Toxic and essential metals in liver, kidney and muscle of pigs at slaughter in Galicia (NW Spain)

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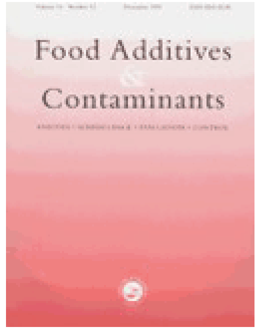

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Abstract

The aims of this study were to evaluate toxic and essential metal concentrations in meat and offal from pigs in NW Spain, to compare these to reported metal concentrations in pigs in other countries and in cattle in this region, and to relate the observed concentrations to maximum acceptable concentrations. Samples from 63 pigs aged 6 months were randomly collected at slaughter. After acid digestion, levels of metals were determined by ICP-OES and ICP-MS. As regards the toxic metals, mean concentrations in liver, kidney and muscle were 0.073, 0.308 and 0.009 mg/kg fresh weight for cadmium, 0.004, 0.008 and 0.003 mg/kg for lead, 0.013, 0.011 and 0.003 mg/kg for arsenic, and 0.001, 0.002 and 0.001 mg/kg for mercury. These concentrations can be considered low, and in general similar to those reported in similar studies in recent years; in addition, maximum admissible concentrations established by the European Union were not exceeded in any sample. As regards the essential metals, concentrations in liver, kidney and muscle were 14.9, 5.63 and 6.85 mg/kg for copper, 81.3, 28.9 and 42.5 mg/kg for zinc, 195, 51.6 and 26.5 mg/kg for iron; 1.17, 2.51 and 0.656 mg/kg for selenium, 3.32, 1.56 and 1.01 mg/kg for manganese, 0.023, 0.027 and 0.003 mg/kg for cobalt, 0.120, 0.077 and 0.131 mg/kg for chromium, 0.009, 0.027 and 0.026 mg/kg for nickel, and 1.62, 0.683 and 0.140 mg/kg for molybdenum. These concentrations are all within the accepted adequate-safe ranges for this animal species, and in general are in line with those previously reported in the literature.

Keywords: toxic and trace metals, liver, kidney, muscle, pig

Introduction

One of the most important aspects of environmental pollution for humans is the intake of toxic elements in the diet. Although contamination of food by toxic metals cannot be entirely avoided given the prevalence of these pollutants in the environment, there is a clear need for such contamination to be minimized (SCAN, 2003).

Meat and meat products form an important part of the human diet. Although toxic metal contents in muscle are generally low, offal products such as liver and kidney often accumulate higher metal concentrations than most other foods. Maximum admissible levels have been established by the European Union for meat and meat products (European Commission, 2001), and monitoring programmes have been carried out in many countries with the aim of avoiding the distribution of foodstuffs that could pose a risk to human health if consumed (Vos et al., 1986; Jorhem et al., 1991; Salisbury et al., 1991; Tahvonen and Kumpulainen, 1994; Doganov, 1996). These monitoring programmes have been accompanied by legislation and other measures to reduce metal content in animal feed, with the aim of reducing metal residues in meat, as well as toxic effects on livestock (EFSA, 2004a,b): examples include the great reduction in environmental lead levels as a consequence of lead reduction in petrol, or the introduction of raw materials with low cadmium content in fertilizer manufacturing (Jorhem et al., 1991; Niemi et al., 1991; Tahvonen and Kumpulainen, 1994).

In extensive production systems, most of animal feeds are locally produced, and animal metal exposure is directly related to environmental contamination in the area; in fact, livestock have proved to be good biomonitor species for metal contamination worldwide (Petersson-Grawe et al., 1997; López-Alonso et al., 2002). By contrast, in intensive production systems (mainly used for non-ruminant livestock, including pigs, poultry, and fish), animals are typically fed compounded feed, consisting of a mixture of individual non-locally produced feed components (generally imported from various countries), to which additives and/or mineral supplements with considerable amounts of toxic metals are added (EFSA, 2004a).

In a previous study in Galicia, a rural region in NW Spain, we determined toxic and essential metal levels in cattle, the main livestock species in this region, predominantly fed locally grown fodder (Lopez-Alonso et al., 2000). This study found that metal levels in cattle muscle, liver and kidney were generally low, similar to those recently reported in other regions, and only in rare cases exceeding maximum acceptable levels as specified by the European Union. However, information on metal concentrations in other major types of meat from intensive production systems in NW Spain, such as for example pork, is not available. The aims of the present study were (i) to evaluate metal concentrations in swine meat and offal from intensive farming in Galicia, (ii) to compare these with reported metal levels in pigs in other countries and in cattle in this region, and (iii) to relate the observed concentrations to maximum acceptable concentrations.

Material and methods

Sampling

Samples (n=63 pigs) of liver, kidney and muscle were taken from randomly selected healthy animals from the slaughter lines of major abattoirs in NW Spain during 2004.

The age of pigs at slaughter is normally around 6 months, when they weigh approximately 120 kg.

