poultry chicken. *J. Appl. Sci.*, 5: 1250-1253.
- WHO, 2001. Environmental Health Criteria 227: Arsenic and Arsenic Compounds. World Health Organization, Geneva, Switzerland.
- WHO, 2002. Environmental Health Criteria Document 134: Cadmium. World Health Organization, Geneva, Switzerland.
- Wlostowski, T., E. Bonda and A. Krasowska, 2006. Free-ranging European bisons accumulate more cadmium in the liver and kidneys than domestic cattle in north-eastern Poland. *Sci. Total Environ.*, 364: 295-300.
- Yatmark, P., C. Nakthong and N. Trakranrungsie, 2010. Comparative evaluation of cadmium contents in livestock's kidney from Maesot district, Tak province and the SW vicinity of Bangkok. *Thai J. Toxicol.*, 25: 81-89.
- Zwicker, R., A. Promsawad, B.M. Zwicker and S. Laoharajanaphand, 2010. Cadmium content of commercial and contaminated rice, *Oryza sativa*, in Thailand and potential health implication. *B. Environ. Contam. Tox.*, 84: 285-288.