Samples of at least 200 g of liver (right lobe) and diaphragm, and a whole kidney, were taken from each animal. All samples were packed individually in plastic bags and immediately transported to the laboratory and stored at –18ºC until analysis.

Chemical analysis

For liver and muscle analyses, approximately 2 g sub-samples were excised from semi-thawed tissues and digested in 5 ml of concentrated nitric acid (Suprapur grade, Merk) and 2 ml of 30% w/v hydrogen peroxide in a microwave digestion system (Milestone, Ethos Plus). Because of the different metal contents in the cortex and medulla, the kidney samples were homogenized before digestion to ensure that the subsample analysed was representative of the whole organ. Digested samples were transferred to polypropylene sample tubes and diluted to 25 ml with Ultrapure water (18 MΩ.cm specific resistivity, Millipore Milli-Q system). Metals at high concentrations in the digest (Cu, Zn, Fe, Mn, Se and Mo) were determined by inductively coupled plasma atomic emission spectrometry (ICP-OES, Perkin Elmer Optima 4300 DV) while metals at low concentrations (Cd, Pb, As, Hg, Co, Cr and Ni) were determined by inductively coupled plasma mass spectrometry (ICP-MS, VGElemental PlasmaQuad II-SOption).

Quality control

An analytical quality control programme was employed. Blank absorbance values were monitored throughout the study and were subtracted from the readings before the results were calculated. The limit of detection in the acid digest was set at three times the standard deviation of the reagent blanks (Table I). The limits of quantification, expressed as concentration in tissue, were calculated on the basis of mean sample weights and volumes analysed. Analytical recoveries were determined from a certified reference material (Pig Kidney CRM 186; BCR Reference Materials) analysed together with the samples. The results are given in Table I and the metal concentrations analysed were in close agreement with the reference values. No information is given regarding Co and Mo in the CRM, and analytical recoveries were determined using spiked samples at a level giving absorbance values that were generally 2-10 times higher than the normal levels in the various tissues: recoveries were 91 and 97% respectively. The precisions of the analytical method and the overall procedure were evaluated as the relative standard deviations of 12 absorbance readings from the same digest and single absorbance readings from 12 digests of the same sample, respectively, these values being 0.63-7.91% for the analytical method and 3.02-11.3% for the overall procedure.

[Insert Table I about here]

For statistical purposes, non-detectable concentrations were assigned a value of half of the detection limit.

Results and discussion

Descriptive statistics for toxic and essential metal levels in liver, kidney and muscle samples are presented in Tables II and III respectively.

[Insert Tables II and III about here]

Data on toxic and essential metal levels reported for pigs from other countries are presented in Tables IV-XV. Comparisons of data between studies must be done with caution. For example, average metal concentrations in tissues, especially in liver and kidney, depend in part on the age, sex and breed of the animals, which are usually not reported. In addition, for metals at very low concentrations with many samples very close to or below the quantification limit (especially toxic metals in muscle), the reported mean values are highly dependent on the limits of detection of the technique (which often vary between studies by more than one order of magnitude), the value assigned to non-detected concentrations (zero, half the limit of detection, or the limit of detection) and their inclusion or not in the calculation of mean values, and even the way in which the data are presented (arithmetic or geometric means, medians or ranges).

Cadmium

Cadmium concentrations in the samples analysed in this study ranged from 0.002 to 0.669 mg/kg fresh weight (Table II). Mean cadmium concentrations were significantly higher in the kidney (0.308±0.103 mg/kg) than in the liver (0.073±0.019 mg/kg), and mean concentrations in both were higher than in muscle (0.009±0.007 mg/kg).

[Insert Table IV about here]

Cadmium is possibly the most important toxic element in animal products, because of its accumulation in offal, and for this reason fairly extensive data is available in the literature (Table IV). In general, cadmium residues in pig tissues in our study are very similar to values reported for pigs slaughtered at similar ages (5-8 months) in other countries. The Scandinavian countries are the exception, with cadmium concentrations about half those reported elsewhere, possibly reflecting the great effort made by these countries in recent decades to reduce cadmium levels in feedstuffs, especially phosphate mineral supplements and fertilizers (Vos et al., 1986; Niemi et al., 1991; Tahvonen and Kumpulainen, 1994).

Cadmium concentrations in our pig samples were higher than those seen in young cattle (slaughtered at 6-10 months) in the same region (liver 0.032, kidney 0.070, muscle 0.001 mg/kg fresh weight; López-Alonso et al., 2000). In contrats, results of previous comparative studies of both livestock species in other countries have found higher cadmium concentrations in cattle than in pigs (Jorhem et al., 1991; Niemi et al., 1991; Tahvonen and Kumpulainen, 1994), which has generally been attributed to differences in age at slaughter: around 6 months for pigs and generally more than two years for cattle.

We do not have sufficiently precise information about cadmium concentrations in feed in cattle and pigs in NW Spain to evaluate whether the observed differences between species are linked to differences in cadmium content in the diet or to physiological differences in metal accumulation. Cadmium contamination levels seem to be very low in Galicia (Caridad-Cancela et al., 2005) and in fact cadmium levels in cattle (fed local products) are among the lowest reported in the literature. For pigs, feed is non-locally produced, and cadmium contents in pig feeds may be similar throughout Europe. Mean concentrations of cadmium in commercial compound feeds for farm animals reported by the European member states (EFSA, 2004a) are similar for ruminants (mean 11, range 0.03-0.85 mg/kg dry matter) and pigs (means for different ages 0.07-0.16, range 0.01-0.50 mg/kg dry matter). It is possible that the higher cadmium levels in pigs could be related in part to the widespread practice in intensive production systems of giving copper and zinc supplements (Rambeck et al., 1991). Experimental studies have demonstrated that in pigs receiving a conventional intensive diet, cadmium concentrations in the liver and kidney were twice as high as in animals that received high copper supplements (Rothe et al., 1992) compared to the control animals. In connection with this, the European Food Safety Authority (EFSA, 2004a) has pointed out that high copper supplementation of feeds for pigs increases the risk of undesirable cadmium accumulation in the liver and kidney.

Lead

Lead concentrations in the tissues of Galician pigs were very low and varied between non-detected and 0.046 mg/kg fresh weight (Table II). The kidney was the tissue with the highest lead concentrations (0.008±0.006 mg/kg), followed by the liver (0.004±0.002 mg/kg), whereas in muscle lead concentrations were undetectable in most samples (74%).

[Insert Table V about here]

Lead concentrations have been also widely monitored in meat and meat products. Unlike cadmium, tissue levels of which are very similar between studies, lead concentrations vary by more than 100-fold (Table V). Lead concentrations in our

Galician pig tissues were at the lower end of the ranges reported in the literature, similar to those recently reported from Finland and Sweden, countries where there were early measures for reducing the use of leaded petrol, the main source of lead pollution to the atmosphere (Jorhem et al., 1991; Tahvonen and Kumpulainen, 1994). These measures have possibly contributed to significantly reduced lead concentrations in animal products in recent years in many countries (see Table V), as well as in other foods (Bellés et al., 1995). But differences in lead concentrations between studies may also be related in part to the analytical techniques: detection of lead in animal products is problematic (especially in muscle) and concentrations may be overestimated when they are close to the detection limit (Falandysz, 1993b). In fact, in the opinion of Jorhem et al. (1996) a major reason for the apparent widespread decrease in lead levels in muscle in recent years may be improvement in analytical methods.

Lead residues in Galician pigs were lower than those previously found in calves from this region (liver 0.053, kidney 0.052, muscle 0.009 mg/kg fresh weight; López-Alonso et al., 2000). Similar results have been obtained in other pork-beef compatative studies in Finland (Tahvonen and Kumpulainen, 1994), Sweden (Jorhem et al., 1991) and Slovenia (Doganov, 1996). Since lead does not accumulate with age in the tissues analysed in this study, these interspecies differences in lead accumulation could be associated with differences in dietary lead content (lead concentrations in forage crops are generally higher than in concentrate feed materials; EFSA, 2004b), as well as interspecies differences in lead accumulation and tolerance: pigs seem to be more tolerant of lead poisoning than most other species, including ruminants (EFSA, 2004b).

Arsenic

Arsenic concentrations in the tissues of pigs in this study varied between non-detected and 0.026 mg/kg fresh weight. Appreciable arsenic concentrations were found only in the liver (0.013±0.003 mg/kg) and kidney (0.011±0.008 mg/kg), whereas in muscle arsenic concentrations were undetectable in most samples (98%).

[Insert Table VI about here]

The arsenic concentrations in our pigs are in general in good agreement with those reported in other countries (Table VI); though in Canada (Salisbury et al., 1991) and the USA (Doyle and Spaulding, 1978) arsenic residues were about one order of magnitude higher than in other countries, which has been associated with the use of organoarsenicals such as arsanilic and phenilarsonic acids as growth promotants in pigs (Salisbury et al., 1991). However, nowadays these arsenic compounds are not allowed and arsenic concentrations in pig feeds depend mainly on the content of products derived from fish and other marine organisms (Jorhem et al., 1991; EFSA, 2005).

Arsenic residues in our Galician pigs were lower than those previously found in calves in this region (liver 0.043, kidney 0.055, muscle 0.004 mg/kg fresh weight; López-Alonso et al., 2000). In general arsenic concentrations reported in cattle products have been very low (see López-Alonso et al., 2000 for review) and similar to or even lower than those reported for pigs from the same countries (Jorhem et al., 1991; Salisbury et al., 1991; Kluge-Berge et al., 1992); this is possibly because arsenic concentration in forages is low compared to commercial compound feeds (EFSA, 2005). The relatively high mean arsenic concentrations found in the liver and kidney of Galician cattle were due to a small proportion of animals having relatively high arsenic burdens (maximum of 0.474 mg/kg fresh weight) which could be associated with relatively elevated levels of arsenic in some soils in Galicia; in fact, a positive association between arsenic content in the soil and arsenic residues in the liver and kidney of cattle has been demonstrated (López-Alonso et al., 2002).

Mercury

Mercury levels were very low in pig meat and offal in this study: undetectable concentrations were found in 86, 68 and 97% of samples for liver, kidney and muscle respectively, while the remaining samples were very close to the detection limit (maximum value: 0.008 mg/kg fresh weight) (Table II).

[Insert Table VII about here]

Mercury levels in pigs in our study were in good agreement with data reported in the literature (Table VII), in which a tendency for declining mercury content in meat products has been observed in recent decades, largely reflecting prohibition of the use of organomercurials for dressing seed, and the reduced use of fish products in pig feed (Jorhem et al., 1991; Falandysz, 1993a).

Mercury levels in the liver (0.0008 mg/kg fresh weight) and muscle (0.0004 mg/kg) of Galician calves were even lower than in the pigs analysed in this study, whereas in the kidney of calves mercury concentrations were higher (0.012 mg/kg) (López-Alonso et al., 2003a). In a previous pork-beef comparative study, mercury concentrations were in general higher in pork samples (Jorhem et al., 1991), which was attributed to the higher mercury content of compound feeds for pigs. In Galicia, however, the mercury exposure of cattle has been shown to be associated with atmospheric mercury emissions from coal-fired power plants, which explains most of the inter-individual variability in kidney mercury levels in animals grazing in the vicinity of these plants (López-Alonso et al., 2003b).

Essential metals

Concentrations of the main essential metals (copper, zinc, iron, selenium and manganese) in the liver and kidney of our Galician pigs (Table III) were within the adequate-safe ranges for this animal species as proposed by Puls (1994), and in general are in good agreement with those reported in the literature (Tables VIII-XV), which indicates that levels of these elements in current pig diets are appropiate and/or that pigs have effective homeostatic mechanisms that maintain tissue metal concentrations within acceptable ranges. Cobalt concentrations in the liver and kidney of pigs in our study were below those considered adequate for this animal species (liver 1.0-2.0, kidney 0.40 mg/kg dry weight; Puls, 1994), but in good agreement with those reported in previous studies (Table XIII). Other essential metals that have been less extensively studied in animal products are nickel and chromium. Although their essentiality has been demonstrated in experimental studies, adequate levels in pigs and other livestock have not been well established; in addition, nickel and chromium concentrations in pig tissues have varied widely from study to study (Tables XIV-XV), possibly reflecting variation in the limits of detection of the method. It is therefore not possible to draw meaningful conclusions about the levels of these metals in Galician pigs versus pigs from other regions. Finally, we are not aware of any previous studies of molybdenum concentrations in pigs, and the adequate-safe range has not yet been established for this animal species.

[Insert Tables VIII to XV about here]

It is worth noting that mean concentrations of most of the essential metals in muscle of pigs in this study are higher than reported in previous monitoring studies. This is especially true for mean copper, manganese and selenium concentrations, which were 5- to 10-fold higher than reported from other countries. These differences may be due to differences between studies in the type of muscle analysed: diaphragm contains significantly more copper than pectoral muscle in cattle (López-Alonso et al., 2000), and it is possible that the concentrations of other metals can also be different. Unfortunately, information about the muscle sampled is rarely reported.

Comparison of essential metal concentrations between Galician cattle and pigs is not meaningful since in animals receiving adequate diets essential metal concentrations in tissues depend basically on homeostatic mechanisms, with the result that tissue concentrations of these elements are characteristic for each animal species. However, from a nutritional point of view, it is worth noting that the main difference between the two species in trace metal content is in copper concentrations in the liver. Cattle, and ruminants in general, show a marked capacity to accumulate copper in the liver when this element is supplied at levels above physiological requirements, and in fact a relatively high proportion of calves in Galicia have hepatic copper concentrations above normal levels (López-Alonso et al., 2000). In contrast, pigs do not accumulate copper in the liver and mean concentrations are less than 25% of those seen in cattle, even though pigs in intensive systems receive high copper supplementation as grown promoters. As in other pork-beef comparative studies (Jorhem et al., 1989), liver from NW Spain cattle (López-Alonso et al., 2004) contained approximately 4 times as much cobalt as pig's liver.

Maximum admissible levels in animal products

The European Commission has established maximum admissible levels for cadmium in liver, kidney and muscle of 0.5, 1 and 0.050 mg/kg fresh weight respectively (European Commission, 2001); none of the pigs sampled in this study exceeded these levels in any of the tissues analysed. Although cadmium accumulation rates are high in pigs compared to other livestock, especially when receiving copper supplementation (Rambeck et al., 1991), the fact that these animals are slaughtered very young generally means that cadmium levels in offal do not exceed the maximum limits.

For lead the maximum admissible levels are 0.5, 0.5 and 0.1 mg/kg fresh weigh for liver, kidney and muscle respectively (European Commission, 2001). As with cadmium, none of the sampled animals exceeded these limits: maximum values in our pigs were about one order of magnitude lower.

For the other toxic metals, arsenic and mercury, the European Commission has not established statutory limits for meat products. Mercury levels in our samples very low (about 1000-fold lower than allowed in fish; European Commission, 2001).

Conclusions

The concentrations of the toxic metals cadmium, lead, arsenic and mercury in liver, kidney and muscle of pigs raised in NW Spain are low, and maximum admissible concentrations established by the European Union were not exceeded in any sample. In general, toxic metal concentrations in our Galician pig samples were similar to those reported in other studies from other countries in recent years years, which in general have shown a declining trend. In addition, the lower variability between studies in toxic metal levels in pigs compared to cattle possibly indicates that pig diets are rather standard in their toxic metal contents, and fairly independent of local pollution levels. In the case of the essential metals analysed, their concentrations in pigs in our study are within the adequate-safe ranges for this animal species, and in general are in good agreement with those reported previously in the literature.

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Table I. Detection limits (µg/l) and results of analysis of the certified reference material (Pig Kidney CRM 186) expressed as mg/kg.

Element	Detection limit	Certified Reference Material	
		Certified levels * (mean±95%CI)	Analysed levels (mean±95%CI)
As	0.5	0.063±0.009	< ld
Cd	0.04	2.71±0.15	2.47±0.10
Co	0.02	---	0.287±0.032
Cr	1.4	(58-142)	198±43
Cu	2.5	31.9±0.4	29.6±0.3
Fe	3.0	299±10	284±10
Hg	0.15	1.97±0.04	1.76±0.05
Mn	0.9	8.5±0.3	7.94±0.29
Mo	3.8	---	3.54±0.10
Ni	0.62	(0.420)	0.478±0.051
Pb	0.26	0.306±0.011	0.329±0.053
Se	13	10.3±0.5	11.0±0.5
Zn	2.8	128±3	124±3

* In parentheses, indicative values only given by the manufacturer; ld: limit of detection.

Table II. Concentrations of the toxic metals cadmium (Cd), lead (Pb), arsenic (As) and mercury (Hg) in liver, kidney and muscle (mg/kg fresh weight) in Galician pigs.

	Tissue	N (<ld)	Mean±DS	Median	90^{th} percentile	Range
Cd	liver	63	0.073±0.019	0.068	0.100	0.043-0.136
	kidney	62	0.308±0.103	0.292	0.446	0.172-0.669
	muscle	62	0.009±0.007	0.007	0.015	0.002-0.038
Pb	liver	63 (16)	0.004±0.002	0.004	0.007	ND-0.012
	kidney	62 (1)	0.008±0.006	0.007	0.011	ND-0.046
	muscle	62 (46)	0.003±0.003	0.002	0.006	ND-0.018
As	liver	63	0.013±0.003	0.013	0.017	0.009-0.023
	kidney	62 (26)	0.011±0.008	0.013	0.022	ND-0.026
	muscle	62 (61)	0.003±0.001	0.003	0.003	ND-0.013
Hg	liver	63 (54)	0.001±0.001	0.001	0.004	ND-0.005
	kidney	62 (42)	0.002±0.002	0.001	0.006	ND-0.008
	muscle	62 (60)	0.001±0.000	0.001	0.001	ND-0.004

<ld: below the detection limit; ND: not detected.

Table III. Concentrations of the essential metals copper (Cu), zinc (Zn), iron (Fe), selenium (Se), manganese (Mn), cobalt (Co), chromium (Cr), nickel (Ni) and molybdenum (Mo) in liver, kidney and muscle (mg/kg fresh weight) in Galician pigs.

	Tissue	N(<ld)	Mean±SD	Median	90th percentile	Range
Cu	liver	63	14.9±12.6	11.3	25.3	5.7-87.2
	kidney	62	5.63±1.44	5.32	7.40	3.42-9.78
	muscle	62	6.85±1.48	6.50	9.20	4.60-10.24
Zn	liver	63	81.3±19.7	78.5	107	47.8-137
	kidney	62	28.9±4.5	28.0	35.6	20.5-41.9
	muscle	62	42.5±6.9	41.4	53.1	32.0-60.7
Fe	liver	63	195±71	190	278	61-430
	kidney	62	51.6±13.6	51.7	68.0	25.2-95.3
	muscle	62	26.5±5.4	26.3	33.7	18.6-38.9
Se	liver	63	1.17±0.13	1.16	1.33	0.890-1.44
	kidney	62	2.51±0.33	2.52	2.93	1.82-3.16
	muscle	62	0.656±0.134	0.653	0.843	0.370-0.979
Mn	liver	63	3.32±0.44	3.33	3.81	2.30-4.38
	kidney	62	1.56±0.20	1.55	1.83	1.16-2.07
	muscle	62	1.01±0.23	0.96	1.30	0.65-1.59
Co	liver	63	0.023±0.004	0.023	0.042	0.014-0.032
	kidney	62	0.027±0.010	0.024	0.003	0.012-0.064
	muscle	62	0.003±0.001	0.003	0.041	0.002-0.013
Cr	liver	63	0.120±0.028	0.115	0.139	0.078-0.284
	kidney	62	0.077±0.025	0.071	0.091	0.052-0.215
	muscle	62	0.131±0.054	0.116	0.165	0.070-0.441
Ni	liver	63 (28)	0.009±0.007	0.008	0.017	ND-0.031
	kidney	62 (14)	0.027±0.025	0.024	0.044	ND-0.161
	muscle	62 (1)	0.026±0.012	0.022	0.041	ND-0.079
Mo	liver	63	1.62±0.23	1.65	1.81	0.810-1.99
	kidney	62	0.683±0.079	0.680	0.792	0.519-0.837
	muscle	62	0.140±0.022	0.141	0.164	0.097-0.203

<ld: below the detection limit; ND: not detected.

Table IV. Published data on cadmium concentrations in pig liver, kidney and muscle. Unless otherwise specified, values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
_	0.6 (315)	_	Australia [d]	Morcombe et al. (1992)
n.c. (662)[a]	0.26 (607)	_	Canada	Korsrud et al. (1985)
0.09 (2062)	0.46 (2061)	_	Canada	Salisbury et al. (1991)
0.0325 (13)	0.1471 (14)	0.0079 (14)	Czech Republic [e]	Raszyk et al. (1996)
0.0314 (41)	0.465 (42)	0.00907 (42)	Czech Republic [e]	Ulrich et al. (2001)
0.070 (4)	0.180 (4)	0.005 (20)	Finland	Nuurtamo et al. (1980)
0.028 (218)	0.17 (217)	0.0015 (121)	Finland	Niemi et al. (1991)
0.00619 (258)[b]	_	<0.00039 (241) [b]	Finland	Tahvonen and Kumpulainen (1994)
0.069	0.379	0.004	Germany	Potthast (1993)
0.069 (80)[c]	0.378 (80) [c]	0.003 (80) [c]	Germany	Hecht (1983)
0.012 (200)	0.066 (200)	0.011 (200)	Hungary	Gyõri et al. (2005)
0.199 (30)	0.666 (30)	0.048 (30)	Italy	Amodio-Cocchieri and Fiore (1987)
0.075 (131)	0.429 (203)	0.004 (203)	The Netherlands [f]	Vos et al. (1986)
_	0.09 (567)	_	Norway	Kluge-Berge et al. (1992)
0.052 (806)	0.28 (805)	0.017 (926)	Poland	Falandysz and Lorenc-Biala (1989)
0.041 (1509)	0.24 (1516)	0.005 (658)	Poland	Falandysz (1993a)
0.09 (73)	0.39 (272)	0.009 (84)	Slovenia [g]	Doganoc (1996)
0.019 (426)	0.11 (626)	0.001 (426)	Sweden [h]	Jorhem et al. (1991)
_	0.11 (1051)	_	Sweden [i]	Pettersson-Grawé et al. (1997)
0.05 (13)	0.1 (13)	_	UK	MAFF (1998)
0.14 (326)	0.30 (321)	n.c. (326)[a]	USA [j]	Coleman et al. (1992)
0.21 (282)	0.65 (281)	n.c. (281)[a]	USA [d]	Coleman et al. (1992)

[a] not calculated, because more than 70% of the values were below the detection limit; [b] calculated per wet weight based on dry matter contents of 26% for meat, 29.5% for liver and 20% for kidney; [c] median value; [d] adults; [e] age 8 months; [f] age 3-24 months; [g] age more than 2 years; [h] age around 6 months; [i] age 5-7 months; [j] market hogs.

Table V. Published data on lead concentrations in pig liver, kidney and muscle. Unless otherwise specified, values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
n.c. (662) [a]	n.c. (607) [a]	_	Canada	Korsrud et al. (1985)
0.07 (2062)	0.07 (2061)	_	Canada	Salisbury et al. (1991)
0.137 (41)	0.1515 (42)	0.099 (42)	Czech Republic [d]	Ulrich et al. (2001)
0.1415 (13)	0.1250 (14)	0.1236 (14)	Czech Republic [d]	Raszyk et al. (1996)
<0.020 (4)	0.020 (4)	0.020 (20)	Finland	Nuurtamo et al. (1980)
0.038 (206)	0.04 (205)	0.015 (187)	Finland	Niemi et al. (1991)
0.00324 (258)[b]	_	0.00234 (241) [b]	Finland	Tahvonen and Kumpulainen (1994)
0.055	0.023	0.033	Germany	Potthast (1993)
0.055 (80) [c]	0.029 (80) [c]	0.033 (80) [c]	Germany	Hetch (1983)
0.075 (200)	0.070 (200)	0.079 (200)	Hungary	Gyõri et al. (2005)
0.357 (30)	0.511 (30)	0.19 (30)	Italy	Amodio-Cocchieri and Fiore (1987)
0.05 (131)	0.13 (203)	0.03 (204)	The Netherlands [e]	Vos et al. (1986)
_	0.00 (567)	_	Norway	Kluge-Berge et al. (1992)
0.16 (804)	0.2 (805)	0.092 (926)	Poland	Falandysz and Lorenc-Biala (1989)
0.094 (1509)	0.12 (1516)	0.02 (334)	Poland	Falandysz (1993a)
0.06 (72)	0.06 (274)	<0.05 (83)	Slovenia [f]	Doganoc (1996)
0.019 (426)	0.016 (626)	<0.005 (426)	Sweden [g]	Jorhem et al. (1991)
0.3 (13)	0.09 (13)	_	UK	MAAF (1998)
n.c. (318) [a]	n.c. (312) [a]	n.c. (318) [a]	USA [h]	Coleman et al. (1992)
n.c. (280) [a]	n.c. (279) [a]	<0.5 (279)	USA [i]	Coleman et al. (1992)

[a] not calculated, because more than 70% of the values were below the detection limit; [b] calculated per wet weight based on dry matter contents of 26% for meat, 29.5% for liver and 20% for kidney; [c] median value; [d] age 8 months; [e] age 3-24 months; [f] age more than 2 years; [g] age around 6 months; [h] market hogs; [i] adults.

Table VI. Published data on arsenic concentrations in pig liver, kidney and muscle. Unless otherwise specified, values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
n.c. (662) [a]	n.c. (607) [a]	_	Canada	Korsrud et al. (1985)
0.26 (2062)	0.17 (2061)	_	Canada	Salisbury et al. (1991)
<0.02 (1)	<0.02 (1)	<0.02 (20)	Finland	Nuurtamo et al. (1980)
0.005 (62)	0.008 (65)	0.003 (65)	Germany	Holm (1978)
0.026 (385)	0.037 (387)	<0.005 (48)	Germany	Crossmann (1981)
0.006 (103)	0.005 (174)	0.002 (183)	The Netherlands [b]	Vos et al. (1986)
0.01 (563)	_	_	Norway	Kluge-Berge et al. (1992)
0.023 (625)	0.019 (338)	0.024 (338)	Sweden [c]	Jorhem et al. (1991)
0.19	0.13	0.01	USA	Doyle and Spaulding (1978)

[a] not calculated, because more than 70% of the values were below the detection limit; [b] age 3-24 months; [c] age around 6 months.

Table VII. Published data on mercury concentrations in pig liver, kidney and muscle. Unless otherwise specified, values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
n.c. (662) [a]	n.c. (607) [a]	_	Canada	Korsrud et al. (1985)
0.01 (2062)	0.02 (2061)	_	Canada	Salisbury et al. (1991)
0.0149 (41)	0.026 (42)	0.00504 (42)	Czech Republic [b]	Ulrich et al. (2001)
0.01 (13)	0.0138 (14)	0.0088 (14)	Czech Republic [b]	Raszyk et al. (1996)
0.011 (4)	0.013 (4)	<0.002 (20)	Finland	Nuurtamo et al. (1980)
0.012 (183)	0.014 (95)	0.011 (163)	Finland	Niemi et al. (1991)
0.002 (131)	0.007 (200)	0.002 (204)	The Netherlands [c]	Vos et al. (1986)
_	0.01 (567)	_	Norway	Kluge-Berge et al. (1992)
0.005 (181)	0.008 (180)	0.003 (181)	Poland	Falandysz and Gajda (1988)
0.0037 (1516)	0.007 (1516)	0.0019 (1513)	Poland	Falandysz (1993a)
0.015 (390)	0.019 (626)	0.009 (390)	Sweden [d]	Jorhem et al. (1991)
0.02 (156)	_	0.011 (156)	USA	Sell et al. (1975)
0.01 (136)	0.02 (136)	0.003 (136)	USA	Doyle and Spaulding (1978)

[a] not calculated, because more than 70% of the values were below the detection limit; [b] age 8 months; [c] age 3-24 months; [d] age around 6 months.

Table VIII. Published data on copper concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
12.0 (662)	7.3 (607)	_	Canada	Korsrud et al. (1985)
12.2 (2062)	7.58 (2061)	_	Canada	Salisbury et al. (1991)
16 (4)	6.0 (4)	0.87 (20)	Finland	Nuurtamo et al. (1980)
_	_	0.5	Italy	Lombardi-Boccia et al. (2005)
_	7.9 (71)	_	The Netherlands [a]	Ellen et al. (1989)
6.2 (804)	6.2 (805)	0.7 (926)	Poland	Falandysz & Lorenc-Biala (1989)
8.5 (661)	8.4 (663)	1.1 (658)	Poland	Falandysz (1993a)
9.0 (126)	6.1 (75)	0.9 (126)	Sweden [b]	Jorhem et al. (1989)
60.5 (13)	3.57 (13)	_	UK	MAFF (1998)
11.1 (326)	6.65 (321)	1.16 (326)	USA [c]	Coleman et al. (1992)
18.3 (282)	6.73 (281)	0.93 (281)	USA [d]	Coleman et al. (1992)

[a] age 4-24 months (mean 7 months); [b] age around 6 months; [c] market hogs; [d] adults

Table IX. Published data on zinc concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
61.6 (662)	25.9 (607)	_	Canada	Korsrud et al. (1985)
65.6 (2062)	27.4 (2061)	_	Canada	Salisbury et al. (1991)
90 (4)	26 (4)	22 (20)	Finland	Nuurtamo et al. (1980)
_	_	15.5	Italy	Lombardi-Boccia et al. (2005)
_	22.7 (71)	_	The Netherlands [a]	Ellen et al. (1989)
39 (804)	39 (804)	20 (926)	Poland	Falandysz & Lorenc-Biala (1989)
50 (661)	30 (663)	26 (658)	Poland	Falandysz (1993a)
74 (126)	22 (75)	24 (126)	Sweden [b]	Jorhem et al. (1989)
39.8 (13)	18.8 (13)	_	UK	MAFF (1998)
66.9 (326)	25.0 (321)	24.0 (326)	USA [c]	Coleman et al. (1992)
63.7 (282)	24.7 (281)	33.8 (281)	USA [d]	Coleman et al. (1992)

[a] age 4-24 months (mean 7 months); [b] age around 6 months; [c] market hogs; [d] adults

Table X. Published data on iron concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
–	–	4.18 (104)	Germany	Reichardt et al. (2002)
–	–	4.2	Italy	Lombardi-Boccia et al. (2005)
56 (804)	57 (805)	14 (926)	Poland	Falandysz & Lorenc-Biala (1989)
54 (661)	63 (663)	13 (658)	Poland	Falandysz (1993a)
123 (15) [a]	–	21 (15) [a]	Thailand	Kongkachuichai et al. (2002)
191.0 (326)	46.5 (320)	10.2 (326)	USA [b]	Coleman et al. (1992)
363.0 (282)	79.0 (281)	16.5 (281)	USA [c]	Coleman et al. (1992)

[a] median value; [b] market hogs; [c] adults

Table XI. Published data on selenium concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
0.470 (4)	1.710 (4)	0.070 (20)	Finland	Nuurtamo et al. (1980)
0.56 (48)	2.41 (48)	0.08 (48)	Finland	Salmi and Hirn (1984)
–	–	0.16 (50)	Norway	Froslie et al. (1985)
0.51 (48)	2.34 (48)	0.14 (48)	Sweden	Kolar (1983)
0.50 (72)	1.9 (72)	0.094 (72)	Sweden [a]	Jorhem et al. (1989)

[a] age around 6 months

Table XII. Published data on manganese concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
3.9 (4)	1.5 (4)	0.13 (20)	Finland	Nuurtamo et al. (1980)
_	1.45 (71)	_	The Netherlands [a]	Ellen et al. (1989)
1.1 (804)	1.1 (805)	0.11 (926)	Poland	Falandysz and Lorenc-Biala (1989)
1.3 (663)	1.3 (663)	0.11 (658)	Poland	Falandysz (1993a)
3.0 (46)	1.5 (46)	0.12 (45)	Sweden [b]	Jorhem et al. (1989)
4.20 (324)	1.40 (318)	0.13 (324)	USA [c]	Coleman et al. (1992)
2.37 (281)	1.22 (280)	0.14 (280)	USA [d]	Coleman et al. (1992)

[a] age 4-24 months (mean 7 months); [b] age around 6 months; [c] market hogs; [d] adults

Table XIII. Published data on cobalt concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
0.010 (4)	0.070 (4)	<0.010 (20)	Finland	Nuurtamo et al. (1980)
0.010 (36)	0.004 (36)	0.001 (36)	Sweden [b]	Jorhem et al. (1989)
n.c. (324) [a]	n.c. (318) [a]	n.c. (324) [a]	USA [c]	Coleman et al. (1992)
n.c. (281) [a]	n.c. (280) [a]	n.c. (280) [a]	USA [d]	Coleman et al. (1992)

[a] not calculated because of large number of data below the detection limit ; [b] age around 6 months; [c] market hogs; [d] adults

Table XIV. Published data on chromium concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
0.010 (4)	0.010 (4)	0.040 (20)	Finland	Nuurtamo et al. (1980)
_	n.c. (71) [a]	_	The Netherlands [c]	Ellen et al. (1989)
<0.010 (71)	<0.010 (71)	0.014 (71)	Sweden [d]	Jorhem et al. (1989)
0.006726 (4) [b]	0.00716 (5) [b]	_	USA [e]	Lindemann et al. (2004)

[a] not calculated because of large number of data below the detection limit; [b] calculated per wet weight based on dry matter content of 26% for meat, 29.5% for liver and 20% for kidney; [c] age 4-24 months (mean 7 months); [d] age around 6 months; [e] sows.

Table XV. Published data on nickel concentrations in pig liver, kidney and muscle. Values shown are average concentrations (mg/kg fresh weight). The numbers of samples analysed are in parentheses.

Liver	Kidney	Muscle	Country	Reference
<0.020 (4)	<0.020 (4)	<0.020 (20)	Finland	Nuurtamo et al. (1980)
_	0.045 (71)	_	The Netherlands [b]	Ellen et al. (1989)
0.011 (34)	0.011 (34)	<0.010 (34)	Sweden [c]	Jorhem et al. (1989)
2.14 (326)	0.57 (320)	n.c. (326) [a]	USA [d]	Coleman et al. (1992)
0.26 (282)	0.29 (281)	n.c. (281) [a]	USA [e]	Coleman et al. (1992)

[a] not calculated because of large number of data below the detection limit; [b] age 4-24 months (mean 7 months); [c] age around 6 months; [d] market hogs; [e] adults.